A MANUAL OF HISTOLOGY

RADASCH
TO MY
FRIEND AND COLLEAGUE
PROF. RANDLE C. ROSENBERGER
THIS VOLUME IS
AFFECTIONATELY DEDICATED
PREFACE TO THE SECOND EDITION

In this revision the author has added new material and rewritten some sections so as to meet the teaching of the present time. He has constantly borne in mind the advisability of keeping the text within practical limits and avoiding the general tendency of including too much in the way of theories and hypotheses. The limited time that the medical and average collegiate student has for each subject makes it incumbent upon an author to present his text in a concise and logical manner, with as little repetition and deviation from the main path as possible.

Twenty two new photomicrographs have been added and those representing the phases of Karyokinesis are from preparations made by the author at the University of Leipsic in 1903. Those familiar with the Ascaris megalcephala in this country will note the unusual size of the centrosome and chromosomes in the illustrations. This seems to be a characteristic of the parasite of the continental countries. One of these stages, the nuclear spindle, shows but two chromosomes in each half of the spindle, which is an unusual and rather rare form of Ascaris megalcephala univalens. All of the other illustrations represent the usual form of Ascaris megalcephala bivalens, but the stages are all good and characteristic.

Several stain methods have been added to the chapter on Technic and the section on Serous Membranes has been entirely rewritten. To the section on Bone have been added the results of the author’s recent studies upon the composition of compact bone.

In the section on Blood numerous additions have been made, while to the description of the Stomach the result of recent studies on the Acid Cell has been included. Many, though not necessarily large, additions have been made to the structure of the Eyeball; the tracts of the Spinal Cord; the Pineal Body, and the Accessory Nasal Sinuses. The functions of many of the organs have also been given, as the function is dependent upon the structure.
The author is indebted to Dr. Kenneth Whyte for several of the slides from which illustrations were made. For assistance in making corrections and in proof-reading he tenders his thanks to Paul Scofield; also to the publishers for their many courtesies and valuable suggestions.

Malvern, Pa.

H. E. Radasch.
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PRACTICAL HISTOLOGY

CHAPTER I

TECHNIC

For a thorough understanding of Histology a knowledge of technic is requisite, as sections for study must be properly prepared, and this requires skill and care.

Tissues may be studied in a fresh or living condition as well as after fixing and staining. Muscle, tendon and fibrous tissue may be placed upon a slide with a little normal salt or Ringer's solution or glycerin and gently torn apart with needles. Ringer's solution is prepared as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Sodium chlorid</td>
<td>90.0</td>
</tr>
<tr>
<td>Potassium chlorid</td>
<td>4.2</td>
</tr>
<tr>
<td>Calcium chlorid (anhydrous)</td>
<td>2.4</td>
</tr>
<tr>
<td>Potassium bicarbonate</td>
<td>2.0</td>
</tr>
<tr>
<td>Distilled water</td>
<td>10,000.0</td>
</tr>
</tbody>
</table>

Peritoneum, mesentery or omentum may be spread upon a slide, covered with salt or Ringer's solution and a cover-glass and then studied. Ciliary action may be shown by placing a small piece of the gill of a clam upon a slide and keeping it moist with salt or Ringer's solution. The circulating blood in the web of a frog's foot may be studied by using a special stage for the support of the frog. The effect of heat and cold may be studied by the use of a special stage permitting a flow of hot or cold water.

Tissues may be subjected to the action of special agents as blood serum and pericardial fluid. Thin sections may also be made with a double-bladed knife or the fresh tissue may be frozen and cut in a special freezing microtome.
Maceration is employed to separate tissues by dissolving or softening certain ones and affecting others. The latter may be isolated then by shaking.

1. Hydrochloric Acid. 20 Per Cent. Aqueous Solution.—Place small pieces of tissue therein for twenty-four to forty-eight hours and then wash thoroughly. This is especially adapted for the isolation of uriniferous tubules as it dissolves the interstitial tissue. The tubules may then be mounted in glycerin jelly. If used in the strength of 1 to 250 parts of water this agent will separate voluntary muscles fibers at the discs.

2. Potassium hydroxid, as a 20 to 40 per cent. solution, acts in fifteen to sixty minutes for cells of the nails, hairs and epidermis. If smooth or cardiac muscles are used, small cubes of the tissue are placed in a large quantity of the reagent and shaken. When dissociation has been accomplished the tissue is then transferred to a saturated aqueous solution of potassium acetate to neutralize the hydroxid. Later the tissues are washed in water, stained for twenty-four hours in alum carmin, washed with water and mounted in glycerin.

3. Nitric acid in a 10 to 20 per cent. aqueous solution or physiologic salt solution may be used to isolate muscle fibers. It requires from twenty-four to forty-eight hours to act. J. B. MacCallum recommends the following for heart muscle: Nitric acid one part, glycerin two parts, distilled water two parts. Small pieces of tissue remain from eight hours to several days in this solution and are then transferred to a 5 per cent. aqueous solution of glycerin.

Schwalbe recommends a 20 per cent. solution of nitric acid, at 40°C. for twenty-four hours, for the isolation of nerve fibers for measurement.

Digestion Method.—The chief agents for this method are gastric juice (pepsin) and pancreatic juice (trypsin, or pancreatin). Tissues should be fresh or fixed in alcohol only. Pepsin digests collagen and mucin readily and elastin slowly; nuclein is only slowly or not at all affected while keratin, neurokeratin, chitin, fats and carbohydrates not at all. Pancreatin digests elastin, mucin and nuclein readily; collagen, reticulin, chitin, keratin, fats and carbohydrates are not affected.
Tissues to be digested are placed in the solution and the container placed in an incubator at 37°C. for several hours. The process may be carried on in a warming chamber if sections of tissues are utilized. **Kuskow's solution** consists of one part of pepsin dissolved in 200 parts of a 3 per cent. solution of oxalic acid. Pieces of hardened ligamentum nuchæ are placed in the freshly prepared solution and are allowed to remain from ten to forty minutes.

**Pancreatin.**—Add 0.2 or 0.4 per cent. of Mall's or Merck's pancreatin to a 0.3 per cent. solution of sodium carbonate. This is used to demonstrate reticulum tissue in paraffin sections. Remove the paraffin with xylol, wash thoroughly in alcohol and place the sections in ether in a Soxhlet apparatus for several hours to remove the fat. Bring the sections through graded alcohols to water and then place in the digesting fluid for several hours to several days, until all of the cellular elements are removed. Wash with water and stain with an aqueous solution of fuchsin or toluidin blue, then dehydrate, clear and mount.

For reticulum frozen sections 40 to 80 μ thick are placed for twenty-four hours in the following solution: Pancreatin 5 grams, bicarbonate of sodium 10 grams, water 100 c.c. Wash carefully with water and transfer the section to a test-tube and shake thoroughly. Then spread the tissue carefully upon a slide to dry. Then allow a few drops of the following stain to dry upon the section: Picric acid 10 grams, absolute alcohol 33 c.c., water 300 c.c. Stain for one-half hour in the following: Acid fuchsin 10 grams, absolute alcohol 33 c.c., water 66 c.c. Wash a moment with picric acid solution, dehydrate, clear with xylol and mount in balsam.

**TECHNIC FOR FROZEN SECTIONS**

For cutting sections frozen with CO₂ the piece of tissue is placed upon the hard rubber freezing chamber that has been moistened with a little water. The cylinder, that has been fastened to the table, is provided with an outlet tube and a valve; when the tissue is placed in position the valve is gradually opened permitting the CO₂ to enter the freezing chamber, and the freezing process is begun. Freezing should be carried on cautiously. When the specimen is frozen solid it is then set in the automatic feeding microtome and cut at
any desired thickness. Congelation should take place slowly and then sections should be cut as nearly 4μ in thickness as possible. If the block is too hard the cut sections will break over the edge of the knife. However, waiting a few seconds and cutting several sections at intervals will yield good results.

Wright's Method.—1. Place the fresh specimen in a 10 per cent. solution of formalin for about two hours, or it may be boiled for two to three minutes in the same solution but histologic details are not so good.

2. Rinse in water.
3. Cut sections in the freezing microtome.
4. Float the sections upon a slide, smooth out and remove the surplus water.
5. Place a sheet of cigarette paper upon the section, and press this and the section down with a pad of soft, smooth filter paper, the face of which has been moistened with a little 95 per cent. alcohol. Remove the filter paper and carefully strip off the cigarette paper, leaving the section adhering to the slide.
6. Flood the section with absolute alcohol and after thirty seconds drain it off.

7. Flood the section and the adjacent surface of the slide with a thin solution of celloidin, drain the excess off immediately.

8. Flood the slide with 95 per cent. alcohol and then place the slide in water for ten seconds. This hardens the celloidin and prevents the section from curling.

9. Stain with hematoxylin or any combination of stains.

10. Dehydrate in 97 per cent. alcohol.

11. Clear in oil of origanum and mount in balsam.

**Rapid Method.**—Freeze the tissues, with or without preliminary hardening in formalin and cut sections. Transfer the sections to water and draw upon a clean slide. Drain off the water and dry over an alcohol lamp.

Cover with hematoxylin for two minutes, drain and cover with a 50 per cent. solution of lithium carbonate for one minute (to deepen the stain). Stain with Van Gieson’s stain for one minute, wash with water, dehydrate with 95 per cent. alcohol and then absolute alcohol, clear with xylol and mount in balsam.

Frequently tissues (uterine curettings) may be collected into one section by imbedding in gelatin. This medium consists of a 10 per
cent. solution of sheet gelatin in distilled water with one-half of 1 per cent. of carbolic acid to preserve it.

To prepare the block melt the gelatin in a water-bath, pour out a quantity upon a smooth hard surface and arrange the pieces of tissue therein. Let this set for about one-half hour, cut out the area containing the pieces, freeze in the chamber and make sections as above. The cut sections should be fastened to the slides in the following manner:

Cover a slide with a thin layer of Mayer's albumen, float the section thereon and remove the wrinkles; flatten the section upon the slide by pressing it with smooth blotting paper. After the section is dry cover it with a mixture of equal parts of clove oil and anilin oil and wash this off immediately with 95 per cent. alcohol. Place the slide in water to remove the alcohol and then stain as in ordinary preparations.

ORDINARY TECHNIC

If the freezing method is not used various steps are necessary to prepare a piece of tissue for sectioning as Fixation, Dehydration, Clearing, Infiltration and Blocking.

FIXATION

Fixation is the process by which the intercellular substance and the protoplasm of the cells are coagulated by the aid of solutions, or gases, thereby keeping them as nearly like normal as possible. Such solutions are fixing fluids, of which there are a great many combinations. Simple fixatives, which are not numerous, will be given first, and under each, its combinations.

Certain salts, as those of chromium, osmium and platinum, interfere with subsequent staining and must be removed by thorough washing after fixation. Alcohol, formalin, picric acid, corrosive sublimate and acetic acid are either neutral or favorable to stains.

For fixation, one-quarter inch cubes or slices of organs, \( \frac{1}{8} \) inch thick and cut at intervals, are the most satisfactory.

1. **Heidenhain's solution** consists of a saturated solution of bichlorid of mercury in a normal salt solution.

\[
\begin{align*}
\text{Bichlorid of mercury} & \quad 112 \text{ gms.} \\
\text{Sodium chlorid} & \quad 7.5 \text{ gms.} \\
\text{Water} & \quad 1000 \text{ c.c.}
\end{align*}
\]
Add the bichlorid to the hot salt solution and when dissolved set aside to cool. The excess of bichlorid will crystallize and keep the solution saturated.

Three to 5 per cent. of *glacial acetic acid* aids the penetration of the bichlorid and assures more thorough fixation.

This solution requires from two to four hours to fix ½-inch cubes.

2. Potassium Bichromate.—This salt in a solution of 3½ per cent. strength is a good fixative and hardener. The strength is gradually increased ½ of 1 per cent. by frequent renewal, to 6 per cent., in the course of six weeks. It will not injure tissues left in it for a longer time. It is not often used alone but in combinations mentioned below.

(a) **Müller’s fluid** depends upon potassium bichromate for its action. Penetration is aided by sodium sulphate.

| Potassium bichromate | 60 gms. |
| Sodium sulphate       | 30 gms. |
| Water                | 3000 c.c. |

This solution requires from three to six weeks for fixing, but a longer time does not injure the tissues. It is commonly used in the dark, and renewed as often as it becomes cloudy.

(b) **Zenker’s fluid** is a mixture of **Müller’s fluid** and bichlorid of mercury.

| Müller’s fluid | 1000 c.c. |
| Corrosive sublimate | 112 gms. |
| Mix and add before use | |
| Glacial acetic acid | 5 per cent. |

This solution requires from twelve to twenty-four hours to act and should be freshly prepared each time before using.

(c) **Zenker-formalin** is made as follows:

| Zenker’s solution | 90 c.c. |
| Glacial acetic acid | 5 c.c. |
| Formalin            | 10 c.c. |

The last two reagents should be added just before using. This solution requires twelve to twenty-four hours for fixation.

Maximow uses 10 per cent. formalin in place of the acetic acid and the results are said to be excellent.
Helly's Fluid.—This is merely Zenker's fluid in which the acetic acid is replaced by the same proportion of formalin. This is especially adapted for tissues in which the granules of the cytoplasm are to be studied (chromaffin granules, etc.).

(d) Tellyesniczky's fluid consists of a 3 per cent. solution of potassium bichromate to which is added 5 per cent. of glacial acetic acid (5 c.c. per 100). It is allowed to act twelve to twenty-four hours and then the tissues are thoroughly washed and dehydrated. Nuclei are better preserved by this solution than by the usual bichromate mixtures.

(e) Potassium bichromate and formalin:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Amount</th>
</tr>
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<tbody>
<tr>
<td>Potassium bichromate (3.5 per cent.)</td>
<td>90 parts.</td>
</tr>
<tr>
<td>Formalin (40 per cent.)</td>
<td>10 parts.</td>
</tr>
</tbody>
</table>

The tissue may remain in this solution from three or four days to two weeks. It should then be thoroughly washed and dehydrated. This solution answers very well for nerve tissues.

3. Chromic acid is generally used in 0.1 to 0.5 per cent. solutions, and should be allowed to act one to eight days, as it penetrates slowly. It is to be frequently changed. It is especially adapted to connective tissues and where mitotic figures are to be studied.

Fixation with chromium salts should be carried on in the dark and thorough washing should follow their use. When corrosive sublimate is used the excess must be removed before staining. This may be done with iodin solution, in block or in sections; the iodin is then removed by means of alcohol or weak solutions of potassium iodid or sodium thiosulphate.

4. Osmic Acid.—This reagent is used in 0.5 to 1 per cent. solutions as well as in combination with others. It is a specific reagent for adipose tissue, but if turpentine or alcohol-ether is used for clearing the osmicated fat will be removed. The time for fixation depends upon the strength, usually from twelve to twenty-four hours for 1 per cent. solutions.

Stock solutions may be prevented from reducing by adding sufficient potassium permanganate to impart a slight violet tint. When the solution becomes colorless, repeat.
Tissues fixed in osmic acid solution should be washed for several hours in running water and transferred to 90 per cent. alcohol.

(a) Flemming's Solution:

Osmic acid (2 per cent. solution)............................... 4 c.c.
Chromic acid (1 per cent. solution)............................ 15 c.c.
Glacial acetic acid............................................. 1 c.c.

This is the stronger solution recommended by Flemming.
This solution which fixes the tissues in from one to two days, although a longer time will not injure them, should be changed at least once. The tissues are then thoroughly washed and dehydrated. This fluid, which is good for the study of mitotic figures, should be prepared just before using, as it does not keep.

(b) Golgi's Solution:

Osmic acid (2 per cent. solution)............................... 2 parts.
Potassium bichromate (2 to 2.5 per cent. solution)......... 8 parts.

Harden for three days in this solution and impregnate with silver nitrate solution. This is used to stain nerve cells and their processes and glial cells.

5. Formalin is a saturated solution of formaldehyde gas in water. It is not used in full strength, but usually as a 4 to 10 per cent. solution. A 10 per cent. solution is prepared as follows:

Formalin................................. 10 c.c.
Sodium chlorid (5 per cent. solution)........................ 90 c.c.

This requires from twelve to twenty-four hours for its action, and is especially useful in the nerve system. It may be used with potassium bichromate as given above.

6. Nitric acid is used as a 3 per cent. solution, and small pieces of tissue are allowed to remain therein from one-half to one hour. Large specimens (embryos) require from four to eight hours. After fixation the tissues are immediately transferred to 70 per cent. alcohol.

It is especially adapted to connective tissues, ova, and embryos.

7. Picrosulphuric Solution (Kleinenberg).—This solution is prepared as follows: To 200 c.c. of saturated aqueous solution of picric acid add 4 c.c. of concentrated sulphuric acid. Allow the
precipitate to settle then filter. Dilute the filtrate with 600 c.c. of water. Filter after twenty-four hours if necessary.

This solution is used for the fixation of young embryos and delicate tissues. It requires from one to twenty-four hours. After fixation the embryos are transferred to 70 per cent. alcohol until bleached.

8. Alcohol.—There are several strengths of alcohol suitable for fixation. Besides acting as fixatives they at the same time dehydrate.

(a) Absolute Alcohol.—This should be of at least 99.2 per cent. strength. It acts very rapidly and thoroughly, but its expense prevents its routine use. It must be changed several times. After twenty-four to forty-eight hours the tissues are ready to be cleared.

(b) Ninety-five per cent. alcohol acts in the same way as the above, but some (Mallory and Wright) hold that shrinkage results if any solution weaker than the absolute alcohol is used. This strength has, however, yielded good results in the nerve system. It must be frequently renewed.

9. Bouin’s Fluid.—This consists of the following:

Picric acid, saturated aqueous solution.......................... 75 c.c.
Formalin............................................................. 20 c.c.
Glacial acetic acid.................................................. 5 c.c.

This solution is especially applicable to the fixation of embryos, small ones requiring four to six hours and large ones from twenty-four to forty-eight hours. Specimens, after fixation, should be washed in 70 per cent. alcohol and then 80 per cent. alcohol. This should be changed until the alcohol is no longer colored.

Tissues that have been fixed in solutions containing either osmic acid or chromium salts must be thoroughly washed before dehydration. Golgi’s method of staining is an exception, as will be seen when its steps are considered.

Blood spreads are readily fixed in a solution of equal parts of absolute alcohol and ether in which they are allowed to remain from twenty minutes to an hour. Another good fixative is absolute alcohol, nine parts, and formalin, one part. The time for fixing is about the same.
The blood spreads may be subjected to a temperature of 120°C. for twenty minutes. Ehrlich prefers this method of fixation to the above.

DEHYDRATION

After the tissues have been fixed in one of the above solutions and washed, they are ready for the second step, that of dehydration. Dehydration, or hardening, is the removal of the water from the tissues, and is accomplished by alcohols of ascending strengths. The tissues are transferred to a 50 per cent. solution for six to twenty-four hours, unless otherwise directed. This is followed by immersion in a 70 per cent. solution for the same time, and then in a 95 per cent. solution for at least twenty-four hours. During this time, the last should be changed once. To insure perfect dehydration, the specimens, after being drained, may be placed in absolute alcohol for twelve to twenty-four hours.

If the following steps are not to be carried out immediately the tissues should be transferred to a solution of 70 or 80 per cent. alcohol in which they may remain indefinitely.

Tissues fixed in salts of chromium should be dehydrated in the dark.

CLEARING

After dehydration is completed the tissues are ready for the clearing agents.

Clearing or dealcoholization is the process by which the alcohol is removed and an agent that will mix with the infiltration medium substituted. If paraffin is to be used, an oil or fluid miscible with both alcohol and paraffin is necessary; if celloidin infiltration is to follow, then a mixture of absolute alcohol and ether is used.

For the paraffin method the tissues are removed from the 95 per cent. or absolute alcohol, drained a few minutes and then transferred, usually to an oil, for twenty-four hours. The oil penetrates the tissues, removes the alcohol, and remains in its place.

Chloroform, xylol, and various oils may be employed, among them being turpentine, which usually requires twenty-four hours for half-inch cubes.
Xylol requires from six to twenty-four hours, or until the tissue is transparent. If the clearing is not carefully timed the tissue will become hard or brittle.

Cedar oil is used as follows: The tissues are first placed in a mixture of equal parts of cedar oil and absolute alcohol for twenty-four hours. They are then drained and placed in pure cedar oil for the same length of time. If pure oil alone is used, it is changed several times until the tissues are transparent, which usually requires twenty-four to forty-eight hours.

**INfiltration**

After clearing, the tissues are ready for infiltration.

Infiltration is the process by which the interstices of the tissue are filled with an agent that hardens and allows the tissue to be cut without distortion. There are two important agents, paraffin and celloidin. Gum may be used for special purposes. The paraffin method will first be considered.

After clearing, the tissues are drained, blotted with tissue-paper, and then placed in a tube of melted paraffin at a temperature a little above the melting-point, usually 50° to 55°C. This is called paraffin No. 1, and its object is the removal of the bulk of the oil. After twelve to twenty-four hours the tissues are removed to a tube of fresh paraffin and allowed to remain the same length of time. This is paraffin No. 2, and the remainder of the oil is removed and pure paraffin left in the tissues. The tissues are then ready to be blocked.

By the use of chloroform, infiltration with paraffin can be accomplished, to a great extent, in the cold. The tissues are completely dehydrated with absolute alcohol and then placed in pure chloroform to replace the alcohol. This is accomplished when the tissues become submerged, usually four to eight hours. They are then transferred to a warm, saturated solution of paraffin in chloroform, for two to four hours, and then to pure melted paraffin until all the chloroform has disappeared (two to twelve hours).

If delicate structures are to be infiltrated they may be cleared slowly by adding toluol, or benzol, drop by drop, to the specimen in absolute alcohol and mixing after each addition. By this method, 2 c.c. of oil can be added to the same amount of absolute alcohol.
in four to six hours and no shrinkage result. The specimens may then be transferred to a mixture of absolute alcohol (one part) and toluol (three parts) for one to three hours. They may then be placed in pure toluol from one to four hours, the time depending upon the size, one-eighth to one-fourth inch in diameter. From this it may be transferred to a solution of paraffin in toluol for two to four hours, after which more paraffin is added, and the tube transferred to the paraffin-bath, where it remains for an hour or two, and is then cast.

**Acetone-paraffin Infiltration.**—Fix the tissues as usual, place in weak alcohol for several hours and then transfer to the following mixture:

\[
\begin{align*}
\text{Acetone} & : 2 \text{ vols.} \\
\text{Ether} & : 2 \text{ vols.} \\
\text{Water} & : 1 \text{ vol.}
\end{align*}
\]

Allow the tissue to remain as many hours as it is millimeters thick. Transfer to a mixture of equal parts of acetone and ether saturated with paraffin (36° to 40°C. melting point). The tissue should remain here twice as long as in the preceding step. Then transfer to melted paraffin for five to ten minutes for each millimeter of thickness.

**BLOCKING**

**Blocking** may be accomplished by the use of *leaden angles*, *paper boxes*, or *wooden blocks*. The *leaden angles* are of various sizes and are used in connection with brass plates. These are all cooled in ice-water, quickly dried and the angles put into place. A small layer of paraffin is then run into the mold, and the tissue placed therein, and oriented (placed so as to be cut in a definite direction). The mold is then filled with melted paraffin, and as soon as a scum is formed, the whole is immersed in ice-water, and the angles cautiously removed, so that the water can act upon all sides except the bottom. Unless this is done, the paraffin, in cooling rapidly and contracting, will enclose water bubbles that are unnecessary and annoying. A little skill is required to cast successfully. Usually, by this method, the paraffin remains clear, a condition much to be desired.

If **blocks** are used, these should be preferably of oak, an inch and a quarter long, by seven-eighths square. The end is carefully
and tightly wrapped with a strip of thin paper, forming a cup \(\frac{1}{2}\) inch deep. The specimen is then quickly oriented upon a thin layer of paraffin, and the cup filled with paraffin. It is then set aside and allowed to cool. The enclosed air bubbles rise. The paraffin is usually not clear by this method, but is made so by placing the block for several days upon paraffin bath. The warmth clears the paraffin.

After casting, the blocks are trimmed and are then ready to be cut with the microtome.

For the **celloidin infiltration** method, **fixation** and **dehydration** are carried out in the same manner as for paraffin, but a different clearing agent is used. A mixture of *equal parts of absolute alcohol and ether* will clear tissues in twenty-four hours, at the end of which time they are ready for the celloidin.

**Celloidin**, or *pyroxylin*, is prepared as follows: Wash an ounce of celloidin with distilled water, dry thoroughly, place it in a tightly stoppered container and cover with 200 c.c. of absolute alcohol. After several hours add 200 c.c. of ether. A clear solution should result. This may be thinned to any desired consistency by the addition of a mixture of equal parts of absolute alcohol and ether. The celloidin may also be prepared in various strengths as 4, 6, 8, 10 and 12 per cent.

After clearing the tissues are transferred to the thin celloidin for one to four days. Transfer the tissues to Stender dishes, cover deeply with celloidin and leave the cover on loosely so as to permit the alcohol and ether to evaporate slowly. This thickens the celloidin and prepares the tissue for blocking.

The most satisfactory way of blocking is to continue the evaporation of the alcohol and ether until the celloidin is fairly firm. Then place the dish in a jar of 80 per cent. alcohol until the celloidin is hard. The celloidin should be transparent. The tissues may then be cut out in block form and preserved in 80 per cent. alcohol until the technician desires to cut them.

Each block is then removed from the alcohol, dried carefully and placed, for a few seconds, in a mixture of equal parts of absolute alcohol and ether, dipped into the thick celloidin and is then placed upon a wooden block that has previously been dipped in the
alcohol-ether and thick celloidin. After standing a few minutes in the air the block is transferred to 80 per cent. alcohol until the cementing celloidin is hard (usually a number of hours) and then it is ready to be cut. The cementing celloidin may be rapidly hardened by placing the block in pure chloroform. These blocks may then be cut in ten to fifteen minutes.

It is inadvisable to preserve the mounted blocks in alcohol for any length of time as the tannic acid of the wood seems to affect the stain reaction unfavorably. Preserve the celloidin blocks in 80 per cent. alcohol until sections are wanted, then mount upon the wooden blocks and cut immediately.

If the celloidin is not hard enough, the blocks may be placed, for twenty-four to forty-eight hours, in 80 per cent. alcohol, containing 1 to 5 per cent. of glycerin.

**Gum.**—This infiltration medium is prepared as follows:

Syrup:

\[
\begin{align*}
\text{Cane sugar} & : 28.5\text{ gms.} \\
\text{Water} & : 30\text{ c.c.}
\end{align*}
\]

Gum:

\[
\begin{align*}
\text{Gum Acacia} & : 57\text{ gms.} \\
\text{Water} & : 310\text{ c.c.}
\end{align*}
\]

Mix together four parts of the syrup, five parts of the gum and to this add nine parts of a saturated solution of boric acid. Filter through muslin.

The tissues are thoroughly washed free of any trace of alcohol, and are then placed in the above solution, and allowed to remain until penetrated, which requires at least twenty-four hours if half-inch cubes are used. A longer time is better. The process is aided by allowing the jar with the tissues to stand in a warm place.

Tissues infiltrated with gum **must be frozen** and cut in a freezing microtome.

**SECTIONING**

After the above steps have been finished, the tissues are ready to be sectioned.

Paraffin blocks are **cut dry**, the knife of the microtome being placed so that it meets the block squarely. When large objects are cut it is sometimes necessary to place the knife obliquely. Very thin sections may be straightened for mounting by floating them on warm
water. The slide prepared with Mayer's albumen (see p. 57) is then dipped beneath them, and if carefully lifted, the section rests smoothly in place thereon.

Celloidin blocks are treated differently. The knife is placed obliquely and kept moist with 80 per cent. alcohol. The block likewise is kept moist and as the sections are cut they are transferred, by means of a large sable brush, to a dish of the same strength alcohol and allowed to remain there until required. If the celloidin

Fig. 3.—Minot Automatic Rotary Microtome.
(Bausch and Lomb Optical Co.)

is too soft, the sections will be quite thick. This may be remedied by hardening the blocks in alcohol containing 1 to 5 per cent. of glycerin. Celloidin answers very well for the nerve system, but where thin sections are desired the paraffin method is preferable.

Rapid Technic.—There is a rapid method of technic that gives good results. The steps are as follows:

1. Fix small pieces in formol-Müller solution for eighteen to twenty-four hours. (Formol 20 c.c., Müller's solution 80 c.c.)
2. Place in 95 per cent. alcohol for two hours.
3. Fresh 95 per cent. alcohol two hours.
4. Absolute alcohol twelve to twenty-four hours.
5. Place in anilin oil at 52°C. until transparent.
6. Place in paraffin at 46°C. for one hour.
7. Place in paraffin at 54°C. for three to four hours.
8. Block.
This method requires about fifty-six hours.

STAINING

In order to study the various portions of a cell, they must be differently stained. There are three classes of stains; (1) Chromatic, or Nuclear, (2) Plasmatic, or Protoplasmic, and (3) Special; of these, two are generally used—nuclear, or basic; and protoplasmic, or acid. The nuclear stain is used first, followed by the protoplasmic stain; this is called counter-staining. Two stains are used so as to contrast the two main portions of the cell.

Stains are employed in aqueous or alcoholic solutions. The quality of an aqueous solution is better but an alcoholic stain penetrates more rapidly. The quality of the stain reaction often depends upon the fixative used. Salts of chromium, osmium and platinum hinder the actions of stains while bichlorid of mercury, formalin, and alcohol make the stains more brilliant or are neutral in their action.

Intravitam staining is employed to tinge the cytoplasm of the tissues and cells while these are in the living condition. The living nucleus does not stain.

Nuclear Stains.—The most important of the chromatic stains are hematoxylin and the basic anilin dyes. The latter depend upon a color base for their action and hence the name basic stains is sometimes given to them.

The staining action of hematoxylin solutions is due chiefly to the hematein that is formed during the ripening process. It stains chiefly the nucleic acid and this is affected through the phosphates in the tissues. Hematoxylin solutions "go bad" for various reasons. The alum solution should be fresh as the older solutions form sulfuric acid which changes the stain from a bluish or purplish color to a reddish tint, in which condition the stain reaction is poor. The
hematein too may continue to oxidize, forming a precipitate thereby injuring the staining qualities. To prevent this the hematoxylin solution should be filtered from time to time. Fresh alum solution should also be added from time to time to keep the stain limited to the nucleus as in the older stains the action becomes diffuse.

**Hematoxylin.**—**Silver Hemateinate.**—(a) Dissolve 1 gram of silver nitrate in 100 c.c. of distilled water. To this add 50 c.c. of a 10 per cent. aqueous solution of potassium hydroxid (5 grams of KOH in 50 c.c. of distilled water). Shake well. Allow this to stand for one minute, decant and wash four times by decantation using 150 c.c. of distilled water each time.

(b) Dissolve 2.5 grams of hematoxylin in 50 c.c. of absolute alcohol. Pour this upon the silver oxid and heat upon a water bath until the mixture boils, shaking frequently. The mixture should be a deep orange color. Filter. To the filtrate add twenty times its volume of a 5 per cent. solution of potassium alum. The stain is ready for immediate use.

**Hematoxylin (Harris).**

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematoxylin</td>
<td>1 gm.</td>
</tr>
<tr>
<td>Absolute alcohol</td>
<td>10 c.c.</td>
</tr>
<tr>
<td>Potassium alum (sat. aq. sol.)</td>
<td>200 c.c.</td>
</tr>
</tbody>
</table>

Dissolve the hematoxylin in the alcohol and add it to the alum solution. When this is brought to a boil, add 1 gram of red mercuric oxid, and cool the solution rapidly. The oxygen liberated ripens the solution immediately, and the stain is ready for use when cool. It should be filtered and diluted with two to three times the quantity of water, when ready, and will require three to five minutes to stain. It is advisable to add a small piece of camphor or thymol to prevent the formation of molds.

Carrazi uses potassium iodate as an oxidation agent and claims that his stain will keep for years.

**Delafield’s hematoxylin** is prepared as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematoxylin</td>
<td>4 gms.</td>
</tr>
<tr>
<td>Alcohol</td>
<td>25 c.c.</td>
</tr>
<tr>
<td>Ammonium alum (sat. aq. sol.)</td>
<td>400 c.c.</td>
</tr>
</tbody>
</table>
Dissolve the hematoxylin in the alcohol and add this solution, drop by drop, to the alum solution. Expose this to the light and air for a week or more, and then filter. To the filtrate add

Glycerin.................................................. 100 c.c.
Methyl alcohol........................................... 100 c.c.

Expose again for a long time, and filter. This solution must be diluted three to four times.

**Mallory's Phosphomolybdic Acid Hematoxylin.**

Hematoxylin crystals........................................ 3.5 gms.
Phosphomolybdic acid crystals.......................... 2 gms.
Water ......................................................... 400 c.c.

Powder the hematoxylin and dissolve it in the water, by the aid of heat if necessary, and then add the phosphomolybdic acid. Expose this solution to the light for six weeks using cotton as a stopper in the flask. This stain may be used over and over and is used especially upon tissues that have been fixed in bichromate of potassium solutions, i.e., nerve and connective tissues.

**Mallory's Phosphotungstic Acid Hematoxylin.**

Hematein ammonium....................................... 0.2 gm.
Water ......................................................... 200 c.c.
Phosphotungstic acid (Merck)........................... 4 gms.

Dissolve the hematein in some of the water and add this to the phosphotungstic acid dissolved in the remainder of the water. This solution may be allowed to ripen as above or by the addition of a \( \frac{1}{4} \) per cent. solution of potassium permanganate (5 c.c.). This stain is used especially for fibrin, neuroglia and structures in mitosis.

**Acid Hematoxylin** is made up as follows:

Hematoxylin............................................... 1 gm.
Absolute alcohol........................................... 30 c.c.
Glycerin..................................................... 60 c.c. \( \text{Saturated} \)
Water ......................................................... 60 c.c. \( \text{with alum} \).
Glacial acetic acid........................................... 3 c.c.

Add the glycerin and water to the hematoxylin, dissolved in the alcohol, then add the acid. This solution must be exposed to the light for three weeks, when it becomes bluish. Sections stained in
it are not dark at first, but when exposed to the light they become bluish.

If the reaction with hematoxylin is not deep enough this may be remedied by washing the section with a little dilute alum solution, or with water containing a faint trace of ammonia.

Most of the anilin dyes are not stable, but fade when exposed to the light.

**Methylene blue** is used in connection with the nerve system and blood.

**Methyl green** is used for organs and tissues containing mucin, and in blood stains.

**Safranin O** is the best. Mix equal parts of a saturated aqueous and saturated alcoholic solution using absolute alcohol (Lee). Sections remain in this stain from two to twenty-four hours. They are then washed in plain alcohol for thirty seconds to differentiate. Clear in cedar oil, oil of bergamot or xylol and mount in balsam.

The author has found that the saturated aqueous solution will produce results in about twenty minutes when the alcoholic stain has practically no effect.

**Bismarck Brown.**—This stain is not very soluble in water. A saturated solution is made by boiling the stain in water, and then filtering. This gives a 3 to 4 per cent. solution, which is diluted by adding one-third volume of absolute alcohol. This stains rapidly but does not overstain. It is used to advantage in contrast with hematoxylin, in connective tissues and cerebellum. It answers well in staining the acid cells of the stomach. The sections should first be deeply stained with hematoxylin, and then subjected, five minutes, to the above stain. The acid cells are distinctly brown, while the peptic cells have a bluish cast.

**Polychrome methylene blue** is a metachromatic stain and is used diluted ten or even more times. It is allowed to act from ten to twenty-four hours. The sections are then washed with water, covered with water containing glycerin-ether for ten minutes. They are then washed with water, dehydrated with absolute alcohol, cleared with xylol and mounted in balsam. This is an excellent stain for plasma and mast cells. Alcoholic fixation is preferable.
The nuclei stain blue, the granules of mast cells are red and those of the plasma cells are blue.

Other basic stains are toluidin blue, thionin, dahlia, fuchsin, gentian violet, etc.

**Plasmatic, or Protoplasmic Stains.**—These stain the cytoplasm and intercellular substance. The more common stains are eosin, Van Gieson, carmin and acid anilin dyes.

**Eosin** is the most used plasmatic stain. It is employed after the nuclear stain has been used and washed off. There are a number of eosins, some soluble in water and some in alcohol. There are also blue and yellow eosins. The blue eosin seems to be the better for general purposes.

Eosin is commonly used as a 0.5 to 1 per cent. aqueous or alcoholic solution. It requires one to two minutes, and should be washed off with water, if an aqueous solution has been used; otherwise with alcohol. The aqueous solution is more desirable for general purposes.

Eosin is a specific stain for blood-cells and certain granules of the leukocytes, and is, therefore, used extensively in Hematology with methylene blue.

**Picric Acid.**—A saturated aqueous solution is used for fifteen to thirty seconds. It is then washed quickly with 95 per cent. alcohol.

**Picrorufusin (Van Gieson)** consists of picric acid and acid fuchsin.

\[
\begin{align*}
\text{Picric acid (sat. aq. sol.)} & \quad 1800 \text{ c.c.} \\
\text{Acid fuchsin (1 per cent. sol.)} & \quad 85 \text{ c.c.}
\end{align*}
\]

Stain from one to three minutes, and wash with alcohol. A little stronger solution is used for the nerve system. Sections should be cleared in oil of origanum.

There are stains that affect both nucleus and protoplasm sufficiently to differentiate each well. They are used chiefly in **bulk staining**, especially for entire embryos.

**Borax carmin** consists of carmin boiled in a **solution of borax**.

\[
\begin{align*}
\text{Carmin} & \quad 2 \text{ gms.} \\
\text{Borax (2 per cent. aq. sol.)} & \quad 200 \text{ c.c.}
\end{align*}
\]

Boil, and then add a few drops of a 5 per cent. solution of acetic acid and 100 c.c. of 70 per cent. alcohol. After a few hours filter, and to the filtrate add a small piece of thymol or menthol, to preserve.
Allow the solution to stain sections for fifteen or twenty minutes, and then differentiate with acid alcohol prepared as follows:

- Hydrochloric acid (concentrated) .......... 1 c.c.
- Water ........................................ 29 c.c.
- Alcohol (95 per cent.) ..................... 70 c.c.

This stain is also used for bulk staining.

**Alum Carmin.**—This is prepared by boiling 1 gram of carmin with 100 c.c. of a 5 per cent. solution of ammonium alum. This is filtered when cool, and preserved as above. It also requires the same time for staining.

**Picrocarmin** is a double stain, and its preparation is not so simple. It consists of the following:

- Carmin ........................................ 4 gms.
- Ammonia (concentrated) .................. 10 c.c.
- Water .......................................... 200 c.c.

Dissolve the carmin in the ammonia, to which a little water has been added. Then add the water, and, after twenty-four hours, filter. Allow the solution to stand until most of the ammonia has evaporated and add an aqueous saturated solution of picric acid until precipitation occurs. The solution must be stirred all the time. Set it aside to crystallize and to evaporate to one-third of its bulk. Pour off the liquid and evaporate it to dryness. Dissolve the first crystals and evaporate to dryness. This residue, as a 1 per cent. solution in water, is a very good double stain.

**Paracarmin** consists of the following:

- Carminic acid .............................. 1 gm.
- Aluminum chloride ......................... 0.5 gm.
- Calcium chloride ........................... 4 gms.
- Alcohol (70 per cent.) ................... 100 c.c.

Dissolve and filter.

This stain is especially useful in embryology, as it does not over-stain, and may be used again and again. On sections, it is a good contrast stain to Weigert's elastica stain.

**Ehrlich-Biondi-Heidenhain Stain.**—This stain is used especially in blood work or those tissues containing many leukocytes. It is composed of:
Orange (G) (saturated aq. sol.) .......................... 100 c.c.
Acid fuchsin (Rubin S) (saturated aq. sol.) .............. 20 c.c.
Methyl green (00) (saturated aq. sol.) ..................... 50 c.c.

This solution is diluted to make a solution of 1–100, which, upon the addition of acetic acid, must be bright red. It is difficult to prepare, and so is better bought ready for use.

Tissues should be fixed in corrosive sublimate, and sections stained for twelve to twenty-four hours, washed with 90 per cent. alcohol, and dehydrated with absolute alcohol, cleared and mounted in balsam.

**Acid fuchsin** is quite soluble in water and is used as a 0.5 per cent. aqueous solution. Sections are stained only a few minutes, washed a few seconds with acidulated water and then with alcohol, cleared and mounted. Sections fixed in chromosmium fixatives require twenty-four hours to stain.

**Orange G** is readily soluble in water and is used in a 0.5 per cent. solution. It is of advantage in blood staining and in mixtures.

**Ruthenium red** is used in a dilute aqueous solution to stain free-hand cross-sections of dried tendon. The tendon cells and the septa are stained red while the tendon fibers are only slightly affected.

**Congo Red.**—This is especially adapted to fetal or young tissues and is used like eosin.

Congo red .......................................................... 1 gm.
Distilled water ..................................................... 100 c.c.

If a few drops of dilute acetic acid be added to the above then the stain will be brighter and more differentiated.

Other plasma stains are neutral red, anilin blue, nigrosin, light green, methyl blue, etc.

**Special Stains.**—Under this head are classified (1) those that stain by either depositing a coloring substance in the form of a precipitate in certain tissues or spaces, as silver nitrate and gold chlorid; (2) those that have a selective affinity for certain tissues as iron hematoxylin, elastica, reticulum fat and myelin stains.

The metallic stains, silver nitrate and gold chlorid, produce negative or positive impregnations. In the former the intercellular substances alone are colored, while in the latter the cells alone are
affected. Lee states that stock solutions of nitrates and chlorids of osmium, uranium, gold, silver and platinum keep better in clear bottles and that a good sunning actually improves them. These metallic stains are used only upon living or very fresh tissues.

Silver Staining.—Corneal Lymph Spaces.—In the solid state silver nitrate may be rubbed over the cornea of a freshly removed eyeball. This surface is then removed, placed in distilled water and then brushed with a camel’s hair brush to remove the epithelium. Expose to the light and the silver nitrate that has penetrated the intercellular spaces will be reduced and turned black.

Mesothelial Cells.—Remove the omentum, central tendon of the diaphragm or peritoneum of a freshly killed animal, wash in distilled water and stretch over a slide or nested vulcanite rings. Place in a 0.75 per cent. solution of silver nitrate until opaque (ten to fifteen minutes); wash with distilled water and expose to the sunlight until reddish brown; then dehydrate, clear and mount in balsam. The cell outlines are stained black and the nuclei and the cell contents are quite distinct.

Vascular Endothelium.—Into the aorta of a narcotized rat or guinea-pig inject 50 to 80 c.c. of a 1 per cent. solution of silver nitrate. In fifteen to twenty minutes follow this with 100 to 150 c.c. of 4 per cent. formalin and expose to the sunlight. When reduction is complete (reddish brown) remove small pieces of the mesentery, dehydrate, clear and mount in balsam. The endothelium of the vessels will be clearly outlined.

Nerve Cells and Processes.—Cajal-Golgi Method.—Thin pieces of nerve tissue are placed in the following solution and hardened for three days:

1. Potassium bichromate solution (2 to 2.5 per cent.) 8 parts.
   Osmic acid solution (1 per cent.) 2 parts.

2. Transfer tissues to a solution of silver nitrate of $\frac{1}{2}$ to $\frac{3}{4}$ per cent. strength. First blot off the bichromate solution and then rinse tissues thoroughly in some silver solution. Then place tissues in at least thirty times their volume of silver solution and allow them to stand in the dark for three days. Change the silver solution after the first eight to twelve hours.
3. Return to the following solution for one to two days:
   Potassium bichromate solution (2 per cent.)................. 20 parts.
   Osmic acid solution (1 per cent.).......................... 2 parts.

4. Wash quickly with distilled water and return to a fresh solution of silver nitrate of previous strength for thirty-six to forty-eight hours.

5. Dehydrate in twenty times the bulk of 95 per cent. alcohol for twenty minutes; the alcohol should be renewed after the first five minutes.

6. Dehydrate in same bulk of absolute alcohol for thirty minutes; renew after ten minutes.

7. Replace alcohol by same volume of absolute alcohol and ether (equal parts) for twenty minutes.

8. Transfer to thin celloidin for twenty-five minutes and then thick celloidin for ten minutes.

9. Block and harden in chloroform for about ten minutes.

10. Place for thirty minutes in the following clearing solution:

     Carbolic acid (melted) ....................................... 50 c.c.
     Oil of thyme or cedar ....................................... 50 c.c.
     Oil of bergamot ............................................ 25 c.c.

11. Section, keeping knife and block moist with above clearing fluid.

12. Mount on slides, remove clearing fluid by means of xylol, blot, cover with thick balsam, but do not use a cover-glass.

If the pieces of tissue are delicate and thin then embed them in spinal cord or brain until ready to clear and infiltrate.

**Neurofibrils.—Bielschowsky’s Method.**—Pieces of tissue 1 cm. in size are fixed in formalin and placed in pyridin for three to four days. Wash for several hours in frequent changes of distilled water and place in a 3 per cent. solution of silver nitrate at 36°C., for three to five days. Place in an oxid bath for twenty-four hours. Prepare this bath as follows: 20 per cent. solution of silver nitrate 5 c.c.; 40 per cent. solution of sodium hydroxid 5 drops. To this add sufficient ammonia to dissolve the precipitate and then add 100 c.c. of distilled water. This solution keeps only a few hours and should be prepared just before use. After the tissues are
taken from the bath wash for a couple of hours in frequent changes of distilled water and reduce in a 20 per cent. solution of formalin, dehydrate and make paraffin sections.

**Golgi’s Method.**—Fix fresh nerve tissues for six to eight hours in a mixture consisting of equal parts of a saturated solution of arsenious acid, 96 per cent. alcohol and 20 per cent. formalin. Place for one to three hours or days in a 1 per cent. solution of silver nitrate. Reduce in the following: hydroquinon 20 grams; sodium sulphite 5 grams; 20 per cent. formalin 50 c.c.; water 1000 c.c. Wash and carry through celloidin. Sections are to be toned in a solution consisting of sodium hyposulphite 30 grams; sulphocyanid of ammonium 30 grams; water 1000 c.c. and 10 per cent. of a 1 per cent. solution of gold chlorid. Tone until gray and then wash carefully and thoroughly, dehydrate, clear and mount.

Silver nitrate solutions (Golgi’s method) are also used for outlining the secretory canaliculi of the cells of the liver, acid cells of the stomach, etc.

**Gold chlorid** gives a *positive impregnation*. It is used somewhat for the study of lymph spaces, but is chiefly used upon nerve tissues for which it seems to have an especial selective affinity. When it is used upon fresh tissues it is called *pre-impregnation* and when it is used upon fixed and hardened tissues it is called *post-impregnation*. In the *former* the nuclei are unstained, the cytoplasm is well stained and the axis-cylinders are reddish violet. In the *latter* the nuclei are well stained, the cytoplasm is pale and the axis-cylinders are black, differentiating the neurofibrils in the latter (Lee). It was formerly believed that the tissues must be fresh for gold staining but it has been found that the results are better if the tissues are put in a cool place for twelve to twenty-four hours before being subjected to the action of the gold chlorid.

**Pre-impregnation.—Ranvier’s Formic Acid Method.**—Take four parts of a 1 per cent. solution of gold chlorid and one part of formic acid and boil. When cool place small pieces of tissue therein: muscle requires about twenty minutes and epidermis one to two hours in the dark. Reduce in the daylight in acidulated water or in the dark in formic acid one part, water four parts, for twenty-four hours. Infiltrate and make sections in the usual way.
Postimpregnation.—Apathy’s Method.—Fix tissues in a saturated solution of corrosive sublimate in 0.5 per cent. sodium chlorid and 1 per cent. osmic acid. Infiltration may be in either paraffin or celloidin but should be rapid. Sections are to be fixed to the slide and the bichlorid removed with iodin solution and the latter removed with alcohol. Then wash the sections with water, place in formic acid for one minute and wash again with water. Transfer, for about twenty-four hours, to a gold chlorid solution (0.1 to 1 per cent.), wash with water and place (sloping) in 1 per cent. formic acid. The sections should face downward so that the precipitate falls away from them. Reduction is carried on in the daylight in summer or in direct sunlight in the winter, for six to eight hours without a break. If the acid becomes brown it should be renewed. Lee recommends a weak solution of formalin, with or without the formic acid, for the reduction.

Iron Hematoxylin.—Place sections for one-half to two hours in a 1.5 to 4 per cent. solution of ferric sulphate (clear violet crystals). Wash with water and stain for one-half hour in a 0.5 per cent. aqueous solution of hematoxylin. Wash with water and transfer to the ferric sulphate to differentiate. Examine frequently under the microscope and continue the differentiation until the stain is removed from all structures except the chromatin and centrosomes. Wash for one-half hour in running water dehydrate, clear in xylol and mount in balsam.

This stain is used for studying the chromatin, mitochondria and karyokinetic figures. The chromatin, centrosomes and spindle fibers are black while the remaining structures are unstained or grayish.

Fuchsin-Methyl Green (Auerbach).—This stain is used to differentiate between resting and active chromatin. It consists of the following:

1. Acid fuchsin, 1 gram, water 1000 c.c.
2. Methyl green, 1 gram, water 1000 c.c.

These are stock solutions and are mixed in the following proportions just previous to staining.

1. Take 2 parts and add 1 drop of 10 per cent. glacial acetic acid for each 50 c.c. of solution.
2. Take 3 to 4 parts and add to the above.
Sections not over 3μ thick should be stained for 15 minutes and then placed in 95 per cent. alcohol until the green does not leave in clouds; then treat with absolute alcohol, clear with xylol and mount in balsam. Bichlorid fixation is preferred. Chromosomes are green and plasmosomes and linin are red.

Myelin Stain.—Weigert's Method for Myelin Sheaths.—The tissues are fixed in bichromate, though this is not absolutely necessary. Results are more certain if the tissues have been fixed in a bichromate solution, as they respond more readily to the stains and are not so likely to fade. Celloidin infiltration is usually the best.

After the sections have been cut, they are placed, for four to twenty-four hours, in the following solution:

<table>
<thead>
<tr>
<th>Potassium bichromate</th>
<th>5 gms.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrome alum</td>
<td>2 gms.</td>
</tr>
<tr>
<td>Water</td>
<td>100 c.c.</td>
</tr>
</tbody>
</table>

They are then washed thoroughly, and transferred to the following solution for twenty-four hours:

| Copper acetate | 5 gms. |
| Acetic acid (36 per cent.) | 5 c.c. |
| Chrome alum | 2.5 gms. |
| Water | 100 c.c. |

Add the chrom alum to the water, bring to a boil, remove the heat, add the acetic acid, and then the copper acetate, stirring thoroughly until the last of the salt is dissolved. When cold the solution should be clear.

This solution is a mordant. The sections are carefully washed and carried into the following solution:

| Hematoxylin | 1 gm. |
| Absolute alcohol | 10 c.c. |
| Lithium carbonate (sat. aq. sol.) | 1 c.c. |
| Water | 90 c.c. |

The sections are stained from fifteen minutes to two or four hours in this lukewarm solution, and then washed and left in the water for twelve to twenty-four hours to deepen the stain. They are then differentiated in the following:
Potassium ferricyanid. ........................................... 5 gms.
Borax (if granular, use one-half amount) ....................... 4 gms.
Water .......................................................... 200 c.c.

In this solution they must remain until the gray substance becomes yellowish. This change must be watched under the microscope. The sections are immediately washed with water, and left in water for twelve to twenty-four hours, changing frequently. This fixes the stain. They are then dehydrated, cleared and mounted in balsam.

The myelin sheaths will be bluish-black.

**Weigert-Pal Method.**—1. Fix as for Weigert method and after cutting place the sections in a $\frac{1}{2}$ per cent. solution of chromic acid for several hours. This step is not necessary if a chromium salt has previously been used for fixation.

2. Wash and transfer to the hematoxylin solution for twenty-four to forty-eight hours. Use the stain lukewarm.

3. Wash with water containing about 2 per cent. of lithium carbonate. The sections should be bluish.

4. Differentiate in a $\frac{1}{4}$ per cent. aqueous solution of potassium permanganate until the gray substance of the nerve tissue is yellowish-brown in color.

5. Transfer to the following solution until the gray substance is almost colorless:

- Potassium sulphite ........................................ 1 part.
- Oxalic acid ............................................... 1 part.
- Distilled water ........................................... 200 parts.

This solution requires but a few seconds to produce its action.

6. Wash thoroughly with water, dehydrate, clear and mount. By this method all the tissues, except the myelin sheaths, are decolorized.

**Marchi’s Method for Degenerated Nerve Fibers.**—Harden small pieces of nerve tissue in Müller’s fluid for one week, then transfer for a few days to a mixture of two parts of Müller’s fluid and one part of 1 per cent. osmic acid solution. Wash thoroughly with water, dehydrate, embed in celloidin and cut sections. Sections should be mounted in chloroform balsam to retain the osmic acid. The normal sheaths are yellow while the degenerated ones are black.
Neuroglia, Mallory’s Method.—Fix fresh nerve tissue for four days in 10 per cent. formalin and then transfer for four to eight days to a saturated aqueous solution of picric acid. Mordant for four to six days, at 37°C. in a 5 per cent. solution of ammonium bichromate, embed in celloidin and section. Place sections for fifteen minutes in a 0.5 per cent. solution of potassium permanganate, wash and transfer for fifteen minutes to a 1 per cent. solution of oxalic acid. Wash well and stain from two to twenty-four hours in phosphotungstic hematoxylin made as follows: Dissolve 1 gram of hematoxylin in 80 c.c. of water, add 20 c.c. of a 10 per cent. solution of Merck’s phosphotungstic acid and 0.2 c.c. of hydrogen peroxid (U.S.P.). Wash the sections, dehydrate, clear with oil of origanum and mount in balsam. Axis cylinders and cells are pink while the neuroglia is blue.

To make this stain permanent after washing the hematoxylin off of the sections, place them in a 30 per cent. alcoholic solution of ferric chloride for five to twenty minutes, wash with water and finish as above. The nuclei and neuroglia are clear blue and other elements are yellowish or grayish.

Nissl’s Stain.—This is a special stain for the tigroid bodies of nerve cells. It responds well only in those tissues that have been fixed in 95 per cent. alcohol.

1. Stain.
   Methylene blue (Gruebler’s B pat.) .................... 3.75 gms.
   Venetian soap (white castile) .................... 1.75 gms.
   Distilled water ..................................... 1000.00 c.c.

2. Differentiating fluid.
   Anilin oil (pure) ................................. 10 c.c.
   95 per cent. alcohol ............................ 90 c.c.

1. Warm the stain until it steams and immerse the sections for four to six minutes.

2. Rinse with distilled water.

3. Differentiate in No. 2 until the sections are pale blue (twenty to sixty seconds).

4. Wash with 95 per cent. alcohol.

5. Clear in a mixture of equal parts of oils of origanum and cajeput and mount in colophonium dissolved in xylol.

The tigroid bodies of the cytom and dendrites are a deep blue.
Weigert’s elastica stain is used to demonstrate the elastic tissue in organs and tissues, and is prepared as follows:

Fuchsin ........................................ 2 gms.
Resorcin ....................................... 4 gms.
Water ........................................... 200 c.c.

This mixture is brought to a boil, and then 25 c.c. of a solution of liquor ferri sesquichlorati added, the mixture stirred and boiled for three to five minutes. When cool, it is filtered, and the precipitate dissolved upon the filter, in 200 c.c. of 95 per cent. alcohol. This is stirred and boiled until the precipitate is entirely dissolved. The solution is then cooled and brought up to 200 c.c. with 95 per cent. alcohol and 4 c.c. of hydrochloric acid added.

Carbolic acid in the same proportion may be used in place of resorcin.

Sections should be stained, from twenty minutes to an hour, in this solution, washed well in 95 per cent. alcohol, counter-stained with picric acid solution for thirty seconds, washed, dehydrated and cleared and mounted. The elastic tissue should be of a bluish-black color.

Osmic Acid.—This is used as a 1 per cent. solution as a special stain for fat, which it turns black and renders almost insoluble in the ordinary reagents used in technic.

Sudan III.—A solution of this stain is also a special stain for fat, coloring it a deep red. Sections (frozen or cover-glass preparations) are stained from a few minutes to twenty-four hours in a saturated solution of Sudan III in 80 per cent. alcohol. They are washed with 95 per cent. alcohol, then water and mounted in glycerin jelly.

Scharlach R.—This is considered one of the best of this group of stains. The latest is a saturated solution of the stain in

Acetone ........................................ 50 c.c.
70 per cent. alcohol .......................... 50 c.c.

For sections the procedure is as follows:
1. Fix in formalin, freeze and make sections.
2. Dip for a moment in 70 per cent. alcohol.
3. Stain with the above stain for two to five minutes.
4. Wash quickly with 70 per cent. alcohol.
5. Counterstain with alum hematoxylin.
6. Wash thoroughly with water.
7. Mount in glycerin jelly.

The staining process should be carried out in an air tight bottle or dish.

Capsicum red stains the ordinary fat or the fat of sebaceous and ceruminous glands, nerve fibers and fat in pathologic conditions equally well. Sections of fixed tissues or frozen sections may be stained five minutes or longer, washed with 80 per cent. alcohol, then water and mounted in glycerin or glycerin jelly. Sections may be counter-stained with hematoxylin. The stain is prepared by making an alcoholic extract of the ripe capsicum (pericarpium layer) and evaporating this to one-fifth of its bulk.

Cyanin Solution stains fat a bluish color.

Picrofuchs in (Van Gieson).—Although this may be classed under the plasmatic stains, it is, nevertheless, a special stain for white fibrous connective tissue. This it stains a beautiful bright red, while the other tissues are stained yellowish or brown.

Mallory’s Reticulum Stain.—Sections (bichlorid fixation) are placed, after the removal of the bichlorid, in a 0.1 to 0.5 per cent. solution of fuchsin for one to three minutes. Transfer directly to the following solution for ten to twenty minutes.

- Anilin blue (aqueous solution).................. 0.5 gm.
- Orange G........................................... 2.0 gms.
- One per cent. aq. sol. of phosphomolybdic acid.................. 100 c.c.

Wash with water, dehydrate, clear in xylol and mount in balsam. Reticulum, collagen fibrils, amyloid and mucin are blue while the other structures are yellow or red. If staining with acid fuchsin is omitted the collagen fibrils stand out sharper. The nuclei and protoplasm stain yellow.

Amyloid Stain.—Tissues may be stained fresh or after fixation, preferably in alcohol. Stain sections in a weak solution of iodin for three minutes and then wash with water. Treat with a 1 to 5 per cent. solution of sulphuric acid and the color will change from red to blue. Dehydrate, clear in oil of origanum and mount in balsam. The amyloid material will be blue.
**Mucin.**—Fix tissues in corrosive sublimate, imbed in paraffin and stain the section, without removing the corrosive sublimate, for five to fifteen minutes in a dilute solution of thionin (2 drops of the saturated solution in 5 c.c. of distilled water). Wash with alcohol, clear in a mixture of oil of cloves and thyme and then oil of cedar and mount in balsam. The *mucin* is red and the other substances are blue.

**Muchematein (Mayer).**—This is a special stain for *mucin* and stains in from three to ten minutes. It is prepared as follows:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematein</td>
<td>0.2 gm.</td>
</tr>
<tr>
<td>Glycerin</td>
<td>40 c.c.</td>
</tr>
<tr>
<td>Aluminum chlorid</td>
<td>0.1 gm.</td>
</tr>
<tr>
<td>Distilled water</td>
<td>60 c.c.</td>
</tr>
</tbody>
</table>

Mix the hematein and glycerin in a mortar and then add the aluminum chlorid and the water. When mixed add a drop or two of nitric acid to increase its sharpness as a nuclear stain.

**Glycogen.**—Fix small pieces of tissue in the following for ten to twelve hours:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trichloracetic acid</td>
<td>9 parts</td>
</tr>
<tr>
<td>2 per cent. osmic acid</td>
<td>24 parts</td>
</tr>
<tr>
<td>Glacial acetic acid</td>
<td>9 parts</td>
</tr>
<tr>
<td>Distilled water</td>
<td>58 parts</td>
</tr>
</tbody>
</table>

Wash with 50 per cent. alcohol for one hour or longer and then imbed in celloidin. Sections are stained with Best’s alkalin carmin and counter-stained with blue de Lyon for five minutes (10 grams in 250 c.c. of absolute alcohol). Wash with absolute alcohol, clear with xylol and mount in balsam. Fat is black, *glycogen* red and nuclei are blue.

Glycogen is soluble in water and alcohol solutions of less than 50 per cent. strength but not in trichloracetic acid and stronger alcohols.

**Gage's Method.**—Fix the tissues in 95 per cent. alcohol and embed in paraffin in the usual way. Cut sections and mount upon slides, flattening with the following (Lugol’s) solution:

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodin</td>
<td>1.5 gms.</td>
</tr>
<tr>
<td>Potassium iodid</td>
<td>3.0 gms.</td>
</tr>
<tr>
<td>Sodium chlorid</td>
<td>1.5 gms.</td>
</tr>
<tr>
<td>50 per cent. alcohol</td>
<td>300 c.c.</td>
</tr>
</tbody>
</table>
Cover the section with this solution, which acts as the stain, for five to ten minutes, then dehydrate, remove the paraffin with xylol and mount in melted vaselin. To make the preparation permanent ring with shellac. The glycogen granules are mahogany red.

**Mast Cells.**—Small pieces of tissue are placed in the following for twenty-four hours:

- Formalin, 40 per cent ........................................ 100 c.c.
- Alcohol, 90 per cent ........................................ 100 c.c.
- Toluidin blue .................................................. 6 gms.

Place for several hours in 70 per cent. alcohol, changing twice. Transfer to 96 per cent. alcohol for several hours, then absolute alcohol, benzol and paraffin. In the sections the mast cells are an intense blue and sharply outlined upon a pale blue background. This is also a selective stain for the chief cells of the rabbit's stomach.

**Plasma Cells and Mast Cells.**—Sections of tissues, preferably hardened in alcohol, are stained for fifteen minutes to twelve hours in polychrome methylene blue. Wash with water and decolorize with water containing a few drops of glycerin-ether for five to ten minutes. Wash well with water, dehydrate in absolute alcohol, clear with xylol and mount in balsam. The nuclei are blue and the granules of the mast cells are red while those of the plasma cells are blue.

**Mitochondria,** or plasmosomes are readily dissolved by acids and these must not be present in the fixatives used. For this reason Helly's fluid or Flemming's solution (eight days) in which the acetic acid has been reduced to only a few drops are best adapted to this technic. The paraffin sections should not be over 3μ to 6μ in thickness and should be stained by the iron-hematoxylin method. The mitochondria are seen in the form of black rods, filaments or granules while the other structures are grayish (Meves).

According to **Benda's method** fix for eight days in Flemming's solution, as above, and then wash in water for one hour. Then place in a mixture of equal parts of pyroligenous acid and 1 per cent. chromic acid for twenty-four hours. Transfer to a 2 per cent. solution of potassium bichromate for twenty-four hours. Then carry through paraffin infiltration as usual and make thin sections.
Mordant the sections in a 4 per cent. solution of ferric chlorid for twenty-four hours and rinse with water. Place them in a solution of Kahlbaum's sulphalizarinate of soda (1 c.c. of a saturated alcoholic solution of this salt in 100 c.c. of distilled water) for twenty-four hours.

Wash the sections and cover with crystal violet (saturated solution of crystal violet in 70 per cent. alcohol one part; 1 per cent. HCl in 70 per cent. alcohol one part; anilin water two parts); warm the sections until a steam is given off.

Wash with water and differentiate for a minute or two in a 30 per cent. solution of acetic acid, and then wash in running water for ten minutes.

Blot the water, dehydrate in absolute alcohol, clear with oil of bergamot followed by xylol and mount in balsam.

**Chromaffin granules** are readily fixed and stained by chromic acid and salts of chromium. As these granules are readily soluble in acids these must not be present in the fixative. Helly's fluid is one of the best for the fixation and staining of them especially as it permits of the use of various nuclear stains. The granules are stained a light brown.

**CLEARING AGENTS FOR SECTIONS**

After sections have been stained and dehydrated the alcohol must be removed by some agent that will permit of the use of a permanent mounting medium. There are several of these de-alcoholization reagents, some answering better for some stains than others.

**Creosote (Beechwood).**—This oil clears readily and may be used with practically all stains. It has the advantage of not dissolving celloidin and is an excellent agent for general laboratory work. It clears in from three to five minutes.

**Cedar oil** clears tissues readily from 95 per cent. alcohol and does not extract anilin dyes.

**Oil of origanum** clears readily, celloidin is not affected but it removes anilin dyes somewhat. It is especially employed after picrofuchsin stain.
Clove oil acts rapidly but dissolves celloidin and removes anilin dyes. Sections become hard and brittle and yellow with age. It acts better when mixed with an equal part of oil of bergamot.

Oil of Bergamot does not extract anilin dyes nor does it dissolve celloidin. It will, however, remove eosin.

Xylol, toluol, benzol, all act very rapidly, and require dehydration with absolute alcohol. They are useful with anilin stains, and are readily applicable as solvents of balsam. They, however, render celloidin stiff and hard.

Carbol-xylol is a mixture of xylol and carabolic acid.

Xylol ......................................................... 3 parts.
Carbolic acid .................................................. 1 part.

For larger sections, *i.e.*, brain stem, the writer prefers the following mixture:

Carbol-xylol .................................................. 2 parts.
Clove oil ...................................................... 1 to 2 parts.

The clove oil keeps the celloidin soft and pliable so that upon blotting the sections are flat and not raised in ridges.

It acts very rapidly, and is best for hematoxylin and carmin stains; it does not stiffen celloidin.

Anilin oil-xylol consists of anilin oil, *two parts*, and xylol, *one part*. It is more commonly used than the carbol-xylol mixture.

Most of the oils require about *five minutes* to act. The sections are set aside during this time. In the case of rapidly acting agents, the slides are retained in the hand and rocked back and forth until the section is clear. This is usually accomplished in a minute or so.

**MOUNTING MEDIA**

After clearing, the sections are ready for the final step, that of mounting. There are several mounting media, such as balsam, dammar, Farrant’s solution, glycerin jelly and glycerin.

The object of mounting is to make a permanent preparation. The choice of medium may depend upon the stain used. If this is no factor the chosen medium should have a refractive index as
near crown glass as possible (1.518). Aqueous, glycerin and glycerin jelly mounts may be made nearly permanent by preventing evaporation. This is done by ringing as will be explained later.

Sections and tissues that cannot be dehydrated and cleared for special stain reasons are mounted in glycerin, syrup or gum.

**Glycerin Media.**—Glycerin is an excellent preserving medium. When diluted with water structures are more easily examined and studied than when mounted in pure glycerin, but they are not so well preserved. To preserve in pure glycerin it is best to place the object for a few hours in a few drops of glycerin-alcohol mixture (glycerin one, alcohol one, water two parts) so as to allow the gradual evaporation of the alcohol. It may then be covered with pure glycerin, or glycerin jelly and then sealed.

**Glycerin jelly** is a solid at ordinary temperatures and may be softened with heat and then poured upon the object that has been previously treated with glycerin and water. A drop is placed upon the specimen, and the cover-glass quickly applied, as this medium sets rapidly. It is used for special purposes, as for *isolated cells*, *urinary casts*, *crystals*, etc. Neither dehydration nor clearing is necessary.

**Glucose Mixture.**—Mix forty parts of glucose and ten parts of glycerin in 140 parts of water. Then add seventy parts of camphorated spirits and filter. This is especially used for mounting sections and objects stained with the anilin dyes as it preserves these colors. Evaporation may be prevented by ringing.

**Gum and Syrup.**—Dissolve picked gum arabic 50 grams, and cane sugar (not candied) 50 grams in 50 c.c. of distilled water over a water bath and add 0.5 gram of thymol. This sets quickly and gets as hard as balsam. It is used for mounting preparations stained with methylene blue.

**Farrant’s medium** consists of 4 ounces of picked gum arabic, 4 ounces of water and 2 ounces of glycerin. Sections are covered with this, a cover-glass applied and later a cement ring is put on.

**Resinous Media.**—These media comprise gum sandarac, Canada balsam, gum dammar and colophonium. These are all solids and are liquefied by the action of certain volatile solvents.

**Euparal** is a new mounting and preserving medium. This is a mixture of camsal, sandarac, eucalyptol and paraldehyde. It is
colorless or greenish, dries slowly and is considered better than balsam (Lee). The sections can be mounted directly from 95 per cent. alcohol without clearing, or, after dehydration, the sections may be treated with isobutylic, or propylic alcohol and then mounted in euparal.

**Balsam.**—Sections to be mounted in balsam must be thoroughly dehydrated and cleared in an oil. The oil is then removed by blotting, a small drop of balsam placed upon the specimen and a clean cover-glass applied.

The balsam is soluble in *chloroform, turpentine, benzol or xylol*. The latter agent is the best. Sections mounted in this medium are permanent.

**Dammar** is more complex. It consists of the following:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gum dammar</td>
<td>1.5 oz.</td>
</tr>
<tr>
<td>Gum mastic</td>
<td>0.5 oz.</td>
</tr>
<tr>
<td>Turpentine</td>
<td>2 oz.</td>
</tr>
<tr>
<td>Chloroform</td>
<td>2 oz.</td>
</tr>
</tbody>
</table>

The dammar is to be dissolved in the turpentine, and the mastle in the chloroform. Each is to be filtered, the filtrates mixed and the mixture filtered. This is to be kept in a well-stoppered bottle to prevent the evaporation of the chloroform.

**Colophonium.**—Pale colophonium is dissolved in pure turpentine to form a solution of medium consistency. This sets slowly and is injurious to alum hematein stains, but is excellent for methylene blue and other general stains.

After the sections are ready for mounting a drop or two of the selected mounting medium is placed upon the object and a clean cover-glass applied.

**Cements.**—Aqueous and glycerin mounts are rendered permanent by painting the clean edges of the cover-glass with a layer of glycerin jelly and repeating this several times, allowing each coat to set. This seals the cover-glass. This may be followed by a mixture of gold size one part, dammar two parts, dissolved in benzol. Several rings of this are applied at intervals of twenty-four hours.

**Shellac cement** for ringing may be made by dissolving shellac to the desired consistency in wood alcohol, or naphtha. Add 20 drops of castor oil to each ounce.
Bone and teeth may be ground for study. If sections are desired, the inorganic substance must be removed by means of acids. This process is decalcification.

Whole teeth and small pieces of bone are fixed and hardened in solutions containing a salt of chromium, and are allowed to remain as long as required. After being thoroughly washed and dehydrated as above, they are ready for the decalcifying agent, of which large quantities are to be used. The solutions given below are the most important.

**Phloroglucin-nitric acid** is no doubt the best. It consists of

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phloroglucin</td>
<td>1 gm.</td>
</tr>
<tr>
<td>Nitric acid (concentrated)</td>
<td>5 c.c.</td>
</tr>
<tr>
<td>Alcohol (70 per cent.)</td>
<td>100 c.c.</td>
</tr>
</tbody>
</table>

The phloroglucin is dissolved in the nitric acid, and allowed to stand until the fumes have disappeared (about twenty-four hours). The alcohol is then added, and then 5 to 10 per cent. of nitric acid. The teeth or bone are placed therein until readily penetrated by a needle or cut with a scalpel. The tissues are then transferred to alcohol and dehydrated in the manner already stated. Celloidin is the better infiltrating agent, as heat tends to harden osseous tissues. Additional nitric acid may be added from time to time as the solution weakens.

**Mayer’s solution** is a 5 per cent. solution of nitric acid in 95 per cent. alcohol. It acts very well. The alcohol is supposed to prevent swelling of the tissues.

**Trichloracetic Acid.**—A 5 per cent. solution of this is used. It is slower than the nitric acid, but the treatment is the same.

**Picric acid** in a saturated aqueous solution is only adapted to small objects as young embryos and is a very slow reagent. It must be frequently renewed. **Picronitric** and **picrohydrochloric acids** act more rapidly.

Decalcification may be carried on after the tissues have been imbedded in celloidin. The celloidin block is transferred to a 10 to 40 per cent. solution of nitric acid in 85 per cent. alcohol and allowed to remain until decalcification is complete. Then the block is
washed in 85 per cent. alcohol containing precipitated carbonate of calcium to neutralize the acid. The tissue is then ready to be mounted upon a wooded block and cut. This is an excellent method for the temporal bones of mammals.

**GRINDING**

Macerate a tooth or a piece of fresh bone to remove the fat and soft parts. Saw thin sections and cement them to a glass plate with sealing wax. Grind to one-half the thickness on a fine emery wheel. Unseal and reseal the ground side toward the plate and grind the section until quite thin. Remove the section carefully and rub upon a water hone to the desired thinness, then wash, dry thoroughly and mount in balsam.

**Dry Method.**—Cut sections one-sixteenth of an inch thick with a jeweler's saw. Place this section near the end of a microscope slide, heat some shellac just to the melting point and pour it around the section to form a zone about one-half inch wide. Be sure to press the section firmly against the slide while the shellac is setting so as to prevent any of this from getting under the section. The grinding is done upon sand, emery or carborundum papers according to the hardness of the substance to be ground. Sand paper Nos. 2, 1, 00 and 0000 are the best grades. Brittle substances grind best upon No. 00 using a light touch. Tougher substances should be started upon Nos. 2 and 1. During grinding the index finger of the hand holding the slide should be placed back of the section so as to insure uniform pressure to all parts of the section. The section should be moved in an elliptical manner and the paper kept free of the particles resulting from the grinding. When this surface is ground true it is finished upon No. 0000. *Polishing* is accomplished by rubbing the ground surface first upon the back of a piece of sand-paper, then upon a piece of smooth ground glass, upon the palm of the hand or upon a razor strop.

After grinding one surface the section is removed by first chipping the shellac away from the edge and then soaking the specimen in 95 per cent. alcohol or wood alcohol. When the shellac is softened the section may be lifted by slipping a safety razor blade under it and lightly lifting the section to another clean slide. The polished
surface is then cemented to the glass as above. As the second grinding proceeds the section may be examined under the microscope from time to time until the desired thinness has been attained. As the section becomes thinner greater precaution must be taken in grinding. This surface is then finished as before. To remove the section place the slide horizontally in a Petri dish of 95 per cent. alcohol for four or five hours if necessary. The section may then be stained in the regular manner, or the section may be dried and mounted in balsam.

This method was devised by Dr. J. I. Fanz in the preparation of a hard and brittle plant stem where all other methods absolutely failed. The results of this method were exceptionally good and the method works equally well with bone, shell, etc.

A rapid method for grinding bone is as follows:

Cut thin section of fresh bone with a jeweler’s saw. Mix emery flour and cylinder oil to a thin paste upon a piece of plate glass. Place the section of bone upon the glass and work it into the paste by holding it to the glass plate with a large cork stopper. Grind with an elliptical motion and turn the section from time to time so as to grind both sides. Be careful so as to exert an even pressure upon the cork or one edge will be thinner than the other. By this means the section can be ground down almost thin enough for microscopic study. The grinding is then finished upon a water hone. Cross-sections of the entire human femur may be readily prepared in this way. The only drawback is that all of the emery cannot be washed out of the specimen but will remain packed in the lacunae and canals.

INJECTION

Injection Masses.—In order to study the circulatory system, the vessels must be injected with a substance that will outline them. For this purpose, either an aqueous solution of carmin or of Berlin blue, or gelatin masses are used.

Berlin blue is used in water, one part to twenty, and this is injected with a hand syringe or by continuous air pressure. It gives very good results.

The gelatin masses may be either carmin or Prussian blue, or Berlin blue.
The carmin mass consists of the following:

- Carmin: 2 gms.
- Water.
- Ammonia.

Stir the carmin in a little water, and add strong ammonia, drop by drop, until the carmin is entirely dissolved. Filter the solution and add it carefully to the melted gelatin. The latter is prepared by soaking gelatin in double its quantity of water, and melting. The mixture is stirred and then neutralized with dilute acetic acid. If too acid, the carmin will be precipitated, and if the ammonia is not neutralized and the gelatin is quite alkaline, the stain will not be limited to the injected vessels, but will be diffused into the surrounding tissues.

This mass should be filtered while hot, and preserved with a little camphor.

The Prussian blue mass is somewhat similar. Four grams of the Prussian blue are stirred into 80 c.c. of water, and the mixture added to gelatin prepared as above. The solution is filtered while hot, and preserved with camphor, or covered with methyl alcohol.

The entire body, or individual organs, may be injected. When the hand syringe is used, great care must be exercised that the pressure be not too great, as the vessels will rupture and the mass extravasate. The continuous air pressure method is the better. The mass must be melted and the animal kept warm by immersion in warm water. As soon as the injection is complete, the animal or organ is immersed in ice-water, so that the gelatin may set immediately. When the body is cooled, the organs are cut into blocks, and transferred to 80 per cent. alcohol, where they remain until thoroughly hardened, which takes from one to three days. The addition of 5 per cent. of formalin will hasten the hardening. They are then treated with 95 per cent. alcohol to dehydrate, then cleared and infiltrated like any other tissue.

White Mass.—Precipitate 125 to 185 c.c. of a cold saturated solution of barium chlorid by adding sulphuric acid drop by drop. Allow the precipitate to settle for twenty-four hours and decant the clear fluid. The remaining mucilaginous mass is mixed with an equal volume of strong gelatin solution.
Yellow Mass.—Mix equal volumes of concentrated gelatin solution and a 4 per cent. solution of silver nitrate and warm; add a small quantity of pyrogallic acid which reduces the silver rapidly. Then add 5 to 10 per cent., by volume, of glycerin and 2 per cent. by weight, of chloral in a concentrated solution and strain. This mass is yellow in the capillaries and brown in the larger vessels.

Self Injection of Living Animals.—This is accomplished by allowing a definite quantity of blood to escape from an opening in a vein of a living animal and replacing the lost blood by some innocuous coloring substance; in this way the contractions of the heart fill the vessels with much less injury than in the injection methods.

Dissolve 7.75 grams of carmin in 3.6 c.c. of ammonia and add 30 c.c. of distilled water. Filter. Remove 10 c.c. of blood from the jugular vein of a rabbit and then inject 10 c.c. of the above solution. If the larger vessels are then rapidly ligated, first the vein and then the artery, a physiological injection of the vessels will be obtained. The injection may also be accomplished by placing the above fluid in the stomach, rectum and abdominal cavity. After the injection has been accomplished the organs are placed in acidulated alcohol to cause the fixation of the carmin.

For staining the tubules of the kidney Heidenhain uses a cold saturated solution of either indigo blue sulphate or phenizine sulphate of sodium. Inject 25 to 50 c.c. of this into the vein of a medium sized rabbit or 50 to 75 c.c. into a medium sized dog. After the animal has passed blue urine for some time it is killed by bleeding and the coloring matter is fixed by injecting the kidney, with absolute alcohol, through the renal vessels.

Intravitam Injection.—Heat 1 gram of rectified methylene blue in 100 c.c. of normal salt solution; allow this to cool and then filter. Some of this may be injected into the vena cutanea magna of a living frog and the organs removed in one hour and treated as given below. Twenty c.c. of the solution may be injected, subcutaneously, into a young rabbit and repeated in one hour. At the end of two hours the animal may be killed and the nerve system removed. Organs may be injected with the same solution until they have a bluish color, then they are left undisturbed for one hour.
Place pieces of such tissue, not over 3 mm. in thickness, into a saturated aqueous solution of ammonium picrate for forty-five minutes. Transfer to a solution of ammonium molybdate (1 gram to 100 c.c. of water and 10 c.c. of a 0.5 per cent. solution of osmic acid) for four to twelve hours. Wash thoroughly with water, dehydrate, clear in xylol and imbed in paraffin. Section.

Corrosion.—In order to study the normal cavities, the distribution and arrangement of ducts and blood-vessels in an organ, a special mass is injected and the soft parts removed, thereby leaving a cast of the system injected. The mass should fuse at a low temperature (water bath) and should not soften at the high temperature of the summer months. It should take color readily, should harden rapidly and uniformly without cracking.

One of the best mixtures consists of ozokerite two parts, paraffin (45° to 50°C.) two parts and white wax one part. For coloring it is advisable to use the various oil colors put up in tubes. These are added slowly to the melted mass with constant stirring. The various colors are English vermilion, ultramarine blue, Prussian blue, purple lake, chrome green, chrome yellow, Chemnitz white, etc.

A solid metal syringe of sufficient capacity for each injection should be utilized and the canula should narrow abruptly at the point. The blood is removed from the organ by washing and milking the vessels and if fine injections are desired it is best to float the organ in warm water. As soon as the injection is completed the organs are cooled as rapidly as possible. They are then freed of any water in the vessels and placed in a dish and gradually surrounded with fuming commercial hydrochloric acid. At first a glass plate should cover the dish which should stand in the open air or under a chemical hood. The time required varies from several days to a week and as long as the acid fumes it may be used again. Remnants of the organ may be removed by cautiously washing the cast.

Blood vessels and gland ducts may be injected with colored solutions of celluloid. Ordinary celluloid may be readily dissolved in acetone to form a 10 or 12 per cent. solution. This may then be colored and then injected into the vessels or ducts, after first washing them with normal salt solution and then with strong alcohol. The injected celluloid soon sets and the tissues may later be removed.
by placing the organ in concentrated hydrochloric acid until all of the tissue is dissolved. The cast may then be carefully washed with water and mounted as desired.

**BLOOD TECHNIC**

**Blood** is drawn from the finger tip or lobe of the ear. The part is thoroughly cleansed and finally washed with alcohol. A sterilized needle is then plunged to a depth of about one-eighth of an inch, and the blood allowed to flow. The part *should not be squeezed*, as this dilutes the blood with lymph, and causes errors in accurate work.

**Blood spreads** are obtained by touching a drop of blood with a cover-glass, and immediately placing, this upon a second glass. The two are then *slid* apart, so that a *thin film* of blood is present upon each. If the glasses are *lifted* apart, the cells are greatly distorted and useless for study. A better way is to place a drop of blood upon one slide and then drag this drop across the slide with the short edge of another slide; this gives a more extensive and a more even spread.
The spreads are allowed to dry in the air, and then fixed by (1) heat, (2) the absolute alcohol-formalin solution, or (3) absolute alcohol-ether mixture.

If heat is used, the spreads are placed in an oven, and kept at a temperature of 120°C. for twenty minutes. Ehrlich prefers this method.

The alcohol-ether mixture consists of equal parts of absolute alcohol and ether. This fixes the spreads in twenty minutes. Results with this fixative are very good.

The alcohol-formalin mixture consists of nine parts of absolute alcohol and one part of formalin. Spreads are fixed in twenty minutes.

After fixation, the spreads are allowed to dry, and may then be stained like any other tissue. Hematoxylin and eosin give a good result.

Among special stains is the Ehrlich-Biondi-Heidenhain stain. For its composition, see stains, p. 22.

Wright's blood stain is one of the most satisfactory, and is prepared in the following manner:

Steam 1.5 grams of methylene blue in 150 c.c. of a.1 per cent. aqueous solution of sodium bicarbonate for one hour, in a sterilizer. Add a $\frac{1}{10}$ per cent. aqueous solution of yellowish eosin to 100 c.c. of the methylene blue solution until the mixture turns purple, and a yellowish metallic scum forms upon the surface, and a blackish precipitate appears; about 500 c.c. of eosin solution will be required, and it should be added slowly, while constantly stirring. The solution is then filtered, the precipitate dried and made into a saturated solution with methyl alcohol. This solution is filtered and 80 c.c. of the filtrate are diluted with 20 c.c. of methyl alcohol.
Dried spreads are stained for one minute with this solution, and the stain then diluted upon the glass, with water, until the stain is semi-transparent. After two or three minutes, the spreads are thoroughly washed with distilled water, dried quickly and mounted. The acidophilic granules are reddish-lilac and red, while the basophilic granules are deep blue or even black.

This solution both fixes and stains the cells. **Leischman's stain** is a modification of Wright's. It can be purchased in solid form and is very satisfactory. **Eosin** and **methylene blue** give good results. The spreads are stained in a \( \frac{1}{2} \) per cent. alcoholic solution of eosin for two or three minutes, using gentle heat. Then they are placed in a saturated aqueous solution of methylene blue for two or three minutes. The spreads are then thoroughly washed, dried and mounted in balsam. As a rule, the granules of the leukocytes are well-stained.

In order to obtain the bell-shaped red cells, the finger should be thoroughly cleansed, and the blood drawn as usual. The first drop should be wiped off and a drop of 1 per cent. osmic acid solution placed over the puncture. The blood then flows into the osmic acid, which acts as a fixative, and prevents contact with the air until fixation is complete. If this drop be examined under the microscope, the bell-shaped cells will be seen in great numbers.

**Blood platelets** may also be stained in the above way. **Erythroblasts** of the spleen may be studied in spreads made by drawing thin pieces of the organ over cover-glasses. These are then fixed in the following:
Mercuric chlorid ........................................ 78 grs.
Sodium chlorid ........................................ 28 grs.
Water ..................................................... 30 c.c.

This solution should be filtered, and spreads fixed in it for one minute. They should then be washed and stained one-half hour with aqueous hematoxylin, washed and covered with a 3 per cent. solution of eosin for two to three minutes. They are then washed, dried and mounted.

Spreads may be stained for three minutes with eosin, and one-half minute with 5 per cent. methylene blue, then washed, dried and mounted.

To determine the number of blood-cells the hemocytometer is used. This consists of a heavy glass slide, a heavy cover-glass and two pipets. In the middle of the slide there is a small disc of glass upon which are marked 400 squares each side of which is \( \frac{1}{20} \) mm. in length, making \( \frac{1}{400} \) sq. mm. square surface for each square. Surrounding the disc is a glass ring that is \( \frac{1}{10} \) of a mm. higher than the disc so that when the heavy cover-glass is in place the cubic content over each small square is \( \frac{1}{4000} \) of a cu. mm.

The stem of the pipet for counting the red blood-cells is so graduated that it constitutes \( \frac{1}{100} \) of the cubic contents of the bulb portion; above the bulb is a mark 101. The blood to be examined is drawn to the mark 1 (just below the bulb) and then the diluting and staining fluid is drawn to the mark 101, giving, thus, a dilution of 100. The contents of the bulb are then thoroughly mixed by means of a small glass pearl in the bulb and the diluted blood is then ready to be examined. The pipet used for counting the white cells is constructed for a dilution of only ten times.
For the dilution of the blood the following solutions may be used: **Toison’s Fluid.**

Methyl violet 5 B........................................... 0.025 gm.
Neutral glycerin........................................... 30.0 c.c.
Distilled water........................................... 80.0 c.c.

After mixing the methyl violet and the glycerin add the water and to this mixture add the following:

Sodium chloride.......................................... 1.0 gm.
Sodium sulphate.......................................... 8.0 gms.
Distilled water.......................................... 80.0 c.c.

After filtration the solution is ready for use. As the white cells are stained violet they may be counted at the same time as the red cells.

**Hayem’s Solution.**

Bichlorid of mercury.................................... 0.5 gm.
Sodium chloride.......................................... 1.0 gm.
Sodium sulphate.......................................... 5.0 gms.
Distilled water.......................................... 200.0 c.c.

With this solution only the red cells are counted.

**Sherrington’s solution** consists of the following:

Methylene blue........................................... 0.1
Sodium chloride.......................................... 1.2
Neutral potassium oxalate................................ 1.2
Distilled water.......................................... 300.0

After the blood has been drawn the first drop is wiped away and then from the next the blood is drawn up to the mark 1. The pipet is then put into the diluting fluid and this is drawn up to the mark 101 and the contents of the bulb thoroughly mixed. The contents of the stem of the pipette are then forced out and a small drop of the contents of the bulb is then placed upon the small disc of the glass slide and the cover-glass applied. The slide is then placed upon the stage of a microscope and then examined with a fifth inch (5 mm.), or long working distance one-sixth inch (4 mm.) objective. The red cells in at least 25 squares, but better in 100 squares, are counted and the total number divided by the number of squares.
counted. This gives the average content of one square. This number multiplied by the cubic content of a space (4000) and then by the dilution (100) will give the number of red cells per cubic millimeter.

\[
\frac{4000 \text{ (cubic content of one space)}}{a \text{ (number of squares counted)}} \times 100 \text{ (dilution)} \times \frac{n(\text{number of cells counted})}{100} = \begin{cases} \text{the number of red cells per cu. mm.} \\
\end{cases}
\]

A quicker method is to count the number in 80 squares and add 4 ciphers. This will give the number of red cells in each cubic mm.

![Neubauer Ruling](image)

Fig. 9.—Neubauer Ruling.

If the white cells are counted at the same time their number may be got in the same manner. If the white cells alone are to be examined then the 10 dilution pipet is used and the diluting fluid used is a \(\frac{1}{3}\) per cent. solution of acetic acid. By the use of this the red cells are bleached and the white cells are made more distinct. The same counting method is to be followed but the dilution is only 10, or the average number per square may be multiplied by 40,000 instead of by 400,000 as in the case of red cells.

The leukocytes may be counted at the same time as the red cells remembering that the dilution is 1 to 100.

In the differential counting of leukocytes at least 500 white cells should be counted. As each cell is noted it should be placed under
its proper class and at the termination of the count the percentage of each variety may be readily obtained by dividing its number by 500. The count should be made with a \( \frac{1}{12} \)-inch oil-immersion lens and the slide should be mounted in a mechanical stage and moved from side to side. In this manner the recounting of the cells in a given square is avoided.

**Fig. 10.**—**Plan of Counting the Erythrocytes.** (Da Costa.)
The small squares are examined in the order indicated by the arrow, successive blocks of 25 squares being covered until the required number of cells has been counted.

**Erythroblasts**, if present, may also be counted and their number per cubic millimeter determined. The result is only approximate as it represents the ratio of the nucleated red cells to a definite number of leukocytes. The white cells are first counted, say 1000, and the number per cubic millimeter determined; then the number of nucleated red cells in the same area is estimated. The number of erythroblasts per cubic millimeter is then determined by multiplying the number of erythroblasts counted by the number of leukocytes per cubic millimeter and dividing by the number of leukocytes counted (1000). It is also usual to note whether the red cells are
normoblasts, or megaloblasts and it is necessary to determine the ratio of these to each other.

The blood platelets are also estimated indirectly through their ratio to the erythrocytes. The blood to be examined is drawn directly into the diluting fluid (which is placed over the puncture). This is then thoroughly mixed and some is placed in the counting chamber of the hemocytometer. The number of red cells per cubic millimeter is then determined and a definite number in a certain area is counted. Then the number of thrombocytes in the same area is noted and the ratio or number per cubic millimeter is gotten in the same way as that of the nucleated red cells previously mentioned. The average is usually 1 platelet for each 22 erythrocytes.

Determann prefers the following diluting fluids for estimating the number of thrombocytes:

0.9 per cent. aqueous solution of sodium chlorid, methyl violet sufficient to impart a color; or

<table>
<thead>
<tr>
<th>Sodium chlorid</th>
<th>1 gm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium bichromate</td>
<td>5 gms.</td>
</tr>
<tr>
<td>Distilled water</td>
<td>100 c.c.</td>
</tr>
<tr>
<td>Methyl violet sufficient to impart a color</td>
<td></td>
</tr>
</tbody>
</table>

Toisson's or Sherrington's solutions may also be used.

The estimation of the red and white cells in dried film preparations is said to give more accurate results than the hemocytometer method. The cells are counted separately and tabloid stains are employed; that for the leukocytes consists of 0.25 gram of sodium chlorid and 0.004 gram of methyl violet; that for the erythrocytes consists of 0.25 gram of sodium chlorid and 0.0025 gram of eosin. One of each of these tablets is dissolved in 30 c.c. of distilled water and 0.5 c.c. of formalin is added to each and the mixtures are then filtered.

For counting the white cells 5 cu. mm. of blood are drawn into a graduated pipet and then mixed with 495 cu. mm. of the methyl violet diluting fluid (giving a dilution of 1 to 100) and thoroughly stirred. Then 5 cu. mm. of this mixture are drawn into a pipet and then placed upon a slide so as to cover an area about 10 to 12 mm. in diameter. This is allowed to dry and then balsam and a cover-glass are applied. The preparation is then examined under a 1.9
mm. lens (using a mechanical stage) and all of the leukocytes in the film are counted. The number of leukocytes counted multiplied by 20 will give the number of leukocytes per cubic millimeter.

Fig. 11.—Hemoglobinometer of Dare.

R, milled wheel; S, case inclosing the color disc; T, movable wing, which is swung outward; U, telescoping camera; V, aperture admitting light; W, capillary blood pipet; Y, detachable candle holder; Z, slot through which the percentage of hemoglobin is read.

Fig. 12.—Horizontal Section of Dare's Hemoglobinometer. (Da Costa.)

Fig. 13.—Method of Filling the Dare Blood Pipet. (Da Costa.)

In estimating the erythrocytes 5 cu. mm. of the above mixture for examining the leukocytes are added to 995 cu. mm. of the eosin mixture; this gives a dilution of 1 to 20,000. After mixing and allowing the red cells to stain for a few minutes 5 cu. mm. of this mixture
are then placed upon a slide and allowed to dry as previously. The preparation is then covered with balsam and a cover-glass is applied. All of the erythrocytes in the film are counted and this number multiplied by 4000, the result is the number of red cells per cubic millimeter.

The percentage of hemoglobin in the blood is determined by means of an hemoglobinometer, or hemometer. There are quite a few of these instruments but only Dare's and von Fleischl's will be described here.

The **Dare hemometer** consists of a hard rubber case containing a tapering graduated semicircle of glass tinted with golden purple of Cassius. This is attached to a disc and scale so that the glass can be revolved and the scale read (from the outside). The scale gives percentages from 10 to 120. A capillary blood chamber belonging to the apparatus consists of two plates of polished glass; of these the one toward the light consists of opaque glass while the other is transparent. When these two are mounted a shallow space for the blood exists between them. The eye-piece and tube cover two openings, one back of the capillary chamber and the other back of the tinted graduated color standard. The section view gives the principle of the instrument. $J$ represents the candle; $O$ and $P$ represent the two plates of the capillary chamber; $L$ and $K$ represent the color standard and glass disc; $M$ and $M'$ are the openings communicating with the capillary chamber and the disc chamber $N$ is the tube containing the eye-piece.

In using the apparatus the capillary chamber is filled by touching its edge to the drop of drawn blood and then wiping the excess off.
It is then placed in position in the apparatus and the candle is lighted. The instrument is then held to the eye toward a dark wall and the disc revolved until the colors coincide, making sharp quick turns of the milled wheel. The capillary chamber should be taken apart and the plates thoroughly cleaned with water and acid alcohol after each use. J. C. Da Costa considers this instrument the most accurate, simple and convenient for clinical purposes. It has the especial advantages of not requiring a dark room and of using undiluted blood.

The Von Fleischl hemometer consists of a stand upon which is mounted a movable wedge-shaped piece of tinted glass (golden purple of Cassius). Upon the upright of the stand there is mounted a disc of plaster of Paris that is used to reflect the light through the diluted blood and color scale. In the center of the stage of the stand there is an opening to accommodate the mixing chamber. The
mixing chamber is a short cylinder (with a glass bottom) that is divided into two compartments by a metal partition. When properly mounted one compartment overlies the wedge of tinted glass and the other contains the diluted blood and receives the light directly from the reflecting disc. The capillary pipet is of such a capacity that one pipetful of normal blood diluted with one compartment full of water will give a color that will correspond with that of the tinted scale opposite the mark 100.

In making the test fill each compartment about one-quarter with distilled water. Then draw a fine needle and thread through the capillary pipet to clean it and then apply the pipet horizontally to the drop of blood drawn from the puncture. Wipe the outside of the pipet clean being careful that the pipet is exactly full. Then wash the blood into the compartment that is not over the colored scale; this is done by the use of a fine-pointed pipet and the capillary pipet is repeatedly rinsed. Stir the diluted blood with the handle of the capillary pipet until evenly mixed, rinse the handle into the compartment and add water cautiously until the compartment is level full. Then fill the compartment over the colored scale with distilled water until exactly full taking care that no water falls upon the thin partition as this will cause a diffusion between the two compartments and change the result. If the blood solution is turbid, due to the presence of fat, a little ether will clear it. The instrument is then placed in the lightproof box, containing a lighted candle; the lid is closed and the operator then stands at one end of the glass scale and rotates the milled wheel with short and rapid turns. The start should be made at the dark end of the scale and this should be rapidly moved until the colors nearly coincide. After a short rest the colors are made to coincide. If the hemoglobin is 30 per cent. or under it is best to use two or three pipets of blood and then divide the result by two or three as the case may be. It is said that with the best of care an error of 5° may occur on account of the large field of the mixing chamber. To obviate this a metal diaphragm with a slit about one-eighth of an inch in width is placed under the glass bottom of the mixing chamber so that the slit is at a right angle to the partition. This cuts down the field to about 2.5° of the glass scale and thus greatly reduces the error.
Slide Technic.—The preparation of sections for microscopic study requires skill and care.

Paraffin sections are made to adhere to the slide by means of Mayer's albumen. This is prepared by mixing thoroughly white of egg and glycerin in equal parts and filtering. To the filtrate add 1 gram of sodium salicylate. A very thin film is all that is necessary.

The following desk reagents are sufficient for all ordinary work:

Coplin staining jar, containing Iodin.
Coplin staining jar, containing Kerosene, or Xylol.
Coplin staining jars, containing Alcohol. Nos. 1 and 2.
One Barnes bottle, containing Hematoxylin.
One Barnes bottle, containing van Gieson's stain.
One Barnes bottle, containing Eosin.
One Barnes bottle, containing Alcohol.
One Barnes bottle, containing Water.
One Barnes bottle, containing Acid Alcohol.
One Barnes bottle, containing Creosote.
One Barnes bottle, containing Albumen.
One Barnes bottle, containing Picric Acid.

The method of procedure for staining is given in detail below:

1. Cover a clean slide with a thin film of albumen.
2. Add a few drops of water, and upon this float the cut paraffin section.
3. Warm gently over a flame, so as to spread the section, but be careful not to melt the paraffin.
4. Drain and set aside, or in an oven, for six to twenty-four hours. The slide must be perfectly dry before the other steps can be carried out. Put an identification label on the slide.
5. Place in the kerosene for five to fifteen minutes, to remove the paraffin. Xylol is better but is more expensive.
6. Wash with alcohol, to remove the kerosene, and place in the jar of iodin, five to ten minutes, to remove the crystals of bichlorid of the fixing agent.
7. Remove the excess iodin from the slide with tissue paper, wash with alcohol and place in the first alcohol jar for fifteen minutes,
to remove the remainder of the iodin. This may be hastened by the addition of a little potassium iodid to the alcohol.

If a bichlorid fixative has not been used steps 6 and 7 may be omitted.

8. Drain the section, wash with water, cover with hematoxylin for three to five minutes, and wash with water to deepen the color.

9. Counter-stain.—*Eosin* one to two minutes, wash with water to remove excess stain and then alcohol; or,

*Van Gieson* one to one and one-half minutes, wash with water and then alcohol, as above; or,

*Picric acid* fifteen seconds and wash with alcohol.

*Carmin* may be used alone for fifteen minutes, or followed by picric acid, as in the preceding. If carmin is used alone wash the excess off with water and then cover with acid alcohol to differentiate. When the color becomes a brick-red, wash the acid alcohol off quickly with ordinary 95 per cent. alcohol and dehydrate in the usual way. Hold the slide in the hand while differentiating.

10. After washing with alcohol, *dehydrate* in the second jar of alcohol. Allow sections to remain about five minutes.

11. Clean the slide carefully *without allowing the section to dry*. Blot with tissue-paper.

12. Cover with a drop or two of *creosote for five minutes*. This removes the alcohol, renders the specimen transparent, and allows the use of balsam. This is *section clearing*.

13. Drain off the creosote, *blot*, add a drop of *balsam* and cover with a clean cover-glass.

14. Remove the identification label, apply a clean one, and write the name of the section thereon.

After the paraffin has been removed, the specimen should *never be allowed to dry*.

The above technic will answer for all ordinary histologic and pathologic work, and, if strictly adhered to, there will not be the slightest trouble in making excellent preparations.
CHAPTER II

THE CELL AND ITS PROPERTIES

Histology is the science that treats of the minute structure of normal tissues and organs. Although to the unaided eye tissues may have an apparent structure that seems ultimate, when examined under the microscope this structure is seen to be but gross. Each section studied will be found to be composed of minute elements, more or less regular, and definitely grouped and arranged. These elements are cells.

Protoplasm is a viscid substance of neutral reaction and is essentially a colloidal substance. It consists, chemically, of (a) water that constitutes two-thirds of its weight; (b) inorganic substances as salts of calcium, potassium, sodium, chlorin, phosphorus and oxygen (free or in combination); (c) organic salts of usually phosphorus and iron, in the form of proteins and nucleoproteins. In addition certain nonprotein substances as lecithin and cholesterin are essential components of protoplasm.

Physically the cytoplasm consists of colloids and crystalloids held in suspension by the water. The colloids are present in two conditions (1) liquid or sol and (2) semi-solid or gel. The crystalloids are (1) electrolytes (bases, acids and salts) and, (2) nonelectrolytes (urea, sugar). There is no sharp line between colloids and crystalloids. As the fluidity of protoplasm is due to water and as protoplasm is sol it is usually called hydrosol. When, however, it is converted into the semi-solid or gel state it is referred to as hydrogel. This changing from the one to the other is constantly going on in the living cells and should an irreversible hydrogel be formed then life tends to cease.

Living protoplasm in structure is a granular gel. Kite considers it an emuloid of which the colloidal particles are the structural units. It is a viscous hydrogel, apparently homogeneous, in
which are granules of denser gels and liquid globules. Spindle fibers seem to be definite and distinct comparatively rigid threads. The nuclear granules and network he regards as denser masses of nuclear gel that gradually grade into the diluter gel of the achromatin.

**FIG. 18.—MICROSCOPE SUITABLE FOR GENERAL WORK.**

a Ocular or eye-piece; b, draw-tube; c, rack; d, milled head of pinion moving the rack; the rack and pinion (c and d) together are called the coarse adjustment; e, microscopic tube; f, micrometer screw by which the fine adjustment is operated; g, triple nose-piece or revolver which receives the objectives, h; in the above instrument there are three objectives which in turn may be rotated into the optical axis; i, stage on the upper surface of which are clips for holding the slide during examination; j, iris diaphragm in substage condenser; the diaphragm permits variation in the quantity of light admitted, and the condenser properly focuses the rays on the object examined; k, screw for raising and lowering the condenser by which the latter, when not in use, may be thrown to the side; l, mirror for reflecting light into the optical axis of the instrument; m, inclination joint permitting inclination of the instrument. The vertical column below the inclination joint is called the pillar and is solidly joined to the large, heavy, horseshoe base supporting the instrument.
A cell is a small mass of protoplasm containing a nucleus. It is the histologic basis of the body, and has a complex structure. Certain parts are absolutely essential for the proper performance of its various functions, while others are accessories, which most cells possess. The parts of a typic cell are:

2. Nucleus.
3. Centrosome.
5. Cell-wall.

![Scheme of a Cell](image)

Fig. 19.—Scheme of a Cell.—Microsomes and spongioplasm only partly sketched. (Stöhr's Histology.)

1. Spongioplasm; 2, hyaloplasm; 3, microsomes; 4, exoplasm; 5, chromatin; 6, achromatin; 7, linin; 8, chromatic knots; 9, nuclear membrane; 10, centrosome; 11, nucleolus; 12, cell-membrane; 13, inclusions.

1. The cytoplasm or cell-body, may or may not be limited by a cell-wall and, in fixed cells, it consists of two main parts, the spongioplasm, or filar mass and the hyaloplasm, or interfilar mass.

The spongioplasm, as its name indicates, is a framework of comparatively solid structure, in the meshes of which is found the semi-
fluid **hyaloplasm** or **paraplasm**. The elasticity of the spongioplasm is said to give rise to ameboid movements.

In the cytoplasm are to be seen small darkly staining bodies, the **microsomes** and paler masses, the **plastids**. At the outer margin of the cell-body is a narrow, peripheral zone, containing no microsomes, known as **exoplasm**. At times there are other structures present, as **fat globules**, **glycogen**, **secretion granules**, **vacuoles**, **pigment**.

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**Fig. 20.**—**Fat Globules in the Cells of the Zona Glomerulosa of the Adrenal Gland Fixed in Osmic Acid.** (Photograph. Obj. 16 mm., oc. 10 X.)

**Fig. 21.**—**A Section of an Acinus of the Pancreas of a Guinea-pig.** The zymogen granules are in the lumen end of the cell while the mitochondria are basally disposed. (After Bensley.)
crystals, waste products, as creatin, creatinin, urea, urates, etc. These nonprotein substances constitute paraplasm.

The granules may be diffusely scattered or collected into groups and are probably formed under the influence of the nucleus. These vary in size and number in the same cell and different cells. They may be almost ultramicroscopic or large as seen in nerve cells (tigroid bodies). In glandular cells they can be seen gradually increasing in size as the elaboration of the secretion, with which they are connected, is progressing. They respond to different stains in the different cells; some granules are eosinophilic, others basophilic and still others neutrophilic. This is especially distinct in the different types of leukocytes. As regards the functions of granules some are secretory, as in glandular cells, and others are nutritive, as in nerve cells. These granules seem to be formed under the influence of the nucleus.

Some granules seem to form contractile fibrils, which stain distinctly and are called mitochondria; these fibrils sometimes form spherical masses called chondromitomes. Mitochondria seem to be related to the metabolic activities of the cell, the formation of presecretion and excretion granules and the formation of fibrillae in muscle fibers. Meves believes that the mitochondria share with the chromosomes the transmission of hereditary characters and others that they represent the region of and assist in oxidation processes. In the germ cells the mitochondria are of a granular form while in the somatic cells they are filaments or rods. They are found in all types of cells, in living plant cells and in animal cells grown in artificial media. In the latter instance they were studied by W. H. and M. R. Lewis who found that they changed shape, divided into granules and reunited into filaments. In fixed material they seem to be lipid precipitation products having a chemical composition of lipid (phosphatid). Wallin believes that the mitochondria are symbiotic bacteria in the cytoplasm of the cells of all higher organisms.

In many nerve and glandular cells (stomach, liver) is seen a fine network of anastomosing channels, or secretory capillaries, called
trophospongium. These are supposed to be connected with the circulation of nutritive material or secretion products. These may conduct the secretion to the ducts, or to the lymph or blood-vessels. In the two latter instances the secretion would be called internal. Holmgren believes that these channels have definite openings upon the surface of the cell while v. Bergen states that these canaliculi are not permanent but come and go.

Fibrils are noted in various cells. In nerve cells they form a network and are called neurofibrils; in muscle cells they are parallel to one another and are the muscle fibrillae.

Fig. 23.—Intestinal Cells of the Rainbow Trout Showing Mitochondria. (After Jordan and Ferguson.)

Fig. 24.—Intracellular Canaliculi. (After Holmgren.)

The cell-body has affinity for acid, or protoplasmic, stains, such as eosin, picric acid, carmin, orange, etc.

2. The nucleus is usually a darkly staining, refractile body having a sharp outline, and occupying, as a rule, a central position. It is trophic in function, controls metabolic activities and in cell division transmits characteristic features (heredity). It is also the center of oxidation processes. In glandular cells, its location varies with the stage of secretory activity. Its structure resembles that of the cytoplasm, to a certain extent. The nucleus consists of a network and semi-fluid substance, surrounded by a distinct membrane or wall. The network is called the chromatin, or nuclear fibrils, and the semi-solid substance, the nuclear matrix, sap or achromatin.

Chromatin or karyotome is the part of the nucleus that responds to the stains. It is arranged as an irregular network of anastomosing fibrils, each consisting of a delicate central thread, the linin, upon which the real chromatin substance is arranged, in the form
of granules (chromioles). Where the chromatin threads cross each other large masses of chromatin at times are seen; these are called karyosomes. It is the most important portion of the nucleus during the process of cell-division. In glandular cells the chromatin increases during the earlier stages of secretory activity and decreases during the later stages. The diminution probably represents the formation of special secretion products. During cell division the chromatin separates into a number of rod-like structures (chromosomes) that are of the same size and constant in number for the same species of animal, in each nucleus. Each chromosome consists of chromioles and both are capable of growth and of multiplication by division.

Chromatin consists of nucleic acid combined with protein and has an affinity for basichromatic stains. The linin is mucoid in nature, contractile and oxyphilic in reaction.

The achromatin or karyoplasm is a semi-fluid substance that fills in the meshes of the chromatin. In the living condition it is apparently structureless but when fixed and stained it exhibits little granules that respond to the plasmatic dyes, called oxychromioles.

The nuclear membrane is that wall that sharply outlines the nucleus. It is present in all nuclei and is solid. Upon its inner surface it is connected with the chromatin network. It consists of amphipyrenin (basichromatin and linin) and responds to basichromatic dyes.

Of the above structures, the chromatin persists throughout all the stages of reproduction, while the remainder of the nuclear constituents disappear.

The nucleus responds to nuclear stains as hematoxylin and basic anilin dyes.

3. The centrosome is a small darkly staining structure, which, owing to its small size, has been found in but few of the cells of the human body. It is readily seen and studied in the ova of some of the lower animals, especially those of ascaris megalcephala. It
lies, usually, just outside of the nucleus, in a small clear field called the attraction sphere, within which are seen delicate lines that radiate from the centrosome. The attraction sphere and the centrosome constitute the astrosphere, usually less than 1μ in diameter. In many gland cells the centrosome lies where the secretion accumulates. In intestinal epithelium that sends out pseudopodia it lies at the point of origin of these processes. It is occasionally divided constituting then a diplosome. In cells possessing multiple or lobulated nuclei the centriole usually consists of a group of particles (giant-cells of bone-marrow).

Besides starting cell-division, the centrosome seems to play an important part during the resting stage. In pigment cells and white blood-corpuscles, it seems to preside over the movements of the whole cell, and in ciliated and flagellated cells over the action of these processes. It responds to the iron-hematoxylin stain.

4. The nucleolus or plasmosome is a small, oxyphilic body found within the nucleus. It is not always present, and more than one may be found. In nerve cells and ova it is unusually large and readily stained, while in others it is scarcely noticeable. It is probably the result of nuclear activity and at times parts of the nucleoli are passed into the cytoplasm. Some say that these particles are formed into secretion granules and others claim that they represent effete material. Its importance is doubtful, although it is now believed to be concerned in the formation of the central spindle during cell-division. It consists of pyrenin, disappears during cell-division and is considered by some the seat of basichromatin formation. This is utilized by the chromosomes.

5. The cell-wall is a more or less prominent membrane that limits cells. It is not present in all animal cells, though all cells possess a delicate membrane that is solid and of a lipoid nature. In some instances, it consists of the differentiated, peripheral cytoplasm, and in others, is a secretory product of the cytoplasm. When a
well-defined wall surrounds the entire cell it is called a pellicula (seldom used); if it is found upon the exposed surface, as in the intestinal cells, it is termed a cuticular border.

Of the above structures, the cytoplasm, nucleus and centrosome are the essential parts, when the important functions of the cell are considered. In red blood-cells the nucleus is absent, and, as a consequence, these cells cannot reproduce themselves.

Cells differ greatly in form and size from 4μ to 80μ; the nucleus conforms somewhat to the shape of the cell. The lobulated nucleus of the leukocyte is a peculiar modification of this general rule. Usually but one nucleus is present, but in giant cells and voluntary striated muscle, many are to be found.

Cells may fuse so as to form a single mass of protoplasm with nuclei at fairly regular intervals. This is called a syncytium. This term has also been applied to striated muscle tissue on account of the large number of nuclei present.

The cell, like the organism, exhibits a number of properties, such as metabolism, growth, motion, irritability and reproduction.

Metabolism is the sum of all of the changes that take place in a cell during the performance of its functions. The metabolic processes are controlled by the nucleus. The changes are chemical in nature and are increased by warmth and electrical stimuli. When the result is the formation of complex structures, the process is called anabolism; if destructive, the conversion of complex to simple compounds, the phenomenon is termed katabolism. Secretion and excretion are katabolic changes. Secretion may be glandular secretion, or simply an intercellular substance may be formed.

Growth is the result of an anabolic process. The cells increase in size, equally or more often unequally, depending upon the organ. When the latter occurs, the cell-form is changed. By such a change in all cells, the organism increases in size, though the amount contributed by each cell may be microscopic.

Motion.—Cells exhibit the phenomenon of movement under three forms: protoplasmic, ameboid and ciliary.

Protoplasmic movement is difficult of observation on account of the slowness of the process. It has been demonstrated in a few animal cells but in plant cells it is easily observed, the streaming
of the cytoplasm being an example (cyclosis). All animal cells are believed to possess it to a greater or lesser degree. It is made manifest by the changes in the form of the cytoplasm, by movements of the microsomes and by the changes in the position of the nucleus.

**Ameboid movement** is similar to that exhibited by the unicellular animal, the ameba. Nearly all animal cells possess it to some extent, it being well marked in especially a few cells, viz., the leukocytes, lymph cells and wandering connective-tissue cells. If a living leukocyte be studied under the microscope it will be seen to change continually in form. Gradually a bud-like process of the protoplasm will push out from one point or several may start from different points. These *pseudopodia* may retract or be extended for a considerable distance, the remainder of the cytoplasm flowing into one. Other pseudopodia are given off and the process is repeated. These processes may be either massive or *lobed*, or fine and *spine-like*. By this means the cell will gradually crawl across the field of the microscope. It is by means of this ameboid movement that leukocytes pass through the walls of the capillaries (*diapedesis*) and wander through the spaces of the tissues and organs or between other cells. This phenomenon is also exhibited when an ameboid cell takes in foreign particles, *i.e.*, ingestion of food, or when phagocytes attack bacteria or tissues.

**Ciliary motion** is limited to only a portion of the cell, that is, to delicate hair-like processes called *cilia*. In true ciliated cells it is said that a darkly staining body (presumably centrosomic in origin) is to be found at the central end of each cilium. The spermium moves by the action of its tail, a flagelloid structure.

One of the most characteristic examples of motion is exhibited by the muscles, especially the voluntary striated variety; here although the whole cell moves, the motion is limited to one direction. This is parallel to the long axis of the fibers and constitutes *contraction*.

**Irritability** is the property that cells have of responding to external stimuli. This property is exhibited best in the unicellular animals and others that possess no nerve system. In these forms it is a primary change in the cell. These stimuli, although almost innum-
erable, may, in a general manner, be grouped as mechanical, electrical and chemical in their nature, or due to heat or light.

All cells do not respond in the same manner to the same stimulus, nor do all stimuli cause the same reaction in an individual cell. The response of a cell to a specific stimulus depends upon its structure. Some, those of the organ of vision for example, respond to light only, while others may respond to one or more stimuli.

Under mechanical stimuli are pressure, violent shaking and crushing, any one of which will cause cells to respond in some manner.

While heat is a necessary condition for the activities of a cell it must be confined within rather fixed limits, these varying considerably, however, for different cells. If the temperature be raised to $40^\circ$C. ($104^\circ$F.) the vitality of the cell is destroyed; upon the other hand the temperature may be lowered to a considerable extent without the cell being killed. An increase of heat above that at which the cell normally exists causes a marked increase in its vital processes until the heat rigor point ($40^\circ$C.) is reached when a coagulation takes place and the cell is killed. Lowering of the temperature below the normal produces a gradual lessening of activity until cold rigor ($0^\circ$C.) point is reached when the cell passes into a narcotic state. Apparently cells may remain in this state for a considerable length of time without their vitality being destroyed, for if they be gradually warmed up to their normal temperature their vital functions are resumed.

Light, in the higher order of animals, is supposed to be a stimulus to the organs of vision only. In some of the lower animals other tissue cells, especially those of the skin, respond to its stimulation.

Electrical stimuli, when applied in the form of weak currents, cause an increase, strong currents a decrease, in cell activity. If the latter are continued for a considerable time they will cause the death of the cell.

Chemical stimuli are almost numberless and at present their action is not thoroughly understood. Some cause contraction, some increased movements and others increased secretory activity, etc. A striking feature of the unilateral action of chemical stimuli is that known as chemotaxis. This is the property possessed by certain cells of responding to the stimulation of chemical substances intro-
duced into, or formed in the body. Some substances cause cells to approach them (positive chemotaxis); others repel them (negative chemotaxis). The leukocytes respond quickly to this form of stimulation. Such movements may be produced by the addition or subtraction of water, producing relaxation and contraction, respectively. Chemical action is also dependent upon the concentration of the salts and upon the contained electrolytes. Chemotaxis plays a very important part in many physiological phenomena, as for example, the tendency of the red blood cell to seek oxygen, the attraction of leukocytes toward bacterial activity and the attraction exerted by the ovum upon the spermium.

**Reproduction** is the process by means of which a cell or an organism propagates itself and continues its life history. Without this or an analogous process, life would soon cease to exist. The nucleus is the trophic center of the cell and while the cell is small or medium in size the nucleus can control conditions without suffering any want in nutrition. As the cell grows, however, this state becomes unbalanced and the nucleus suffers, hence division and reestablishment of the earlier condition.

Reproduction is of two varieties, direct, amitosis or budding and indirect, mitosis or karyokinesis. Of these, the latter is the more common.

**Amitosis.**—This form of cell division was formerly thought to be the usual method, but it is now known to be restricted to some cells of the bladder, epididymis, cells of Sertoli of the testis, decidual cells, giant cells of the bone-marrow and occasionally to leukocytes and gland cells (medulla of the adrenal). By some it is considered a sign of degeneration. Wieman believes that is a result of the scarcity of oxygen. Experimentally it may be made to occur in some cells that normally reproduce mitotically. Ciliated cells divide amitotically and the cilia are the products of centrosomic division. The centrosomes of mitotic spindles may develop cilia (Meves).
The nucleus in this form of cell division divides without the intranuclear network undergoing the same complicated changes as in the indirect method.

The nucleus first becomes constricted; this constriction gradually increases and finally divides the nucleus into two more or less equal parts forming daughter nuclei; these daughter nuclei draw away from each other by ameboid movement. At times the complete division is delayed and the two nuclei are connected, for some time, by a narrow thread of nuclear material. Division of the cytoplasm takes place by the development, at first, of a constriction in that por-

![Diagram of cell division](image)

**Fig. 28.**—Scheme of the Close Skein and the Division of the Centrosomes. (Stöhr's Histology.)

**Fig. 29.**—Scheme of the Loose Skein and Separation of the Centrosomes. (Stöhr's Histology.)

...tion of the cell body between the nuclei and then finally by the entire separation of the daughter cells thus formed. Like the nucleus the cytoplasm may, in some instances, remain connected, or its division may be delayed while the nuclei go on dividing, the result being an accumulation of nuclei and the formation of a multinucleated cell. Sometimes the nuclear division may take place inside of the original nuclear membrane and again the resulting nuclei may be markedly unequal in size.

**Mitosis** is a very complex process, in which the nucleus plays a very important part. The cytoplasm is almost passive until the late stages of the process. The various stages are the prophase, metaphase, anaphase, and telophase. These are not absolutely separable from one another. The changes that occur may be grouped under three heads—nuclear, centrosomic and cytoplasmic.
Prophase.—The nuclear changes are quite complex. Whereas the chromatin is ordinarily arranged as an irregular network, when division begins the irregular twigs of the network gradually become smooth, and form, usually, a single thin closely convoluted thread, called the spirem, or skein. This thread consists of a double row of chromatin granules (chromioles). The thread becomes thicker and shorter, and soon separates into a number of segments called chromosomes. This sometimes occurs before the spirem is formed. The chromosomes become U- or V-shaped, and arrange themselves

![Fig. 30.—Early Stages of Mitotic Division in Ova of Ascaris Megalocephala.](image)

1. Resting stage showing male and female pronuclei; 2, close spirem; 3, loose spirem; 4, chromosomes. (Photograph, Obj, 4 mm., oc. 10 X.)

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![Fig. 31.—Scheme of the Mother Star, or Equatorial Plate. (Stöhr's Histology.)](image)

![Fig. 32.—Scheme of Metakinesis, Showing the Nuclear Spindle. (Stöhr's Histology.)](image)
along the equator of the cell with the closed ends directed toward a common center, called the polar field. This arrangement is termed the equatorial plate, or monaster, and practically ends the chromatin changes during the prophase. The chromosomes vary from two to sixty-four in different species.

The chromosomes are usually even in number, and the same number is always formed in each cell of the same species. In man, the number is said to be twenty-four.

The nuclear membrane, during these changes, has gradually become more and more hazy, and finally disappears. The achromatin is released, and mixes with the cytolymph.

The nucleolus likewise gradually fades and disappears to assist in the formation of the central spindle (Ferguson).

The centrosome is the dynamic center of the cell. It divides into two portions (if within the nucleus, it passes first into the cytoplasm), each of which becomes surrounded by its own attraction sphere. These centrosomes gradually move apart, through an arc of 90°, to opposite poles of the cell. During this change, some of the intervening rays remain in contact, forming a spindle of delicate threads, which is complete when the centrosomes reach their polar position.

This is the central, or achromatic spindle, and the threads are of the utmost importance, and become attached to the chromosomes of the equatorial plate.

With the formation of the equatorial plate and central spindle, the prophase ends. Variations, too numerous to describe, occur, but the above is the usual course in this stage of mitosis.

Metaphase.—This is the stage during which the chromosomes divide and separate. It concerns the chromatin chiefly and is of short duration.

The chromosomes divide longitudinally into two equal portions. This cleavage occurs at the closed end first, and as it proceeds, the daughter chromosomes become separated, one-half being drawn
toward the one centrosome, and the other toward the second. This gives rise to a second spindle, the **nuclear**, or **chromatic spindle**. The separation is affected by the traction exerted upon the daughter chromosomes by the threads of the central spindle.

**Anaphase.**—This is the stage of complete separation of the chromosomes. The latter collect around their respective centrosomes, and remain connected to the opposite set, for some time, by the central spindle threads. The figures thus formed are the **diasters**, or **daughter stars**.

**Telophase.**—This stage is concerned with the cytoplasmic changes and the formation of a resting nucleus. Up to this time, the cytoplasm has been practically quiescent.

The chromosomes collect around the centrosomes, and unite to form a **close skein**. Lateral twigs are developed that anastomose to form the **nuclear network**, a **nuclear membrane** is formed and a **nucleolus** appears.

The hitherto inert cytoplasm shows changes. A plate of granules (**cell-plate**) appears at the equator of the cell, and separation occurs in the intervening space until two separate masses are formed; these are the **daughter cells**. Frequently the centrosome divides at this stage forming a **diplosome**.

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**Fig. 35.—Later Stages of Fig. 30.**

5. Equatorial plate, surface view; 6, equatorial plate, side view showing the central spindle and the centrosomes; 7, nuclear spindle; 8, separation of the daughter chromosomes. (Figures 7 and 8 represent ova of Ascaris megaloecephala univalens.)
The above changes are usually succeeded by a period of rest.

Although apparently a long process, only about one-half hour is consumed in the division of human cells, but the cells of lower animals require a longer period (three hours).

In the case of giant cells, the nucleus divides and redivides, while the cytoplasm remains unchanged. They may also be formed by the fusion of the cytoplasm of a number of cells with the retention of the individuality of the nuclei.

As all cells are developed from pre-existing elements, it is but natural that the original cell of the body, the ovum, should be of greatest interest. It is the most characteristic cell of the body, and is secreted by the ovary. It is the largest cell, and illustrates the individual parts well.

The ovum consists of a limiting wall, the vitelline membrane, that may be well developed. Within this is the cytoplasm, vitellus, which consists of two parts—the deuto-plasm, or nutritive yolk, and the animal protoplasm, or formative yolk. This is of importance, embryologically. Within the vitellus is found the nucleus, or germinal vesicle, which contains a deeply stained nucleolus, or germinal spot. The centrosome is to be seen in unripened ova. After maturation this body disappears. In what might be termed an embryologic ovum, there are two layers external to the vitelline membrane, the zona pellucida and the corona radiata. Of these, the former is the more important, because of the part which it plays in the early stages of development.

There are a number of processes that occur in the ovum before it can develop into an offspring. Of these, the most important are MATURATION and FERTILIZATION. The former occurs, usually, in the ovary, or shortly after ovulation, and the latter, as a rule, in the oviduct.

Maturation is the process by which part of the chromatin and a small portion of the cytoplasm are extruded in the form of two minute structures called polar bodies. It is a modified karyokinesis,
and its object is unknown. All ova must pass through this process before they can be fertilized.

**Fertilization** is the process in which the male and female elements unite to form a complete and perfect cell, which, by division, gives rise to the cells that ultimately form the whole body.

![Fig. 37.—Unripened Ovum from a Young Guinea-pig.](image)

A, Nucleus; B, nucleolus; C, centrosomes in the attraction sphere.

The **male element**, or **spermatozoön**, or **spermium**, consists of head, middle-piece and tail. Of these the head and middle-piece representing the **nucleus** and **centrosome**, respectively, of a cell of the testicle, enter the ovum and form **eleven** or **twelve chromosomes**. The chromatin of the germinal vesicle of the ovum also forms **twelve**. By longitudinal cleavage **forty-six** or **forty-eight** are formed of which **twenty-three** or **twenty-four** enter into each diaster and, consequently, each daughter cell. By this process the descendants of the fertilized ovum contain double the number of chromosomes that existed in either of the original cells before fertilization. Through the male and female chromatin the offspring receives the characteristics of its parents.

One-half of the spermia contain **eleven** chromosomes and the other half contain **twelve**. The ovum always contains **twelve**. If the ovum is fertilized by a spermium containing **twelve** chromosomes the offspring will be a **female**. If the fertilizing spermium contains only eleven chromosomes the offspring will be a **male**. The male
somatic cells are said to contain but twenty-three chromosomes while the somatic cells of the female contain twenty-four chromosomes.

After fertilization the ovum divides and redivides, forming an irregular mass of cells called the morula, or mulberry mass. Certain of these cells form a complete layer that surrounds the remainder, which constitutes an irregular mass. The layer is the outer cell-mass and the latter the inner cell-mass. This structure constitutes the blastula, or one-layered vesicle. Of these two structures the inner is the more important as it persists and forms the whole body while the outer assists in the imbedding of the ovum and the formation of the placenta.

The inner cell-mass forms two layers, an outer, several cells in thickness, the ectoderm, or epiblast, and an inner, composed of but a single layer, the entoderm, or hypoblast. This is the gastrula, or diploblast. The ectoderm and entoderm each set aside a number of cells which by multiplication form a third layer, the mesoderm, or mesoblast, that lies between the two. This structure receives the name of blastodermic vesicle, or triploblast.

From these three primitive layers all the organs and tissues of the body are formed as follows:

Ectoderm.
The nerve system (cerebrospinal and sympathetic) the retina, the bulk of the crystalline lens, the muscle of the iris and part of the vitreous humor of the eyeball, the epithelium of the cornea and conjunctiva, the epithelium of the internal ear and of the olfactory organ, the medulla of the adrenal.
The epithelial lining of the fossa navicularis of the male urethra, the labia of the female and the glands leading thereto.
The epithelial lining of the mouth and salivary glands, epithelial lobe of the pituitary body, the enamel of the teeth, the cells of the nasal tract, to the pharynx, and glands leading thereto and the lining of the anus.
The epidermis and appendages of the skin, muscles of the sweat glands.
The syncytium of the placenta.
The notochord (primarily).
Entoderm.
The epithelial lining of the bladder, the prostate and glands of Cowper, of the prostatic membranous and penile portions of the male and entire female urethra, vestibule and glands of Bartholin.
The epithelium of the tongue, thymus and thyroid bodies of the parathyroids, middle ear and Eustachian (auditory) tube.
The epithelium of the alimentary and respiratory tracts from the mouth and posterior nares down and the epithelium of all glands opening into these structures.
The notochord (secondarily).

Mesoderm.
The vascular system.
The lymphatic system including the large serous cavities, spleen and thymus body (except the corpuscles of Hassal).
The muscle tissues (except the muscles of the sweat glands and iris).
The connective tissues.
Testicles, vas, seminal vesicles, ejaculatory ducts, ovaries, oviducts, uterus and vagina.
Kidneys, ureters and cortex of adrenals.
CHAPTER III

THE TISSUES

From the preceding table it will be seen that all tissues are developed from the three layers of the triploblast. These tissues are grouped, histologically, under four classes, epithelial, connective, muscle and nerve.

A tissue consists of similarly differentiated cells held together by intercellular substance and performing a definite function. The intercellular substance varies with the different tissues. The cells of a tissue may be so arranged as to form an organ or merely a supporting structure.

A syncytium is a tissue in which the cell boundaries have never appeared or have disappeared. It arises through the continued division of the nucleus without the attendant division of the protoplasm, or through the fusion of a great number of cells with an attendant loss of cell boundaries. It represents an extensive mass of nucleated protoplasm.

EPITHELIUM

The epithelial tissues are characterized by the small amount of the intercellular cement. The cellular elements are usually prominent, and rich in granular cytoplasm. They are found lining cavities and covering surfaces that communicate normally with the air and usually secrete, although they may also have an excretory, absorptive, or protective function or receive sense impressions (special sense). Lymph spaces may exist between them and nerve fibers terminate upon them. The cells are soft and vary considerably in shape in the different organs. As the shape is constant for the various varieties this condition lends itself to the classification of epithelium. In some hollow organs, however, the form of the cells varies considerably at different times depending upon the degree
of distension (urinary bladder). Epithelial tissues are avascular and may be derived from any of the layers of the triploblast. The cells vary in size, form and arrangement, as will be seen later. Simple epithelial cells either secrete or assist in secretion while the stratified cells usually have a protective function.

The epithelial cells may be arranged in a single layer of elements and this variety is called \textit{simple epithelium}. When several layers of cells are present the form is then \textit{stratified epithelium}. In the latter case the variety takes its name from the surface cells as will be seen later. In this form the basal cells are always columnar elements and the intermediate cells are polyhedral. The superficial cells of a stratified epithelium are derived, by division, from the lower layers and when these superficial elements are cast off they are replaced by cells from the layer beneath them. In the simple epithelia when a few cells are lost they are readily replaced by the reproduction of the neighboring cells but when a large surface or area is destroyed or lost then the replacement is very difficult or impossible. In the latter instance the condition leads to serious pathologic conditions.

The \textit{intercellular substance, or cement} varies in quantity. Between the columnar cells of the stomach and intestine it is usually abundant, especially so near the distal extremities of the cells where it forms what is known as the \textit{terminal bars}. This intercellular cement responds readily to silver nitrate staining method.

For convenience of description, the cells are classified as follows:

1. Squamous.
   
   (a) Simple.
   (b) Stratified. Modified.

2. Columnar.
   
   (c) Simple.
   (d) Stratified.

3. Ciliated.
   
   (e) Simple.
   (f) Stratified.

4. Goblet cells.

5. Transitional cells.


1. Squamous.—(a) The \textit{simple squamous} cells consist of a single layer of flattened elements, each containing a large nucleus. This is usually in the center, and has an oval, or round form. The
cytoplasm may constitute so thin a layer that the nucleus produces a bulge. They occur in the descending limb of Henle's loop, the capsule of Bowman in the kidney, the alveoli of the lungs, and in parts of the ventricles of the brain.

(b) The **stratified squamous** variety consists of many layers of cells that are unlike in form. The lowest layer, the *germinial stratum*, is columnar, while those cells just above are polygonal. The succeeding cells become more and more flattened, forming the squames, or scales, from which this variety receives its name. These scales may overlap one another and be keratinized, as in the skin. The cells of the deeper layers of all stratified epithelium are all separated from one another by spaces bridged by protoplasmic processes that connect the various cells together. These spaces vary in extent at different times. These elements were formerly classified as *prickle cells*.
In stratified epithelium the number of layers varies from five to thirty or more. The stratified squamous variety has the greatest number. The cells of the deeper layers are all soft and show karyokinetic figures, indicating reproduction that gives the cells of the superficial layers. Toward the surface the cells become harder and ultimately keratinized forming then the protective scales of the surface of the layer. The amount of keratinization depends upon the location of the layer; upon the surface of the body where the greatest amount of protection is desired the keratinization is most
extensive. Even here it varies according to the use of the part; upon the soles and palms, where the skin is most used, the layer of keratinized scales is thickest; upon the outer parts of the upper and lower extremities and the back (most exposed parts) it is next in quantity; upon the inner parts of the extremities and the ventral thoracic wall it is less marked. The dryness of all of these parts, due to the constant and rapid evaporation of the perspiration, is an important factor in this process of keratinization. In those parts of the body supplied with stratified squamous epithelium, but where there is constant moisture (mouth, esophagus, lips, vagina, etc.), the amount of keratinization is at a minimum in man. In lower animals the keratinization of the epithelium of the tongue and esophagus is more marked than upon the surface of the body.

This process of keratinization is a chemical change and is accompanied by changes in the nucleus. The process starts in the cells above the prickle layer. The nucleus becomes less chromatic and somewhat flattened and the cell-body likewise becomes elongated. The cytoplasm shows a number of coarse granules of eleidin and

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**Fig. 43.—Section of Mucosa of the Human Esophagus. This is a Typic Mucous Membrane.**

*a*, Stratified squamous epithelial cells; *b*, genetic layer of epithelium and basement membrane; *c*, tunica propria; *d*, muscularis mucosae. (Photograph. Obj. 16 mm., oc. 10 X.)
keratohyalin and as the process continues the cells become more scale-like and keratin is formed. By this time the cells in which these changes have been produced are near, or at the surface, to which region they have been pushed by the reproduction of the cells underneath and the desquamation of the cells superficial to them.

Stratified squamous cells are found covering the body as the epidermis, lining the mouth, tongue, pharynx, esophagus, epiglottis, vocal cords, the anus and vagina.

![Figure 44](image1.png)

**Fig. 44.—Stratified Squamous Cells Showing Prickle Cells.**

2. **Columnar.**—(c) **Simple columnar** cells are tall, cylindric elements arranged in a single layer. The nucleus is usually oval, and found nearer the base than the center of the cell. Protoplasmic bribges are said to exist and the intercellular cement is usually abundant, forming the terminal bars. The cytoplasm may be granular or fibrillar and contain fat or other products. The appearance of the

![Figure 45](image2.png)

**Fig. 45.**

a. Simple columnar showing cuticular border. b. Simple ciliated cells. c. Simple columnar and goblet cells.
cytoplasm usually depends upon the state of secretory activity of the cell. These cells may exhibit striated borders which may represent fine canal, or pseudopodial projections may be present. These are more numerous during active secretion or excretion. Such cells are especially noted in the intestine and kidney.

![Fig. 46](image)

*Fig. 46.* a. Isolated columnar cells. b. Isolated ciliated cells. c. Three stages of goblet cells.

This variety is found in the stomach and intestinal tract, the penile portion of the urethra, glands of Cowper and Bartholin, prostate, gall-bladder and seminal vesicles, and in many gland ducts. In the intestine these cells, upon their exposed surface, have a layer of differentiated cytoplasm forming a partial membrane; this is called a *cuticular border.* Low columnars are often called *cuboidal.*

**Pseudostratified** cells are simple columnar, or ciliated, cells, in which the nuclei are not all basal, but occupy different levels, thus
giving the appearance of several layers of cells, where, in reality, but a single layer exists. These are found as ciliated elements in the oviducts, uterus and middle ear and as nonciliated elements in the seminal vesicles (maybe simple) and prostate, according to some writers.

(d) **Stratified columnar** cells consist of a number of layers of columnar elements superimposed upon one another. The cells are not as large as the preceding. They occur in the vas deferens, membranous urethra and the ducts of some glands.

3. **Ciliated Cells**.—(e) **Simple ciliated** cells are simple columnar elements, which bear, upon their exposed surface, a varying number of hair-like processes called cilia. These possess a motion that is directed toward the outlet of the organ in which these cells are found.

It is said that in lower animals the action of the cilia can be reversed. They line the smaller bronchioles, spinal canal, oviducts, uterus, accessory spaces of the nasal fossæ and the ventricles of the brain.

Within the cell each cilium is connected with a pair of granules called *basal body*; these latter are centrosomic in origin. As these basal bodies are not present in the cells of the epididymis and spinal canal their cilia are not considered true cilia. The cytoplasm may contain vacuoles, pigment granules and even secretory granules.

(f) The **stratified ciliated** cells are practically stratified columnar cells, of which the exposed layer alone possesses cilia. They are
found in the epididymis, first part of the vas, Eustachian tube, upper part of the pharynx, in the larynx, trachea and nasal tract.

**Fig. 50.**—Ciliated Cells Showing the Basal Particles. The middle cell shows a diplosome. (*After von Lenhossek.*)

**Fig. 51.**

*a.* Stratified columnar cells of the vas deferens of a guinea-pig showing a cuticular border.  
*b.* Stratified ciliated cells of the trachea of a child at birth showing a cuticular border.

4. **Goblet cells** are cells of the cylindric type, distended with a peculiar secretion called *mucin.* They really represent *unicellular glands.* When these cells are filled they resemble goblets, hence the
name. The secretion makes its appearance in the form of granules (mucinogen) which increase in number and size and respond to special stains (mucemathein). When secretion occurs the granules absorb water, swell and coalesce to form a single droplet. When the secretion has been discharged the cells are long and slender, the part containing the nucleus projecting on either side. After the discharge of the mucin the cells disappear and are replaced by new cells according to some investigators: this seems doubtful as there is some evidence that indicates that cells resume their secretory function. These cells are met with in the gastro-intestinal and respiratory tracts.

5. **Transitional cells** represent a peculiar intermediate form of protective epithelium between the stratified squamous and stratified columnar varieties. These cells average four to six or seven layers though ten layers at times may be present. The genetic layer consists of columnar cells and these are succeeded by several layers of polygonal or pyriform elements. The surface cells vary as follows: in the bladder and ureter, when empty, these cells are polygonal or cuboidal, while in the distended bladder they are flattened. In the urethra they remain polyhedral. This variability of shape indicates the *elasticity* and *extensibility* of epithelium, as pointed out by Harvey.

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*Fig. 52.*—Stratified Ciliated Cells from the Trachea of an Adult Man. (Photograph Obj. 4 mm., Oc. 7.5 X.)

*Fig. 53.*—Transitional Cells.
Keratinization of this variety seldom occurs and the shape of the cells is so characteristic that they can readily be distinguished from vaginal, urethral and epidermal cells in the urine.

This variety is found in the pelvis of the ureter, the ureter, bladder, first portion of the male urethra and the greater portion of the female urethra.

6. **Pigmented cells** are polygonal, or columnar elements in which the cytoplasm contains a number of pigment granules. This pigment may be diffuse or granular in character and is probably intracellular in origin. The polygonal cells are found in the epidermis of colored races and around the nipples and genitals of Caucasians. In the retina of the eyeball the cells are irregular in form and the position of the pigment depends upon whether the retina has been fixed with the exclusion of light or not. The pigment granules may be so numerous as to obscure the various parts of the cell.

**Pigments** are of two kinds, *exogenous*, or those arising outside of the body and *endogenous*, or those arising inside of the body. The *endogenous pigments* are elaborated by the cells of the organism for definite purposes and may be homogenous, granular or crystalline; they may be classified as *melanins*, *hematogenous pigments* and *lipochromes*.

**Melanins** are those especially produced to color the skin, eyeball and hairs; although they may be of various colors, brown and black are the commonest types. This pigment, as far as quantity and depth of color is concerned, may be a racial characteristic or climatic. Melanins are rich in sulphur but contain no iron. These granules form in the epithelial cells under the direction of the nucleus, by the oxidizing action of *tyrosinase* upon *tyrosin* or *ornithin*. These cells, called *melanoblasts*, may retain this pigment, or it may be given over to wandering cells; the latter are then called *chromatophores*.
pigment in the connective tissue cells of the choroid of the eyeball is supposed to be formed in the retinal cells, primarily, and is transferred to the choroidal cells, secondarily. The pigments in the cells of the skin may be increased locally under certain normal and pathologic conditions, *normally* as in exposure to the sun and in pregnancy and *pathologically* as in tuberculosis and around old healing ulcers. In Addison’s disease the skin is peculiarly pigmented but the origin and nature of this pigment are not known. Sometimes cartilage and ligaments exhibit a brownish or blackish pigment related to melanin; this condition is called *orchronosis*.

**Hematogenous pigments** are those that arise from the hemoglobin of the blood and are mostly pathologic in nature. There are several found but they are derived from hematin. When hemoglobin is liberated from the red blood cells in great quantities the free hemoglobin will color the urine and this constitutes hemoglobinuria. Millions of red cells are disintegrating hourly, under normal conditions, and apparently most of this hemoglobin is taken to the liver where it is converted into *bilirubin*, one of the coloring materials of the bile. On the other hand through an overproduction of free hemoglobin, or through a faulty metabolism of the normal quantity of free hemoglobin, this excess may be converted by the living cells into *hemosiderin* or *hematoidin*; the latter contains no iron. The deposition of hemosiderin in an organ constitutes *hemosiderosis* and this may occur in many organs. This pigment occurs in the form of small round granules and phagocytes may take it up and deposit in some other place than that in which it arises.

**Lipochromes** are not well understood, as yet, but they are of a fatty or lipoid origin. These pigments consist of yellowish granules or crystals found in many cells, as in the epithelium of the seminal vesicles, ganglion cells, heart muscle fibers, interstitial cells of the testes, corpus luteum of the ovary and in the adrenal. They may be so abundant as to color the organ deeply, as the corpus luteum, or so few as to be microscopic. As some are found in cells undergoing wasting changes, Lubarsch and Lehrt termed them *wear and tear pigments*. Most of them are not true lipochromes as found in fat but are colored lipoid (fat-like) substances.
Some nerve cells, as in the locus coeruleus and substantia nigra, contain a yellowish, brownish or black pigment which contains lecithin. This seems to increase with age.

**Exogenous pigments** are those that enter the body from without, as carbon, dusts of various kinds, lead, silver, etc.

![Image of pigmented cells](image)

**Fig. 55.—Pigmented Cells of the Human Retina (Surface View).**

a. Cell showing pigmented processes. *(After Greef.)*

In **albinos** there is a lack of pigment in the skin, hairs and eyeballs, that is hereditary. Melanin is scant but the hemoglobin is normal. Also in **scars** pigment is never deposited and the skin may show patches that totally lack pigment as in **leukoderma**.

7. **Neuro-epithelial cells** are epithelial cells that have become so differentiated as to perform a special sense function. They differ according to location, and will be described under each special sense. They occur in the retina (**rods and cones**), in the internal ear (**hair cells**), in the olfactory mucous membrane (**olfactory cells**) in the taste-buds (**gustatory cells**) and as tactile cells.
8. **Glandular cells** are concerned with secretion or excretion and vary according to the nature of the gland in which they are found, as in the liver, pancreas, etc. The cytoplasm is usually granular indicating the formation of a secretion. Immediately after secretion the cytoplasm is usually clear.

![Image of glandular epithelial cells](image)

**Fig. 56.—Glandular Epithelial Cells.**

A. Tubules of the human thyreoid gland showing cuboidal cells. B, Tubules of a human submaxillary gland; a, tubule showing a demilune; b, cross-section of a tubule.

**MUCOUS MEMBRANES**

**Mucous Membranes.**—Within the body proper are a number of recesses and tracts that communicate normally with the exterior; these are lined with epithelial cells that are supported in a special manner, constituting, thus, *mucous membranes*. These in themselves are quite extensive, but their area is greatly increased by offshoots in the form of glands, ducts, recesses, folds and projections (villi). These tracts are the alimentary, respiratory, urinogenital systems and lacrimal apparatus and their connected glands and cavities. To any and all of these the air has access. They all have their
beginnings or endings, or both, at the skin and the line of connection is usually sharply marked. The lining of each tract may differ somewhat from that of another, as their functions are not the same, but the general structure is the same in all cases.

These membranes are firmly attached to the underlying structures in certain regions, as in the nasal cavities and their accessory fosse; in other regions, as the stomach, bladder, etc., the connection is rather loose permitting of considerable distention of these organs without injury to the lining membrane. In some organs the mucous membrane is nearly even and regular in course, as gland ducts; in others it is formed into finger-like projections (villi), as in the small intestine. In still other organs it is thrown into extensive folds, as the intestines, stomach and bladder. By the formation of villi and folds the absorptive and secretory surfaces are enormously increased without a marked increase of the bulk of the organ.

Normally mucous membranes are soft, opaque, or nearly so, slimy and easily torn by moderate force. Ordinarily they are pinkish in color but the depth of color depends on the organ and its function. The color is due to the vascularity of the part and naturally where the vascularity is greater, the color will be deeper, as for instance, in the stomach, pharynx and rectum. The color is deeper in the fetus and infant than in the adult.

A typic mucous membrane consists of four layers, (1) epithelium, (2) basement membrane, (3) tunica propria, (4) muscularis mucosae.

1. The epithelium may be of any variety and will depend upon the function of the membrane. In such regions where protection alone is desired the epithelium is stratified squamous, transitional, or stratified columnar. Where secretion and excretion are being carried on, the variety is simple columnar, cuboidal or goblet. Where protection is desired and where, at the same time, the removal of small foreign bodies, entangled in mucus, must be maintained, the variety is either simple or stratified ciliated.

2. The basement membrane is not always demonstrable and when noticeable it is thin and apparently homogeneous. It usually consists of flattened cells that form a continuous layer or may be united to one another by protoplasmic processes, making thus, a sort of network. Some state that it is secreted by the epithelial
cells but in all probability it is derived from the tunica propria and therefore represents a modification of areolar connective tissue.

3. The *tunica propria* consists of a delicate network of fibroelastic (areolar) tissue that varies in different organs. In some organs (esophagus) the white fibrous tissue predominates and is more closely packed and therefore tougher. In other organs, as stomach and intestines, it is looser and glands and lymphoid tissue in great abundance are found here. It is this layer that supports the capillary blood-vessels, smaller lymph channels and the smaller nerve trunks and fibers. Here are also found, in certain organs, glands and lymphoid tissue. In the small intestine the tunica propria is thrown into an enormous number of finger-like projections called *villi*. These structures are of the greatest importance in the absorption of the digested food products.

4. The *muscularis mucosae* is not present in all mucous membranes. It consists of involuntary nonstriated muscle tissue arranged in two layers. The fibers of the inner layer run transversely while those of the outer layer run longitudinally. The muscle tissue forms an even and definite boundary that sharply demarcates the mucosa from the submucosa. It is usually regular and even in its thickness and is practically at all points equidistant from the epithelial surface. It is found in the mucosa of the lower third of the esophagus, stomach and intestinal tract.

The *functions* may be classed as *absorption, secretion, excretion* and *protection*.

1. *Absorption*.—As a result of the action of digestive fluids the food ingested is converted into substances that are absorbable. This
process is carried on chiefly by the villi of the small intestine. By a "selective action" of the simple columnar epithelial cells covering the villi the water and inorganic salts are passed through and ultimately reach the blood-vessels. All of the sugars, except possibly lactose, are converted into levulose or dextrose and as such are taken into the epithelial cells and transferred to the blood-vessels. In whatever form the carbohydrates are absorbed they never leave these cells except in the form of levulose or dextrose. Proteins are converted into peptones by the digestive fluids and as such are absorbed by the epithelial cells of the villi. Native proteins are also absorbed by the mucosa of the large intestine. After absorption the epithelial cells convert these peptones into plasma-albumen and as such are given over to the blood-vessels. Investigation seems to point to the fact that the end products of protein digestion are not peptones but less complex bodies, as polypeptids, peptids and amido-acids. It is these simpler products that these epithelial cells convert into plasma-albumen and plasma-globulin. Fats are believed, by some investigators, to be converted into an emulsion during digestion and from this emulsion the fat globules are taken by the epithelial cells and passed through them to the lymph vessels. Others believe that as a result of digestion, fats are converted into soaps and glycerin. The epithelial cells take these and reconstruct fats within the cell-body and the fat is then passed to the lymph vessels where with the lymph it constitutes chyle.

2. Secretion.—This term is applied to the fluid that is made by the vital activities of the epithelial cells from the constituents of the lymph that surrounds them. This juice is used in the vital processes of the body. Such juices are the pancreatic and gastric, saliva, bile, etc., and the various internal secretions. These fluids are formed as the result of chemical changes within the cells. That the epithelial cells of the stomach give rise to an entirely different juice than those of the liver or other glands is probably due to the difference in histologic and chemical structure. These epithelial elements are not always active but discharge their secretions at periodic intervals and in between enjoy a period of rest and recuperation. During the inactive period certain substances, as mucin, glycerin, proteins and antecedents of enzymes, accumulate in the
cells, as the result of cellular activity; these substances constitute the secretion. At such times the blood supply is not great. During glandular activity the organ becomes red due to increased vascularity, and as a result a rapid transudation of water and salts into the lymph spaces occurs. As the water passes through the cells the above-mentioned constituents are dissolved and are ultimately discharged into the lumen of the ducts.

The formation and discharge of the secretions are controlled by the nerve system. These nerve centers may be excited by emotional states or by impressions upon the terminals, as for instance, the flow of saliva is increased either by the presence of desirable food in the mouth, or by the mere thought or odor of desirable food.

3. Excretions.—The formation and elimination of waste products which, if retained, would lead to injurious results, constitute excretion. These waste products are emptied into the blood and are the results of the activities of the cells and tissues. Epithelial cells are the prime factors in excretion and are assisted by osmosis and filtration. The chief excretions are the urine, perspiration and bile. The urea and salts of the urine are not made by the kidneys but are merely eliminated by these organs. The epithelial cells of the kidney have a selective power by means of which they take these substances from the blood and simply pass them into the uriniferous tubules. The liver does not make the cholesterin (the excrementitious part of the bile) but merely removes it from the blood and passes it to the intestine. The sweat glands merely remove a small amount of urea and certain inorganic salts, by selective action, and these with water from the blood constitute perspiration.

4. Protection.—In certain organs that do not secrete nor excrete, a protective lining alone is required, as in the mouth, esophagus, bladder, ducts of glands, etc. The epithelial cells here are usually of the stratified squamous, stratified columnar or transitional varieties.

**SEROUS MEMBRANES**

As some writers classify endothelial cells as epithelial, they will be considered here so as to emphasize the differences between them. When an area of epithelial cells is denuded thereof this area is covered,
or healed, by the extension of the epithelial cells at the edges. If this denuded area is not too large the entire part is soon covered by these extended cells. If the area is large then small islands of epithelium taken from other parts of the body and placed upon the denuded area will usually grow and spread, thus covering the uncovered area. On the other hand when the endothelial or mesothelial cells of a serous membrane have been denuded they are replaced by cells from the underlying subendothelial tissue and hence are of connective tissue origin. The structure and functions of serous and mucous membranes differ; lastly the course of inflammations of these two membranes is so different that the lining cells must essentially be different. Although serous membranes are here described it must be remembered that it is for the sake of comparison and not because endothelial cells are considered epithelial cells.

**Serous membranes** line cavities that do not communicate normally with the air, the female peritoneal cavity excepted; such are the blood-vascular and lymph-vascular systems, the pleural, pericardial, peritoneal and scrotal cavities, the spaces of bursæ, tendon sheaths, joint cavities, chambers of the eyeball, scalæ vestibuli and tympani of the internal ear and the subdural and subarachnoid spaces of the meninges. According to some writers the lining cells are called epithelial and are described under the epithelial tissues. But their origin, function and life history are so different from that of the ordinary epithelia that these serous membrane cells seem misplaced under epithelial tissues. The lining elements of a serous membrane are usually called endothelium but in recent years a distinction advocated by Minot was drawn and those cells found lining the blood-vessels and lymph vessels were called *endothelium* and those of the remaining spaces were termed *mesothelium*.

The cells found lining the blood-vascular and lymph-vascular systems are derived chiefly from the ordinary lamellar cells, which in their ordinary state are stellate elements but in the above spaces they become flattened, squamous cells. The vascular endothelium represents a direct change from the lamellar to the squamous cell. In fetal life the cells that line the body cavities were at first cuboidal elements resembling cuboidal epithelium. These soon become
flattened and squame-like resembling, ultimately, the cells lining the vascular system. Their different origin, however, entitles them to a different name and as the original cuboidal celomic cells are now called mesothelium this term is also used to indicate their modified squamous derivatives. During the sixth week of intrauterine life this flattening process is advanced and by the eighth week the flattened state is reached. Strange to say the squamous mesothelial cells may revert to their cuboidal form in the adult in certain pathologic conditions; these have been noted by the author upon the pericardium, pleurae and the splenic peritoneum. Whether these were all reversions or new mesothelial cells ready to flatten is hard to say. In lower animals openings called stomata exist in the serous membranes of the body cavities and these openings are bounded by
special guard cells. Such openings do not exist in blood-vessels nor lymph-vessels under normal conditions.

The joint cavities, tendon sheaths, bursae, chambers of the eyeball, etc., arise as clefts and therein resemble the serous cavities above mentioned. The lining cells of these spaces resemble the endothelium of the blood-vessels in that they are first of the lamellar type that later become flattened and squame-like. In most instances the cells remain in this form but in joint cavities they become cuboidal and therein they resemble the mesothelial cells of the body cavities. In the joint cavities, their functions are different than that of the cells of the true endothelial and mesothelial type. F. T. Lewis has suggested that these cells be called false, or mesenchymal epithelium. This seems inadvisable as these cells are no more epithelial than the mesothelial cells are. Again there exist true mesenchymal epithelial cells as represented by the epithelium of the kidneys, testes, ovaries and adrenal cortex. True epithelial cells are derived from all of the three layers, ectoderm, mesoderm and entoderm, while the cells of the serous membrane are derived from the mesoderm only and are modified connective tissue cells. The true mesodermal epithelial cells never in any way resemble nor revert to connective tissue cells and cannot be formed from them.

Endothelial cells of the blood-vessels and lymph channels are flattened elements possessing a projecting nucleus; this is due to the fact that the thickness of the cytoplasmic layer is less than that of the nucleus. These cells are uniform in size and lanceolate in form with their long axes parallel to that of the vessel; the cell outline, however, is irregular because the edges of the cell are serrated. They are held together by a small amount of intercellular substance and protoplasmic processes. The cytoplasm is usually clear and apparently structureless, but may show some fibers passing from one cell to another. The free surface is said to be covered by a thin layer of vertically striated protoplasm. The endothelium of capillaries is said to be contractile and ameboid. The nucleus is ovoid and eight to twelve microns long by about three to six microns thick; a nucleolus is present and canals may be found in the cytoplasm at times.

Mesothelial cells vary in outline in the different animals but in general they are flattened and very irregular in outline. In the
fetal state these cells are cuboidal in form. They vary from twenty to ninety microns in length and thirty to fifty microns in width. In their adult form they constitute plate-like elements that are broader and more massive than the endothelium of blood-vessels. The cytoplasm is apparently homogeneous but may show canals. The edges of the cells are serrated and dove-tail into one another; the nucleus may bulge. Cilia are sometimes said to be present but these are apparently fibrin as they respond to the fibrin stains. In some places the cells may not completely approximate forming stigmata. These are supposed to be openings leading into the underlying lymph spaces but in all probability they are artefacts.

In the abdominal peritoneum of the frog normal openings, the stomata, exist; they are bounded by specialized guard cells.

The false, or mesenchymal epithelium resembles mostly in origin the endothelium of the blood-vessels but in their structure they are like the mesothelium of the body cavities. They are large, flattened, plate-like elements except in joint cavities; here they are usually cuboidal in form and rest upon a more or less complete basement membrane. Herein they resemble the true epithelia of mucous membranes. The cells appear granular and apparently of a secretory nature. The underlying fibroelastie tissue contains capillary blood-vessels that may be absent in the ordinary serous membranes.

This marked difference between the endothelial and mesothelial cells, upon the one hand, and the epithelial cells upon the other is well put by Hertzler. He says of the endothelial cells of serous membranes, "What is still more important, is that in their mode of reproduction after injury and their conduct in reactive processes these structures are not comparable to any other structures of epiblastic or hypoblastic origin. For this reason they deserve a place in the nomenclature all their own."

The intercellular substance is different from that underlying the cell and responds to silver stains. When exposed to the blood stream it does not coagulate as does the underlying subcellular substance. The intercellular substance does not invite adhesions but if the subcellular substance be exposed adhesions will form. Little is known, chemically, of this intercellular substance; Rollet compares it
to colloidal, Eichwald to the mucin of ovarian cysts and goiters and Schäffer considers it mucin.

Hertzler denies that there are any intercellular bridges and states that stain methods for this purpose are negative. The connecting fibrils found are apparently artefacts due to the silver solution.

If a serous membrane be dried upon a slide, cellular surface down, and then the overlying tissue be stripped, then a complete layer of connective tissue fibrils will be exposed. These apparently support the endothelial cells and this is called by Bizzozero the membrana limitans, while others term it a basement membrane. The intercellular substance between the cells is continued beneath them and apparently fixes the surface cells to the underlying membrane. By slight maceration and then silvering the cells may readily be pencilled out and the intercellular substance and the membrane will remain. The cement substance does not respond to the elastica stain nor to Mallory’s connective tissue stain. It does seem to resemble somewhat the basement membrane of the mucous membranes.

The subendothelial tissue is of the areolar type and contains a network of lymph vessels and blood-vessels. The amount of subendothelial tissue varies in different regions; it is thin where the serous membrane invests an organ and in such places where the peritoneum is firmly attached. Where the peritoneum is freely movable the subendothelial tissue is abundant.

Blood-vessels are not numerous except as service vessels; potential vessels that ordinarily carry no blood are found. Probably they ordinarily carry a serum that contains no red blood cells causing the vessels to be invisible and the area avascular.

The lymph vessels in the peritoneum form a network under the mesothelial cells. The vessels are rather large and irregular in diameter. They connect with the vessels in the mesentery or with the vessels of the organ that the membrane invests.

The peritoneum and other serous membranes, are essentially protective in function and make the organs move as free from friction as possible. Response of the peritoneum in injuries shows its protective nature. Formerly it was thought that the peritoneal cavity was a large lymph space but we know now that the peritoneal fluid and the lymph are not the same. These serous spaces differ from
the lymph spaces in being lined with an unbroken layer of flattened cells that are mesodermal in origin. Exudation (transudation?) and absorption take place here.

Ludwig and his pupils believed that the lymph was formed by filtration. Heidenhain believed that this fluid was a secretion and that the vascular endothelium was involved. Starling's experiments lead him to believe that the presence of the lymph in the interstitial spaces was due to the great permeability of the capillaries. The changes in the vessel wall that increases this permeability seem to be independent of a primary increase of blood pressure and independent of any endothelial action.

All in all it seems that the mesothelial cells of the peritoneum, and possibly of the pleurae and pericardium also, assist in the formation of the fluids of these cavities.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mucous membranes</th>
<th>Serous membranes</th>
</tr>
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<tbody>
<tr>
<td>Where found</td>
<td>Lining cavities that communicate normally with the air.</td>
<td>In cavities that do not communicate normally with the air (female peritoneal cavity excepted).</td>
</tr>
<tr>
<td>Lined by</td>
<td>Epithelial cells of any variety.</td>
<td>Endothelial, Mesothelial cells, one layer.</td>
</tr>
<tr>
<td>Secrete</td>
<td>With few exceptions.</td>
<td>Usually not. Some may.</td>
</tr>
<tr>
<td>Structure</td>
<td>Epithelial cells, basement membrane, tunica propria, muscularis mucosae.</td>
<td>Endothelial cells, subendothelial connective tissue.</td>
</tr>
<tr>
<td>Represents</td>
<td>All four varieties of tissue.</td>
<td>But two varieties (neither muscle nor epithelial tissues).</td>
</tr>
<tr>
<td></td>
<td>Opaque.</td>
<td>Transparent.</td>
</tr>
</tbody>
</table>

The absorption of the peritoneal fluid was thought to be by way of the lymph vessels. Experiments, especially by Starling and Tully, seem to indicate that most of the peritoneal fluid is absorbed by the blood-vessels, contrary to the former belief. Solid particles are taken up partly by the phagocytes and are partly carried to the lymph channels in the central tendon of the diaphragm where they can be
traced. A great many of the experimental foreign bodies are encapsulated with fibrin. These encapsulated particles become surrounded by cells especially polynuclear cells. These may engulf the particles and carry them to a lymph node. Fluids are absorbed with equal rapidity from all parts of the peritoneum. Absorption also takes place through the great omentum. This structure may be absent or be removed without after effects.

GLANDS

A description of epithelial tissues would not be complete without a consideration of glands. The term gland is loosely applied to some organs that, strictly speaking, are not true glands in the sense of epithelial structure. Most of the glands are offshoots or derivatives of mucous membranes and the great majority still retain their connection in the completed condition. Glands may be unicellular, as the goblet-cell, or multicellular, as those that will be considered below. A gland is an evagination of a mucous surface, consists of epithelial cells, arranged in definite groups, and performs a physiologic function. These groups are the secretory units of the organ.

Glands may be classified in several ways: (1) as to structure (2) as to secretion and (3) as to outlet.

1. Structure.—As the secretory units are of different shapes we have the following divisions and subdivisions:

Tubular Glands.

Simple.
Branched.
Coiled.
Compound.

Tubulo-alveolar Glands.

Alveolar, or Racemose Glands.

Simple.
Compound.

Tubular.—Simple tubular glands are mere cylindric depressions in the mucous membrane. They are lined, usually, by simple columnar cells. These rest upon a delicate basement membrane and this is supported by the tunica propria of the mucous membrane.
In the stomach the cells are acid, peptic and some goblet cells; in the small intestine the goblet cells predominate near the outlet while the remainder of the gland is lined with simple columnar elements. At the *fundus* of the glands there are certain cells with granular protoplasm; in some of these cells the granules are acidophilic and in others basophilic. Each gland consists of a *fundus*, *neck* and *mouth*.

Simple tubular glands are found in the cardiac end of the stomach and in the small and large intestines.

The **branched tubular** are like the above, except that the blind end consists of two or more secretory units. Each secretory unit consists of a *fundus* and neck and the single outlet for all represents the mouth. The lining cells may be columnar, or ciliated, as in the uterus. These glands are found in the *fundus* and pyloric portion of the stomach, in the duodenum (Brunner's glands) in the uterus, and in the prostate.

**Coiled tubular** glands are really simple tubes, the secretory portion of which has become coiled and convoluted to occupy as small a space as possible. The lining cells are columnar or cuboidal (low columnar). These rest upon a basement membrane which is further supported by areolar tissue for the capillaries and nerves. Around the outside is a *capsule* that delimits the organ from the surrounding tissues.
Examples of this variety are the sweat and ceruminous glands. **Compound tubular** glands are those in which the primitive tubules have divided and redivided until an enormous number of divisions has resulted. Pure examples of this variety are the liver (also called reticular), testicle, kidney, thyreoid, lacrimal and serous glands of the mucous membranes.

A **compound gland** is surrounded by a *capsule* of white fibrous connective tissue that sends in septa that divide the gland into *lobes*. These are further subdivided by smaller septa into *lobules*,

---

**Fig. 60.—Diagrams of Tubular Glands.**

the **structural units** of the gland. Within the lobule is a delicate reticulum that forms the supportive tissue of the blood-vessels, nerves, lymph channels and epithelium. This constitutes the **interstitial tissue**. The epithelium, or functionating part, constitutes the **parenchyma**. In the lobule a single layer of epithelial cells rests upon a basement membrane; these cells are arranged in the form of tubules or saccules and represent the **secretory units** of the gland. The cavity or **lumen** in the center of each tubule leads into an **intralobular duct** that connects directly with the units. These ducts are lined with low epithelial cells that rest upon a basement membrane supported by areolar tissue. These ducts unite to form larger ducts; the latter and the larger vessels lie in the interlobular tissue. The interlobular ducts unite to form larger ducts that ultimately form the single **excretory duct** of the gland.

The arteries usually enter at one region, the hilus of the organ. They then divide into branches that follow the larger septa and into branches that lie in the interlobular connective tissue. From these interlobular vessels branches ramify the lobules and form a plexus around the tubules and acini. The venous channels arise from this plexus and have a course corresponding to that of the arterial vessels and form usually one vein that leaves at the hilus. As the tissue spaces around the tubules and acini are very numerous the plasma of the blood transudes into these and bathes the cells with nutrient material and into this lymph the effete materials are also passed from the cells. In the case of glands with sinusoidal capillaries (liver, adrenal, etc.) there are very few tissue spaces and the capillaries penetrate between the epithelial cells and lie in direct contact with them. Vessels also supply the ducts and framework of the organ.

The lymph gradually passes into definite vessels (capillaries) and then into larger channels and is then collected into one or several vessels which leave at the hilus and capsular region (deep and superficial lymphatics).

The nerves of glands are for the vessels and for the epithelial cells. Those for the vessels are vasodilators and vasoconstrictors. By the action of the former the blood supply is increased and there-
fore the secretion also; the latter have the reverse action. In some instances the vasodilators are derived from the sympathetic nerves and in others from the cerebrospinal nerves through the sympathetic plexuses. The vasoconstrictors usually arise from the sympathetic nerves. The nerves to the epithelial cells are of two varieties, trophic and secretor. The trophic nerves seem to accompany the vasoconstrictors and by their action cause an increase in the secretion products within the cells. The secretor fibers seem to accompany the vasodilators and produce a rapid discharge of the secretion.

A compound tubular gland may be compared to a bunch of tokay grapes, the grapes representing the secretory units and the various stems the ducts. A full bunch of these grapes will show the small groups of grapes forming larger groups and these can readily be likened unto the lobules and lobes of a gland; the various stems represent, excellently, the various ducts, intralobular, interlobular, interlobar and main ducts. The spaces between the various groups and individual grapes constitute the region of the interstitial connective tissue supporting blood-vessels, nerves and lymph channels.

**Tubulo-alveolar** glands are those in which the terminal secreting units are partly tubules and partly alveoli. Such are the submaxillary, sublingual, mammary glands and the lungs, but the last two resemble compound alveolar glands, as their secretory units are of the alveolar type.

The general structure of these glands is like the preceding. A tubulo-alveolar gland may be likened unto a bunch of mixed grapes, some of the tokay variety and some of the ordinary round, or concord variety. Both varieties may be found in the same lobules, or whole lobules, or lobes may consist of just one form.

**Alveolar.**—The simple alveolar, or saccular, glands are sac-like depressions extending from the free surface. They are comparatively few in number, and occur as the smallest sebaceous glands.

Each consists of a sac-like structure connected to the epithelial surface by a slender neck, or duct. The sac instead of being lined with a single layer of epithelial cells, as in all of the preceding forms, is filled with a solid mass of very large polyhedral cells. Those cells nearest the duct show signs of degeneration and fatty changes;
ultimately they disintegrate entirely and the thick, fatty substance constitutes the secretion (*sebum*). These cells in forming the secretion die. In other glands the secreting cells form secretion over and over and live for a considerable time. In sebaceous glands the disintegrated cells are rapidly replaced by mitosis of the cells toward the basement membrane. Outside of the basement mem-

![Diagram of Alveolar Glands](image)

**Fig. 61.**—Diagrams of Alveolar Glands.  
* A, Tubulo-alveolar; B, simple alveolar; C, compound alveolar.

brane is a tunica propria for the support of blood-vessels, nerves and lymph channels. The peripheral portion of this is condensed to form a *capsule*.

The **compound racemose** glands are like the compound tubular, except that the terminal portions are saccular, instead of tubular. Such glands are the pancreas, parotid, and the large sebaceous glands.

The secreting units of the large sebaceous glands, like in the simple form, are filled with a solid mass of epithelium and the changes here are the same as in the simple glands.
2. **Secretion.**—The function of a gland is to give rise to a substance to be used by the body in some of its many processes or to remove waste products (excretions). The former substance is called a *secretion*, and it may be *liquid* or *cellular* (ovum). The liquid secretions may be *serous*, *mucous*, or *mixed*. These terms, applied to the respective glands as well, have reference to the salivary glands alone.

**Serous** glands are those which form a thin albuminous secretion. The glandular cells respond well to stains. The parotid and pancreas belong to this class.

The appearance of these glands differs when they are in a state of *activity* or of *rest*. At the beginning of the *stage of rest* the cells are comparatively small and shrunken and the lumen of each acinus is large. The nucleus is centrally placed and the cytoplasm is devoid of secretion granules. As the secretion is formed the cytoplasm changes in appearance to either clear or granular according to the gland. In the sweat glands the cytoplasm is clear as the secretion is essentially watery, while in the pancreas and parotid glands the cytoplasm is granular. In the latter glands the secretion is *zygomotic* in character, hence the difference. As the secretion increases the nucleus is forced toward the basal extremity of the cell and the secretion lies toward the lumen end, so that ultimately the cell has a swollen appearance and the lumen is occluded or nearly so.

During the stage of *secretory activity* the secretion is passed into the lumen of the acinus and the cell is smaller and shrunken. The cytoplasm is finely granular, if the secretion has been watery and if the secretion has been granular the cytoplasm is clear.

In many serous gland cells *secretory canaliculi* have been demonstrated. These may open into the lumen of the tubules or into the lymph spaces or blood-vessels. Some of these channels are in the nature of nutrient canals, however. Serous glands stain darkly with the ordinary stains.

**Mucous** glands are those that give rise to a thick viscid substance. The cells here stain but lightly with the ordinary stains. Such are the small glands found in the mouth, esophagus, trachea and the sublingual gland, according to some writers.
The cytoplasm of the cells of the mucin secreting glands is finely granular, the nucleus centrally located, the cells smaller and the lumen comparatively large, during the stage of rest. The granules lie in the lumen end of the cells, increase rapidly in size and, after prolonged rest, occupy over half of the thickness of the cells. The granules are much larger than those of the serous glands and respond to the special stains for mucin. As these granules increase in number and size the cells become swollen and the nuclei and cytoplasm are forced toward the basement membrane and the lumen is practically occluded. In the stage of secretion, by the contraction of the cells or by the transudation of water through them (from the blood or lymph), the granules become swollen, dissolve and form a homogeneous mass which is passed from the cell. The cell then is somewhat shrunken and the area formerly occupied by the secretion shows a delicate reticulum in which the new globules of secretion form. The presecretion globules are called mucinogen and the finished product mucin and they usually behave differently to stains. The secretion granules of the various glands are probably mitochondrial in origin. In most glands the extrusion of the secretion is caused by the action of the nerve system or by hormones in the blood.

The cells of mucin-secreting glands stain lightly in contrast to the cells of the serous glands. This is due to the fact that the granules in the serous cells are not readily soluble in the aqueous or alcoholic fixing agents so that they remain and are stained. On the other hand the secretion globules or granules of the mucin cells are readily swollen or dissolved by water or even alcohol so that in fixed cells they were for a long time unobserved. This action is produced even by normal salt solution and serum. They may readily be seen in fresh tissue examined in a 2 to 5 per cent. sodium chlorid solution. If the tissue be fixed in osmic acid vapor, or in a mixture of equal parts of osmic acid (.5 per cent. in 3 per cent. sodium chlorid) and saturated solution of potassium bichromate, the granules are undissolved and readily found.

Mucin responds to special stains, mucematein and mucicarmin. In the fresh state it is clear, slimy and of a pearly white color. Alcohol coagulates it forming a heavy, white, stringy precipitate.
It does not respond well to the ordinary stains so the part of the cells containing it looks unstained in the ordinary technic.

In most mucous glands groups of darkly staining cells are seen in the bases of tubules. These cells contain a finely granular cytoplasm and are arranged in crescentic groups called the crescents of Gianuzzi, or the demilunes of Heidenhain. These cells and groups vary in size in the different glands. Some consider them the resting stages of the mucin-secreting elements and others consider them as entirely different and independent structures. It seems that they are a form of serous cell. The cytoplasm always responds well to the plasmatic stains and also contains secretory canaliculi that empty the secretion into a canalicular system between the cells of a group. From this system the secretion is ultimately passed into the lumen of the tubule. From this it would appear that the so-called pure mucous glands are really mixed glands in that they contain the demilunes.

Mixed glands are those in which both varieties of secretion are formed. The secretory areas are stained darkly or lightly, according to whether they are serous or mucous. The sublingual and sub-maxillary glands are examples, and of these, the latter is the more characteristic.

The minute structure of these glands will be considered under the Alimentary Tract.

The excretory glands are the kidneys, lungs and sweat glands. Each will be considered in detail, under its respective system.

3. Outlet.—As a rule, all glands, at some period in their development, are connected with the mucous surface by a tube called a duct. This connection, in most instances, persists, but where it disappears, or where it never occurred, the gland becomes isolated, and the term ductless gland is applied. Such are the adrenals, hypophysis and thyroid bodies, parathyroid, carotid and coccygeal glands, certain areas of the ovary and testis and the areas of Langerhans of the pancreas. The cells are arranged in the form of solid cords, tubules and even alveoli. The delicate reticulum supporting these cells usually contains capillaries of the sinusoidal type, that is, the epithelium and the endothelium are in contact with each other and lymph spaces are not numerous or are absent. In some instances
the lymphatics have a similar arrangement so that the internal secretion is passed directly to the blood or lymph vessels. In the liver the secretory capillaries of the cells are said to communicate with the sinusoid thereby emptying the urea formed within the cells directly into the vascular system.

The glands with ducts pour their secretions, or excretions, into the various tracts with which they are connected.
CHAPTER IV

CONNECTIVE TISSUES

The connective tissues are the supportive tissues of the body. They are characterized by the predominance of the intercellular substance over the cellular elements. The intercellular substance varies in consistency from the liquor sanguinis of the blood and the soft fibrous material of areolar and elastic tissues to the harder cartilage, bone and dentin. This variation is due to the function performed. Although there are many varieties they are all derived from the same embryonic type, mesenchyme, and change as they progress in their development. Even in their adult forms some show their close relationship to one another and while some may be looked upon as different stages of the young type others are distinct modifications, as cartilage, bone and dentin. The cellular elements resemble one another somewhat in the different varieties, are comparatively few in number and are arranged singly or in small groups in the intercellular substance. This matrix or ground substance predominates and it is the variation of this that gives us the different varieties of connective tissue. They often replace one another. The ground substance and the fibers are stained by the silver nitrate method showing the numerous lymph spaces existing in most varieties. The vascularity also varies, some forms having few vessels while others are quite vascular. The connective tissues form the framework and supportive substance of the various organs and the body in general and fill up what ordinarily would be spaces.

In the formation of these tissues the fibroblasts of the mesenchyme reproduce rapidly and secrete a semi-solid intercellular substance. With the fusion of the fibroblasts a syncytial structure is formed. The cytoplasm around the nuclei soon differentiates into endoplasm and exoplasm and in the latter the mitochondria are said to form the fibrils at the expense of the endoplasm. The remainder of these
little masses of again isolated cytoplasm constitute the connective-tissue cells. The fibers are of three types, white, elastic and reticular. Additional fibers are said to be formed by the splitting of these.

For the convenience of description, the connective tissues have been subdivided into the following varieties:

**Fibrous.**

1. Areolar.
2. White fibrous.
3. Yellow elastic.
4. Mucous.
5. Embryonic.

**Modified.**

6. Adipose.
7. Lymphoid.
8. Cartilage.
10. Dentin.

**II. Blood.**

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**Fig. 62.**—Areolar Tissue.  
*a,* Lamellar cell; *b,* bundles of white fibers; *c,* plasma cells; *d,* elastic fibers; *e,* clasmocytes; *f,* granule cells.

1. Areolar tissue is a delicate, web-like form representing the most widely distributed variety. It consists of an interlacement of white and yellow elastic fibers containing various cellular elements. The spaces thus formed permit of a wide diffusion of lymph over a great
distance. This variety is found binding the skin to the fascia beneath, as the intermuscular septa, surrounding blood-vessels, nerves and lymph channels and assists in the formation of most of the organs of the body (tunica propria, submucosa, interstitial tissue of glands and gland-like organs).

The cellular elements are lamellar cells, clasmocytes, plasma cells, wandering cells and mast cells.

1. The lamellar cells are the chief cells and are usually flattened, stellate elements. Their processes may anastomose with those of other cells. The cytoplasm is usually clear, but a few granules may be present. The nucleus is oval and stains readily. The youngest cells are round; these become spindle-shaped by the development of several processes and by the formation of more processes become stellate in form. They may be pigmented as in the eyeball. In the lymphatic spaces the lamellar cells are flattened elements that constitute the endothelial cells.

2. The clasmocytes are irregular, elongated elements that are probably derived from the wandering cells. The cytoplasm is granular and may contain vacuoles. The nucleus is large and oval in form.

3. The plasma cells are large, flattened, elongated, or spheroidal elements that may possess processes; the cytoplasm contains some vacuoles and a number of basophilic granules. The vacuoles may be very numerous and may extend into the processes. The nucleus is usually small and eccentrically placed. These cells are most numerous in the blood-forming and lymphoid organs, intestinal mucosa and subcutaneous tissue.

4. The wandering cells are merely leukocytes that have wandered in from the blood or lymph.

5. Mast cells are large, round elements in which the cytoplasm contains a large number of basophilic granules. These cells are found chiefly in bone-marrow and regions where fat is being deposited. They are probably modified leukocytes.

Pigment cells are seen in the iris, choroid and derma and represent a protection against light. These are really lamellar cells in which the pigment granules are collected in the cytoplasm. This substance may be melanin, hemaglobin or fat pigments (lipochromes).
The pigment cells of the derma may have ameboid power to a slight degree. In the skin of the frog this pigment is abundant in the stellate cells and the color of the skin can be varied by the distribution thereof. When the pigment granules are forced out of a fresh cell these granules exhibit "Brownian motion."

The intercellular substance is soft and fibrillar in character. The white (collagenous) fibers consist of delicate bundles of fibrils that pass from one bundle to another. The fibers run in wavy bundles that interlace with one another and with the elastic fibers. Bundles may occasionally anastomose with one another. The elastic fibers are yellow in color and branch. They are not arranged in bundles and are usually thicker than the white fibers. In situ they are straight due to the tension under which they exist. When the tissue is removed from the body these elastic fibers curl due to loss of tension.

Reticulum was at one time considered a special type of connective tissue but it is now considered merely a special arrangement of the areolar form. It forms the supportive substance of glands and gland-like organs and, according to Mall, it represented the least differentiated form of the mesenchymal tissues. It consists of
delicate bundles of fibrils that form a network in the meshes of which are found the functionating cells of the organ. The reticular cells are chiefly flattened elements that clasp the fiber bundles usually at the intersections of the bundles.

The fibers resemble those of the areolar type but are said to be more highly refractile and clearer than those of the collaginous type. This tissue is also more resistant to those agents that dissolve the white variety (hydrochloric acid and potassium hydrate) and is more resistant to pepsin digestion. If reticular tissue differs from areolar tissue there is no sharp line at which one passes over into the other, as these so-called tissues are continuous and give the same stain reactions.

2. **White fibrous tissue** is that variety in which the bundles do not interlace but run parallel to one another. It is white, shiny, tough and yet pliable. It is found as the ligaments, fasciae, dura and tendons.

In fasciae, or aponeuroses the fiber bundles are arranged in layers that run transversely and longitudinally. The bundles of each layer are parallel to one another and do not interlace. In the dura they take different directions and decussate with one another, forming a dense unyielding membrane.

**Tendons** are dense white fibrous tissues, in which all the fiber bundles have a parallel course. The whole structure is surrounded by a sheath of looser tissue, called the epitendineum, from the inner surface of which septa are sent in that divide the tendon fibers into large secondary bundles. These latter are further subdivided into primary bundles, each of which is surrounded by a minute sheath, the peritendineum. In these sheaths or septa are found the blood-vessels, nerves and lymph channels of the tendon. Although the bundles run parallel to one another they receive slips from and give off slips to neighboring bundles. Still this does not interfere with the important operation of tendon-splicing so useful in surgery. Between the bundles of tendon fibers are seen the peculiar tendon cells. These are lamellar cells that are arranged in rows or chains. These cells upon surface view are rectangular, or oblong but upon cross-section they are stellate. This is due to the fact that they are packed in between the bundles and have become moulded by these
Fig. 64.

A.—Mucous Connective Tissue. a, Spindle cells; b, stellate cell; c, intercellular substance. B.—Cross-section of Tendon. a, Epitendineum; b, peritendineum; c, tendon fasciculi; d, interfascicular space. C.—Part of B, highly magnified. a, Epitendineum; b, cell in a; c, peritendineum; d, tendon fasciculus; e, interfascicular space. D.—Tendon Cells from Interfascicular Spaces. E.—Elastic Tissue, Cross-section of Ligamentum Nuchae. a, Elastic fibers; b, white fibrous supportive tissue. F.—E highly magnified. a, Elastic fibers; b, white fibrous supportive tissue. G.—Areolar Tissue. a, White fiber bundles; b, elastic fibers; c, spindle cell; d, granule cell; e, plasma cell; f, stellate cell. H.—Adipose Tissue. a, Interlobular connective tissue; b, fat cells; c, nucleus and cytoplasm of the cell. I.—H, highly magnified. a, Fat cell; b, cytoplasm and nucleus of cell. K.—Lymphoid Tissue. a, Leukocytes; b, stellate connective tissue cells; c, reticulum. L.—Pigmented Connective Tissue Cell from a Pike.
into their peculiar shape. In denser areolar tissue the lamellar cells may have the same form, due to pressure. The cells are thicker in the middle than at the extremities; the nuclei are oval, lightly stained and may contain one or two nucleoli. In two adjoining cells they will be seen near the line of junction, but in the cells on either side of these, they are separated by nearly the length of the two cells. These cells may possess fine branches that pass in between the tendon bundles. The surface cells of many tendons and aponeuroses may form a continuous layer and their irregular outlines may be brought out with silver nitrate.

A few elastic fibers may be found between the larger bundles of tendon fibers. A tendon is very tough and strong and is broken with difficulty. Its strength is greater than a bone of equal diameter.

White fibrous tissue yields gelatin (collagen) upon boiling. The fibers digest in gastric juice and swell when treated with dilute acids. The fibers do not dissolve readily when placed in pancreatin. Picro-fuchsin is a special stain for this variety.

3. Elastic tissue, as its name indicates, has the peculiar property of elasticity. The cellular elements are comparatively few and of the lamellar variety.

The fibers are yellow in color, refractile, and coarser than those of the white variety, averaging from 1 to 15 microns in diameter. It is one of the components of areolar tissue where the fibers branch. In other places it is found in the form of ligaments and in the blood-
vessels it may form a membrane. According to Mall each fiber consists of a delicate sheath surrounding the elastic substance; the latter stains deeply with magenta. In lower animals (quadrupeds) it plays an important part as the ligamentum nuchæ which supports the head. In this ligament the fibers are very heavy and are bound into smaller and larger bundles by white fibrous tissue. In the larger quadrupeds elastic tissue forms an important subcutaneous fascia that assists in supporting the contents of the abdomen.

In man elastic tissue is found in the ligamenta subflava, the cricothyreoid, thyreohyoid and stylohyoid ligaments, in the vocal cords and as longitudinal bands beneath the mucosa of the trachea and its branches. In the blood-vessels it is found as individual fibers or in the form of Henle’s fenestrated membrane.

Elastic tissue is digested by pancreatin and somewhat by pepsin; it is not dissolved by acetic acid. Upon boiling it yields elastin. Special stains are Weigert’s elastica and orcein stains.

White fibrous and yellow elastic tissues are poorly supplied with blood-vessels and nerves but are rich in lymphatics.

The origin of white fibrous and yellow elastic tissues is still unsettled. According to Meves and others the fibers are formed within the cell by the direct conversion of the exoplasm and processes into fibrillae. According to Merkel and others both kinds of fibers are formed in the homogeneous intercellular substance by secretions from the cells and not by the direct change of the cytoplasm. Mall regards the intercellular matrix as exoplasm and the cells and processes as endoplasm. He regards the exoplasm as living substance in which the fibrillae develop.

Recently it has been found that fibrils develop in organizing blood clots, directly from the fibrin without the assistance or intervention of fibroblasts or leukocytes.
4. **Mucous and embryonic connective tissues** are those varieties in which the intercellular substance is semi-fluid. They represent the mesenchyme and the embryonic type may differentiate into the other forms. We will consider these as two distinct forms, the *embryonic tissue* occurring in the fetus and during regeneration of connective tissue and in pathologic neoplasms; the *mucous* is considered a fully developed type of connective tissue occurring in the

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**Fig. 67.— Elastic Fibers. (Lewis and Stöhr.)**

A, Network of thick elastic fibers below, passing into a fenestrated membrane above. From the human endocardium. B, Thick elastic fibers (f) from the ligamentum nuchæ of the ox; b, white fibers. C, Cross-section of the ligamentum nuchæ, lettered as in B.
vitreous humor of the eyeball, the pulp of the teeth and as Wharton's jelly of the umbilical cord.

In the mucous connective tissue the cells are chiefly of the branched lamellar type; in the umbilical cord these cells are numerous but in the vitreous humor they are few in number. The fibers are fairly numerous in the umbilical cord and form layers around the large vessels. In the vitreous humor the fibers are less numerous and tend to form a delicate network. The ground substance is more gelatinous than in the embryonic type and also contains mucin. Mucous connective tissue is devoid of blood-vessels, nerves and lymph channels.

In the pulp of the teeth the fibrils are most numerous. They form a meshwork for the support of the abundant blood-vessels, nerves and lymph channels of the tooth. The cellular elements are greatly modified, those most important being arranged upon the surface of the pulp in a single layer. These are the odontoblasts; they are flask-shaped and from the peripheral surface a number of processes extend into the dentinal tubules. Beneath this layer, toward the center of the pulp is a layer of irregular cells that are supposed to be converted into odontoblasts as these are needed.

5. Embryonic connective tissue is the form found in the fetus and during the growing period. It also occurs during reparation changes and in new growths of a pathologic nature. The cells are chiefly spindle-shaped though round and stellate cells are found. The young cells are usually large and in later stages they at times may exhibit ameboid movements. The fibers are few in number and fine; they form a network in the meshes of which is the predominating semi-solid ground substance.

Modified.—In these varieties of connective tissue, the intercellular substance varies from liquid (blood) to the hard, unyielding material found in bone and dentin.

The cellular elements also differ, as will be seen when each variety is discussed.

6. Adipose tissue, or fat tissue is areolar fibrous tissue, in which the cells have become repositories for fat globules. These cells are quite numerous, but the stellate shape is lost. It represents a storage of nutritious material as well as a protective structure.
The minute globules unite to form a single large drop that distends the delicate cell-membrane. By this coalescence, the cytoplasm and nucleus of the cell are forced to one side, and are seen as a thin band, or crescent. The nucleus may contain vacuoles. Fat is supposed to originate from peculiar ovoid granules in the cytoplasm. 

*Fat cells* are spherical, when not closely packed, as the fat is liquid at the body temperature. After death, *margarin crystals* are seen in the cytoplasm. The cells are collected into groups called *lobules*, and these form large masses called *lobes*. Blood-vessels, nerves and lymphatics are present in considerable number. The first named are especially numerous, as there is a close relation between fat deposition and the vascularity of the part.

According to some writers, *fat cells* are specialized connective cells that exist in no other form. This seems doubtful, however, as experiments have shown that when animals are starved, the *spherical*, fat-containing cells return to the *stellate* form as the fat is removed. When this removal occurs the cytoplasm increases, is peculiar in appearance and does not respond readily to the usual stains. These cells still contain a few droplets of fat and are called *serous fat cells*. From this, it would seem that these cells act merely as storage cells.
When adipose tissue is studied, after ordinary preparation, merely a network of fibers and cell boundaries is seen. These spaces (fat cells) measure from 40 to 80 microns in diameter. This is due to the fact that the fat has been removed by the alcohol leaving the insoluble white fibrous supportive tissue. In such sections, the nucleated crescents of cytoplasm are readily observable. In sections of osmicated fat, the peripheral cells are circular in outline, while the deeper ones are irregular and black, due to the
action of the osmic acid, which is a characteristic reagent for fat. *Sudan III*, also used as a test for fat, stains the globules dark red while *cyanin* stains it blue. These stains must be used on fresh tissue or frozen sections that have not been in contact with alcohol or ether.

Adipose tissue is found widely distributed over the body wherever areolar tissue is found, except in the penis, scrotum, ear, eyelid, lungs and cranial cavity. From the orbit and around the kidneys it never entirely disappears, though death be due to starvation.

According to E. F. Bell the deposition of fat is preceded by the appearance of a peculiar open network in the areolar tissue. This he calls "preadipose tissue." As fat is being deposited a rich capillary plexus develops.

According to some investigators the formation of fat is due to certain ovoid granular cells that are always seen in the areas of fat deposition. It has also been shown that fat cells can be formed by endothelial cells enclosing free globules of fat.

The first appearance of fat is in the form of very fine granules that are derived from the mitochondria through segmentation. These segments pass through the nuclear membrane in the form of spherical granules, elongate and segment into secondary granules. These granules then liquefy and coalesce into fat droplets.

7. **Lymphoid** tissue is a special form of the connective variety consisting of a network of reticular areolar tissue, in the meshes of which are found *leukocytes*, or *white blood-cells*.

These cells are usually the *small lymphocytes*, although varying numbers of the *large lymphocytes* (hyalin cells) and *polynuclear cells* are to be seen. For a description of these cells, see *Blood*.

For readiness of comprehension, **lymphoid** tissue is divided into the following forms: *(a)* **Diffuse**; *(b)* **Nodule**; *(c)* **Lymphatic Organs**. The latter form comprises **lymph nodes**, the **spleen**, the **tonsil** and the **thymus body**.

*(a)* **Diffuse lymphoid** tissue is an indefinite collection of leukocytes in a structure. The cells are not especially arranged, neither is there a special supportive tissue present, as in the next two varieties. The cells may be so numerous as to hide entirely the tunica propria of the structure or the reticulum of the organ.
It is found in the tunica propria of the alimentary, respiratory and urinogenital tracts, and the cells are merely scattered between the bundles of white fibrous tissue. It forms the medulla of the thymus body, and the bulk of the tonsil and spleen, and is transient in character.

Fig. 71.—Section of the Mucosa of the Jejunum of the Cat.

(a) Simple columnar and goblet cell layer separated from the core of the villus b; the latter is filled with diffuse lymphoid tissue. c, Simple tubular glands with the intervening tunica propria filled with diffuse lymphoid tissue. (Photograph Obj. 16 mm., oc. 7.5 X.)

(b) Nodules are small, dense collections of lymphocytes. The supportive tissue is said to be reticulum, the meshes of which are larger in the germinal center than at the periphery. Bloodvessels are inconspicuous; although the outline may be slightly irregular, it is sharp. Each nodule usually shows a lighter center in which the cells are fewer and younger. This is called the germinal center, and here the new cells are formed by karyokinetic division.
As the new cells are formed the excess cells are crowded to the periphery of the nodule, forming there a denser mass giving this area a darker appearance.

1. **Solitary nodules** are individual, discreet groups of leukocytes (chiefly lymphocytes) forming a round or ovoid mass. The outline is usually quite sharp and fairly regular; a germinal center is usually present. This is the commonest type of nodule and is widely distributed, as in the alimentary and respiratory tracts and tonsil.

![Fig. 72.—Splenic Nodule of the Spleen of a Monkey.](image)

2. **Secondary nodules** are modified nodules that are found in the lymph nodes. In a well marked node these form the cortex, but instead of each nodule being a discrete and individual mass of lymphocytes the medullary surface of each nodule extends into the medulla of the lymph node in a cord-like manner, forming the medullary cords of a lymph node.

3. **Splenic nodules** are ordinary solitary nodules in general appearance and structure, with the exception that each nodule usually shows
a distinct, eccentrically placed arteriole. Such occur only in the spleen.

4. **Lenticular nodules** are solitary nodules that are somewhat flattened and shaped like a biconvex lens. These are found only in the mucosa of the stomach and are said to be more numerous in the pyloric than in the fundal or cardiac parts.

5. **A Peyer's patch** or *agminated nodule* is a more or less regular collection of solitary nodules sharply outlined from the surrounding tissue and 1 to 5 cm. long. Each patch consists of ten to sixty solitary nodules, each of which usually shows a *germinal center*. Most patches really consist of a hundred or more nodules.

Each nodule may be partially or completely surrounded by a thin capsule of white fibrous tissue, although usually the nodules merge more or less into one another. They are located in the submucosa of the ileum opposite to the attachment of the mesentery. Some state that they are also found in the jejunum. The long axis is directed parallel to the long axis of the bowel. They are visible to the unaided eye. Although they are said to be limited to the submucosa, more commonly they are seen invading the mucosa, having broken through the muscularis mucosae. Usually in those areas, where the nodules approach the epithelial surface, the glands are absent. At the edge of the nodules the glands are seen arranged in the form of a circle. Often the villi over such an area are likewise absent.

(c) **Lymphatic organs** comprise **lymph nodes**, the **spleen**, the **tonsil** and the **thymus body**. As these are closely related to the **lymphatic system**, their structure will be considered there.
8. **Cartilage** is a firm substance that is elastic, yields to pressure and is readily cut with a sharp knife. It is characterized by the presence of a solid intercellular substance and the cells differ materially from those of the preceding varieties of connective tissue. **Three varieties** are found in man: **hyaline**, **white fibrocartilage** and **yellow elastic**. The general structure will first be considered under **perichondrium, cells and intercellular substance**.

The **perichondrium** is a fibrous sheath that surrounds cartilage and gives rise to its cellular elements. It is composed of white fibrous tissue, and is divided, functionally, into two parts. This division is not apparent under the microscope, as the layers merge into each other. The **outer** part is the **fibrous** layer, and contains few cells. The **inner portion**, or **chondrogenetic layer**, is rich in cells that are not of the stellate type, but flattened and elongated, or spindle-shaped. These are the **chondroblasts**, which become cartilage cells. Some blood-vessels also are present. Bundles of fibers from the perichondrium pass into the matrix.

The **cartilage cells**, or **chondroblasts**, vary in the different portions of the cartilage. Just beneath the perichondrium, they are flat and thin, indicating an early stage. Toward the center, they gradually become broader until, finally, they are oval or round in form. Each cell is rich in cytoplasm, which contains one or more vacuoles, often glycogen and occasionally fat droplets. The nucleus is spheroidal, appears granular and may contain one or
more nucleoli. Each cell lies in a cavity of the matrix and usually fills this. There may be a space (lacuna) due to shrinkage of the cell. The boundary of the cavity is the capsule; this resembles the matrix and is firmly attached to it. Sometimes the capsule stains more deeply than the matrix. The capsule is a product of secretion of the cell and represents the exoplasm and is a cell wall. It is cast off, as a rule, each time the cell divides. Each cell may be individual or several may occupy one cavity. This is due to the fact that each new cell did not form a capsule for itself after division. The opposed sides of these cells are flattened by pressure of one against the other.

The intercellular substance varies. In the hyalin variety it is apparently homogeneous; white fibrocartilage is composed mainly of

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**Fig. 75.—Sections of Cartilage.**

A.—Hyalin Cartilage. *a*, Fibrous layer of perichondrium; *b*, genetic layer of perichondrium; *c*, youngest chondroblasts; *d*, older chondroblasts; *e*, capsule; *f*, cells; *g*, lacuna. B.—Elastic Cartilage. C.—White Fibrocartilage.
white fibrous tissue; in yellow fibrocartilage it is composed of yellow elastic fibers.

**Hyalin Cartilage.**—In this variety the *cellular elements* are as above. They are quite numerous and close together just beneath the perichondrium. Farther in they are larger and more widely separated and several may be found within one capsule.

The *intercellular substance*, or *matrix*, is apparently homogeneous.

![Fig. 76.—A Vertical Section of Articular Cartilage.](image)

_Fig. 76._—A _Vertical Section of Articular Cartilage._

_a_, Bone; _b_, calcified cartilage; _c_, perpendicular groups; _d_, irregular groups; _e_, horizontal groups, parallel to the surface. (After Schäfer.)

Upon careful study, however, and often without treatment with special reagents, it shows a fibrillar character; in this fibrillar meshwork is seen the ground substance, which is homogeneous. This fibrillar structure is especially noticeable in young cartilages. The ground substance is formed by the fusion of the castoff capsules and usually responds to mucin stains.

**Articular Cartilages.**—In these the cells are smaller and arranged in short rows. At the free surface of the cartilage the rows are parallel to the surface of the bone. The rows of deeper cells
gradually alter their direction until those next to the bone are perpendicular to the bony surface. No perichondrium covers the free surface of the articular cartilage. The matrix is granular and after maceration, under pressure it separates into fibrils that run vertical to the surface.

At the margins of the articular cartilages connective tissue fibers pass from the periosteum or synovial membrane into the cartilage matrix and there is a gradual transition from cartilage to stellate connective tissue cells.

Hyalin cartilage is found covering articular surfaces of bones, as the costal, nasal, tracheal and most of the laryngeal cartilages. It precedes, with a few exceptions, all the bones of the body, and may ossify in old age.

**White fibrocartilage** consists of islands of the *hyalin* variety, separated by an *intercellular substance* made up of delicate, wavy bundles of white fibrous tissue that have a parallel course. The amount of hyalin matrix varies in these cartilages. In the *intervertebral discs* the cartilage cells are more numerous toward the central pulp. In the *symphysial cartilages* the cells are more numerous at the surface attached to the bone.

This variety is not very abundant but is widely scattered. It is found as *marginal cartilages* (deeping joint cavities); as the *intervertebral discs*; as *intra-articular cartilages*; *lining grooves in bone* where tendons move and occasionally as *sesamoid fibrocartilages* in tendons.

**Yellow-fibro- or elastic cartilage** is that variety in which the intercellular substance is composed of *elastic fibers*. The elastic tissue forms a meshwork in which the hyalin islands are found.

It is practically *hyalin* cartilage in which the hyalin matrix has been replaced by *elastic tissue*. The cartilage cells are found in small groups, surrounded by only a small amount of the hyalin substance. This variety rarely ossifies or calcifies, and is to be looked for in regions where elasticity is required, as in the epiglottis, ear, Eustachian (auditory) tube and small laryngeal cartilages.

Cartilage contains few or no *blood-vessels*, except in the perichondrium, and during the developing stage. *Lymph channels* are said to be absent, so that its nutrition is not of a very high order.
Upon heating cartilage to 120°C. in a hermetically sealed tube *chondrin* is obtained. This will not dissolve in either alcohol or cold water. It is precipitated by acetic acid, insoluble in an excess of this but soluble in some mineral acids.

When cartilage begins to develop the polygonal cells of the mesenchyme become clearer and the nucleus more distinct. The tissue immediately surrounding the cells also becomes clear and constitutes the cohering capsules of the adjacent cells and represents the matrix. If the matrix remains in this condition permanently it is called *parenchymatous*. Glycogen appears early in the cytoplasm of these cells. This is followed by the rapid increase in size and multiplication of the cells with an attendant increase in the matrix. As the cells reproduce the old capsules are cast off and blend with the matrix of which they soon become an indistinguishable part. In each succeeding division more cells are formed, more capsules are cast off and the matrix thus becomes increased in quantity. As a result of the latter condition the cells become more widely separated. According to Kölliker the capsule is secreted by the cell, but according to M. Schultze it represents the superficial cytoplasm (exoplasm) of the cell.

In elastic cartilage the matrix is at first entirely hyalin. Gradually fine, albuminoid granules appear in the matrix close to the cells and gradually extend outward toward the perichondrium. From these granules the elastic fibers are derived. The fibers of the white fibrocartilage are said to appear at the same time as the matrix but in what manner is not exactly known.

Cartilage regenerates. When a cartilage is cut the wound is healed by white fibrous tissue. Later this is gradually transformed into cartilage. Costal cartilages, when fractured, heal by a fibrous connection often. This is usually very dense at its circumference and ossification may later occur in this dense tissue.

9. **Bone** is the most highly differentiated of the connective tissues. It is characterized by the presence of a very hard, unyielding intercellular substance that has a characteristic arrangement.

**Bone** is composed of *inorganic* (66 per cent.) and *organic salts* (34 per cent.); the *former* are soluble in mineral acids, by which they may be removed and the tissue cut. The *latter* are removed by burn-
ing, after which process the inorganic substance remains as a porous mold of the bone. The earthy material gives hardness and rigidity, while the animal material gives tenacity and elasticity. The organic material consists of collagen, osseomucoid and small quantities of other albumenoid substances.

The percentage of organic and inorganic substance in compact bone previously given are those generally mentioned in Anatomies and Histologies. In a recent series of determinations the author has found these percentages to be incorrect. Four different methods were employed in order to see if the previously accepted percentages were correct; in none of these experiments were the previous results obtained. The bones of individuals of various ages (20 to 90 years) were used with the following results:

<table>
<thead>
<tr>
<th>Method</th>
<th>Age Range</th>
<th>Organic Substance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green bone</td>
<td>20-60 yrs</td>
<td>40.75</td>
</tr>
<tr>
<td></td>
<td>61-90 yrs</td>
<td>42.32</td>
</tr>
<tr>
<td>Oven dried bone</td>
<td>20-60 yrs</td>
<td>37.15</td>
</tr>
<tr>
<td></td>
<td>61-90 yrs</td>
<td>36.22</td>
</tr>
<tr>
<td>Alcohol extracted bone</td>
<td>20-60 yrs</td>
<td>35.07</td>
</tr>
<tr>
<td></td>
<td>61-90 yrs</td>
<td>36.22</td>
</tr>
<tr>
<td>Ether extracted bone</td>
<td>20-60 yrs</td>
<td>36.72</td>
</tr>
<tr>
<td></td>
<td>61-90 yrs</td>
<td>37.00</td>
</tr>
</tbody>
</table>

The determinations obtained from green bone are the ones that should be accepted, so the author believes. As noted the results run from 7 to 9 per cent. over the usually accepted amount. Another fact hitherto not mentioned is that in old age the organic substance increases in quantity. The brittleness of the bones in the elderly cannot, therefore, be due to a reduction of the organic material but is apparently due to a reduction in thickness and an increase in porosity of the bones.

Bones, like cartilage, are surrounded by a fibrous sheath, the periosteum, beneath which is the bone substance proper; the latter consists of cells and intercellular substance.

The periosteum of young bones consists of three layers, fibrous, fibroelastic and osteogenetic. It constitutes a membrane that limits and controls the osteoblast to which it has given origin but does not make bone tissue. That is done by the osteoblasts.
The *fibrous layer* is composed of coarse bundles of white fibrous tissue that serve to connect the periosteum to the surrounding tissues. The *fibroelastic layer* consists of more delicate bundles of white fibrous and especially elastic tissues.

The *inner, or genetic*, layer is rich in cells and capillaries and contains only sufficient white fibrous tissue to support these. These cells are the *future osteoblasts* that secrete the osseous tissue. From its inner surface, it sends in bundles of fibers that pierce the layers of bone at right angles, and bind them together. These are *Sharpey's fibers*. Some of these are derived from the tendons inserted into the periosteum. In addition there are the *lamellar fibers*. These are delicate bundles of white fibrous connective tissue that pass through the various lamellae some at right angles and others obliquely. Some of the fibers are elastic. In the adult, after growth ceases, the vessels in the innermost layer of the periosteum are reduced in number and the osteoblasts are only sufficient in number for the purpose of regeneration of the bone. The fibroelastic layer becomes correspondingly thicker.

The periosteum not only gives rise to the osteoblasts but also serves for the support of blood-vessels, nerves and lymph channels and for the attachment of muscles, tendons and ligaments.

The *cells* are all of the irregular stellate type, and consist of flattened bodies and short processes that extend into small canals, to be described later. The cytoplasm is not very abundant, and the nuclei are oval, and often vesicular. No doubt but that the osteoblasts assist in the nutrition of the bone by modifying the nutritive elements derived from the blood and distributing it to the osseous tissue through the lacunae and canaliculi. These latter structures represent the cell spaces of the ordinary connective tissues. The osteoblasts are homologous to the lamellar cells of areolar tissue.

The *intercellular substance* is hard and resistant but elastic. It consists of osseous material that is secreted by the cells, and is
peculiarly arranged in the compact variety. It contains spaces, or lacunae, from which extend minute canals, or canaliculi. Beside these, there are a great number of canals that vary in length and diameter. These are the Haversian canals.

There are two varieties—cancellous, or spongy, and compact, or solid.

Cancellous bone consists of spicules and lamellae forming a network resembling a sponge, or lattice. The lamellae run in the direction of the greatest strain. The spicules have a lamellar structure and contain delicate Haversian canals surrounded by a few thin, con-

Fig. 78.—Lamellæ Stripped from a Decalcified Parietal Bone. (Sharpey.)

a, a, Lamellae exhibiting decussating fibers with openings for the perforating fibers. b, b, Stripped lamellae with the perforating fibers c, c.

centric lamellæ; in addition there are little spaces called lacunæ. In the living, or recent condition these spaces are occupied by osteoblasts, the bone-forming cells.

This variety is found at the extremities of the medullary cavity and in the extremities of the long bones, and forming the central portion of the flat, irregular and short bones. The meshes of the network are covered by the endosteum and are filled with marrow.

Compact bone has a characteristic structure. The osseous matter is arranged in layers, or lamellæ, between which lie the lacunæ.
CONNECTIVE TISSUES

Fig. 79.—A Section of Cancellous Bone Showing the Marrow Reticulum and Adipose Tissue between the Bony Spicules. (Photograph Obj. 16 mm., oc. 5 x.)

Fig. 80.—Cross-section of Human Compact Bone.

a, Periosteum; b, peripheral lamellae; c, Haversian canals; d, lacunae; e, interstitial lamellæ; f, perimedullary lamellæ; g, marrow; h, Haversian lamellæ. (Stöhr's Histology.)
There are four varieties of lamellae: (a) periosteal, peripheral, or circumferential; (b) Haversian, or concentric; (c) intermediate, ground, or irregular; and (d) perimedullary, or internal.

Although these lamellae differ in size and arrangement the structure of all is the same. Each consists of an interlacement of bundles of fine fibrils of the white fibrous type. In the meshes of this is the real osseous substance; in the usual preparations this osseous tissue predominates and so hides the fibrillar material. While in several neighboring lamellae the fiber bundles of the meshwork may have the same general direction, in other lamellae the direction may be opposite. In addition to these fiber bundles other small bundles join the various lamellae together, constituting a perforating type. These lamellae are pierced by the canaliculi and some are pierced by the large perforating fibers of Sharpey and by Volkmann's canals.

(a) The peripheral, periosteal, or external lamellae are those formed directly by the periosteum. The layers are few in number, and no one layer makes a complete circumference of the bone but is composed of several segments. Between them are a number of irregular
spaces, lacunae, from which little canals extend, the canaliculi. The external layer has a number of small depressions called Howship's foveae or lacunae. These are occupied by large bone-destroying cells called osteoclasts. Haversian canals are not present, but larger canals, containing blood-vessels from the periosteum, are seen. These are Volkmann's canals, and they communicate with the Haversian canals farther in.

Fig. 82.—Longitudinal Section of Compact Bone (Ground) Showing Branching Haversian Canals. The irregular dark spots are the lacunæ. (Photograph Obj. 16 mm., oc. 7.5 X.)

(b) The Haversian lamellæ, which are probably the most numerous, are thin, cylindric layers concentrically arranged around a small central canal called the Haversian canal. These layers are separated in places by the lacunæ, and pierced by the canaliculi. The lamellæ of a system are parallel to one another, but the different systems usually run at various angles.

An Haversian system consists of the lamellæ, canal, lacunæ and canaliculi.

The Haversian canals are occupied by blood-vessels, nerves and lymphatics. Those nearest the marrow cavity are the largest, contain marrow and communicate with the marrow cavity. The
short canals are generally parallel to the long axis of the bone, anastomose freely with one another and measure 25μ to 125μ in diameter. There may be from 4 to 20 lamellae to each Haversian system.

(c) The intermediate, interstitial, or irregular lamellae lie between the Haversian systems, and are irregular in size and form. They are the remains of Haversian and periosteal lamellae, altered by the growth of the bone in diameter. No canals are found here, but lacunae and canaliculi are present between the lamellae.

(d) The perimedullary, or internal, lamellae are not very regular, and are found surrounding the medullary, or marrow cavity. The lacunae are small, flat, irregular spaces found between the various lamellae throughout the bone, and occupy a portion of each of the adjacent lamellae, and do not lie in one alone. Each space measures from 13μ to 31μ in length, 6μ to 14μ in width and 4μ to 9μ in depth. The walls of the lacunae and canaliculi are more resistant to acids than the remainder of the osseous tissue. These spaces are said to be lined by a delicate membrane and they contain the osteoblasts.

Extending in all directions, are small canals, or canaliculi (1 to 2 microns in diameter), that communicate with those of other lacunae, so that a series of intercommunicating spaces results. Those lacunae lying nearest the Haversian canals, communicate with them, but the peripheral ones of a system do not communicate, to any great extent, with those of the interstitial lacunae. The canaliculi serve as supports for the processes of the osteoblasts.

The compact portions of the extremities of bones contain no Haversian systems and no large lacunae so that pressure can more readily be borne. Vessels do not enter the bone here.

The flat, short and irregular bones consist of a thin shell of compact bone covering a mass of cancellous bone that constitutes the bulk of these bones. Where the bones are thin, or have small processes, no cancellous bone is present.

The medullary cavity, which contains the nutrient marrow, is a large space, in the shafts of the long bones; it is lined by the endosteum which is analogous in structure and function to the periosteum; it also constitutes a covering for the marrow.
The **marrow** is of two varieties, *red* and *yellow*. The *red* marrow is found in the marrow cavities and in the cancellous bone of the extremities of the long bones and in the cancellous tissue of the flat and irregular bones, in *young persons*; in *adults* the marrow in the marrow cavities of the long bones becomes yellow. The marrow in the extremities of the long bones and in the flat and irregular bones (in adults) remains red throughout life. It is here that red blood cells are being constantly renewed and if there were no red marrow in the adult there would be no replacement of red blood cells. The difference is due to the presence of a great deal of fat in the yellow marrow, whereby the color becomes changed. It is not a blood-making tissue as the cellular elements are few or may be entirely wanting. In disease, however, it may again become red.
The **red marrow** consists of (1) a delicate network of reticulum, derived from the endosteum, supporting (2) a dense vascular capillary plexus, (3) nerves and (4) lymphatics and a number of different cells. These cells are (1) myelocytes, or marrow cells; (2) nucleated red blood cells, or erythroblasts; (3) erythrocytes; (4) white blood cells, or leukocytes; (5) myeloplaxes; (6) osteoclasts; (7) osteoblasts; (8) fat. The red bone marrow is the most important red cell-forming tissue in the body throughout life.

1. The **myelocytes** are large nucleated masses of granular cytoplasm that resemble the leukocytes of the blood. The *granules* of the cytoplasm are in some of these cells fine and neutrophilic or acidophilic in reaction; in other cells they are coarse and basophilic in reaction. The *nucleus* is usually large, oval and lobulated and the chromatin small in quantity. Some of these cells are *ameboid* and *phagocytic*; the latter contain reddish-brown pigment granules that are probably converted hemoglobin. Some consider these cells as derivatives of the blood lymphocytes and others maintain that they are the ancestors of the oxyphils and basophils of the blood.

2. The **erythroblasts** differ from the erythrocytes in that each contains a nucleus and this may show mitotic figures. These cells vary somewhat in size but are seldom over 9.5μ in diameter. By the loss of the nucleus these cells become the erythrocytes, or normal red blood cells.

Two varieties are described: The *erythroblasts* that possess a nucleus rich in chromatin network and poor in hemoglobin. These cells gradually change to the *normoblasts* in which the nucleus shows no chromatic network and the cytoplasm is rich in hemoglobin.

Some classify all of the nucleated red cells as *erythrocytes* of which the *megaloblast* is the original cell, the *normoblasts* and *erythroblasts* modifications, which by the loss of the nucleus become the normal red cells or *erythroplastids* as they call them.

3. **Erythrocytes** (*erythroplastids*) are the preceding cells that have lost their nuclei and are ready to enter the blood-stream. The manner in which the nucleus is lost is still questionable. Some state that the entire or fragmented nucleus is extruded (*karyorrhexis*); others believe that the nucleus is absorbed (*karyolysis*); Emmel has found that the red cell of the pig is formed by *budding*.
4. The leukocytes are of different varieties of which the first three varieties below given are the most numerous.

(a) The finely granular oxyphil (polymorphonuclear neutrophil) is 7.5 to 10μ in diameter. There are several stages of these cells, the younger showing a centrosome and nuclei that contain only a little chromatin and fewer modifications of shape and the older ones that have a dense chromatic network and more varieties of nuclear shapes. The younger cells are said to be capable of cell division to a slight extent and the older ones not at all.

(b) Eosinophils are of the same size as the preceding. They differ from these, however, as the granules in the cytoplasm are much larger in size but fewer in number and strongly acidophilic in reaction. The younger cells contain a centrosome and are capable of division but the older ones are not.

The oxyphil and neutrophil granules are probably intracellular in origin. They seem to arise from the chromidia extruded from the nucleus and so are originally basophilic in reaction; by chemical changes within the cytoplasm they change their character. Weidenreich believes that these granules represent hemoglobin from the disintegrating red cells as the latter are numerous in the marrow and spleen.

(c) Basophils (mast cells) are believed to be formed in the red marrow. The nucleus varies in shape and the cytoplasm contains a number of large, coarse, basophilic granules. They are also found in areolar tissue where they probably end their existence. Some claim that these cells are normally found in the blood-stream but this is doubtful. In certain diseases, however, they increase in number in the marrow and spleen and are also found in the blood under those conditions.

(d) The lymphocytes are the smallest of the leukocytes, measuring from 5μ to 7.5μ in diameter. The cytoplasm is small in quantity, does not stain deeply and may be basophilic in reaction. The nucleus is large and nearly spherical in form and the chromatin stains readily. These cells are not numerous and while some are developed here most of this type are formed in the lymphoid structures and organs.

(e) The hyalin cells (large lymphocytes) are the largest leukocytes measuring from 11μ to 15μ in diameter. They are said to be derived
from the lymphocytes which they resemble. The nucleus, however, does not respond so well to stains so that the whole cell has an hyalin appearance, hence the name.

A more detailed description of these leukocytes will be found under Blood.

5. Osteoclasts are very large spheroidal, or flattened cells. Their outline is regular and the granular cytoplasm contains two to ten or more clear round nuclei. These cells are numerous in developing and regenerating bone. The side of the cell attached to the bone is often striated. They are also found in connection with the roots of the milk teeth. They are of great importance in bone destruction from which the name osteoclast is derived. They are capable of ameboid movements and are phagocytic.

6. Myeloplaxes, or megakaryocytes are also giant cells 30μ to 100μ in diameter. The cytoplasm is granular and the large single nucleus is usually horseshoe-shaped or annular. It contains a large number of nucleoli and a number of centrioles. It is ameboid but not phagocytic. The blood platelets are said to be derived from their segmented pseudopodia.

7. Osteoblasts occur at the periphery of the marrow along the endosteum.

8. Platelets.

9. Adipose tissue is seen in red marrow. During adolescence it gradually increases in the marrow cavities of the long bones and so replaces the bulk of the red marrow, forming the yellow marrow. As the cellular elements in this are very few it is no longer an hematopoietic structure.

The blood-vessels of bone are very numerous. In the flat, irregular and short bones many vessels penetrate the superficial compact bone and enter the spongy parts branching into many channels that supply the marrow and osseous tissue. Another set of vessels in the periosteum supplies the superficial compact bone and the underlying spongy bone. In the long bones the superficial portions are supplied by the periosteal vessels. These penetrate the outer compact bone, through Volkmann's canals, and branches pass in to the Haversian canals. At the extremities these periosteal vessels send branches into the superficial portion of the spongy bone.
**Fig. 84.—Osteoclasts.**

A, Ordinary osteoclast.  
B, one showing a striated border.  
C, a bone trabecula from the mandible of a calf embryo with the osteoblasts at the ends causing absorption and osteoblasts covering the sides and depositing bone. (After Kölliker.)

**Fig. 85.—Giant Cell of Bone Marrow Showing Multiple Centrioles at f.**

a, b, c, d represent the different zones of cytoplasm; e, nucleus. (After M. Heidenhain.)
also. The marrow and the deeper parts of the bone are supplied by
what is commonly called the nutrient vessel. This is usually one
large trunk that enters at the nutrient canal of the diaphysis,
passes to the marrow and forms here branches that proceed toward
each extremity. These latter branches give rise to vessels that
supply the marrow, the compact bone and the cancellous bone.
The branches of the two systems anastomose freely. The veins
start in wide venous capillaries that empty into large venous channels
that, in cancellous bone run in bony canals separate from those of
the arteries. These veins are thin-walled, possess no media and are
valveless. They issue from the bones through numerous large
openings. The circulation in the red marrow of mammals is believed
to be an open one. The walls of the venous capillaries are supposed
to be incomplete permitting the passing of the cellular elements of
the marrow into the blood-stream. This seems doubtful for in this
case there would be nothing to prevent the abnormal constituents,
as myelocyte, myeloplasces, osteoclasts, etc., from entering the blood-
stream. The blood coming from the marrow contains more than
the usual number of leukocytes.

Lymphatics occur in the periosteum and in the Haversian canals
in which they may entirely surround the blood-vessels. The lymph
passes into the denser parts through the lacunae and canaliculi.
The nerves accompany the arteries which they supply. Whether
or not any come into relation with the bone cells is not known. In
the periosteum nerves supply the blood-vessels and also sensor
organs, Pacinian bodies, are found.

Development of Bone.—Bone is not a primary, but a secondary
tissue. It is preceded by cartilage or by fibrous tissue. Bone
developed from hyalin cartilage is called endochondral, while that
developed in fibrous tissue is referred to as intramembraneous bone.
The area where bone-formation begins is called the center of
ossification.

Endochondral bone-formation is the process by which the hyalin
cartilage is replaced by spongy bone. It is, in reality, a com-
bined process, for so soon as the spongy bone is formed, this is
changed to the compact variety by the intramembranous, or periosteal
method.
When **ossification** begins, the cartilage cells in that vicinity begin to multiply rapidly, increasing in size at the expense of the matrix, which shows evidence of calcareous deposits above and below this area; the other cells arrange themselves in rows parallel with the long axis of the bone. This grouping of the cells is probably due to the course of the lymph stream and the pressure exerted by the groups upon one another. Multiplication is most rapid in the center of the area, and, as a result, the new cells are unable to form new capsules for themselves; in consequence, a large number are seen in one space called a **primary areola**, or **marrow space**. The cells then become vesicular and shrunken, do not respond readily to stains and show signs of degeneration. In the cartilage between these spaces, calcareous material is deposited, and the cells above and below arrange themselves into parallel rows. The cells within the areolæ either **disappear** or become **osteoblasts**, and **osteoclasts** (Stöhr and others believe that all disappear). The latter, 45 to 90 microns long and 30 to 40 microns wide, dissolve the cartilaginous and calcareous partitions between the spaces. As a result of the latter, larger spaces are formed, and these are the **secondary areolæ**. The **osteoblasts**, lay down a thin layer of osseous tissue upon the remaining partitions, so that, at first, these consist of a

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**Fig. 86.—Section of Developing Bone from a Fetus.**

* A, Cartilage cells in rows; P, periosteum slightly separated from the bone; P', perichondrium. (Photograph Obj. 32 mm. oc. 7.5. X.)
core of calcific material covered by a thin veneer of true bone. As the process continues, the calcareous matter is entirely removed and is replaced by bone.

While these changes have been in progress, the perichondrium has become the periosteum, which now forms osteoblasts. These, with trabeculae of the periosteum and blood-vessels, pass inward toward the center of ossification, and enter the areolae. This vascularization forms the first marrow. The blood-vessels pass upward and downward from the center, following the process of calcification. Gradually, the delicate rod of cartilage is converted into a rod of spongy bone. The articular portions are separated from the shaft by an interposed disc, the epiphyseal cartilage.

Periosteal bone formation now begins. Upon the inner surface of the periosteum a thin layer of osseous tissue is deposited by the osteoblasts, and these osteoblasts remain surrounded by a small space that is continued along its processes. This space and its continuations are the lacunae and canaliculi.

With the formation of periosteal bone, the various lamellae are formed. The peripheral are deposited beneath the periosteum. The Haversian system and lamellae are formed in the following manner. From the inner surface of the periosteal layer, projections are formed at various angles. These meet other projections, thereby enclosing a small space, the primitive Haversian canal. Osteoclasts gain access and make this space regular and larger. Then osteoblasts lay down layer upon layer of osseous material until only a small channel, the Haversian canal, is left. The remains of the peripheral lamellae between the various systems go to make up the interstitial lamellae.

With the formation of the peripheral lamellae, the network of spongy bone is removed from the center by osteoclasts. This leads to the formation of a marrow cavity. As the bone increases in size, the cavity increases in proportion, by the destruction of the surrounding bone. During the prime of life, bone formation exceeds cavity formation, but in old age, the reverse is the case, so that the shaft becomes thinner, and the cavity larger.

Ossification of the epiphyses occurs much later. The blood-vessels from the diaphysis invade the epiphysial cartilage. Ossi-
fication begins as in the diaphysis but the extremity expands by the maintenance of a layer of cartilage around the periphery. The cartilage is replaced by cancellous bone that persists. As long as the bone continues to grow the cartilage layer is maintained and is permanent upon the articular surface. Between each epiphysis and the diaphysis a pad of cartilage, the epiphysial cartilage, is maintained until full growth is attained. Then ossifica-
tion of these discs unites these parts completely. Apophyses are formed in the same manner.

The bone increases in diameter by the continued addition of peripheral lamellæ, as a tree grows in thickness. It grows in length by the interposition of a disc of cartilage between the shaft and heads of the bone. The perichondrium of this disc is thicker than the periosteum of diaphysis and epiphysis producing thus a groove about the bone at the site of the disc. This is the ossification groove. In this disc, new cartilage is formed by its perichondrium as rapidly as ossification occurs. This is the cambium layer, and should it ossify, that end of the bone would no longer increase in length. This change occurs normally when full height is reached.

In man, between the first and fifth years, the long bones grow chiefly in length. The rate of growth of the two extremities of a bone is not the same, some growing more rapidly at the proximal extremity and others at the distal extremity. As the bone increases in length and thickness absorption is also taking place as pointed out above. This is carried on by the osteoclasts. When these appear and apply themselves to the bone the surface with which they are in contact seems to melt away and a lacuna is formed. As this process continues the bone gradually disappears. This solvent action is probably due to a secretion from the osteoclast.

This method of bone formation occurs in all bones except those of the face and of the vault of the cranium.

Intramembranous bone formation is the process whereby osseous tissue is formed within white fibrous tissue without the intervention of cartilage. At the center of ossification the mesodermal cells become enlarged, increased in number and form a sort of a membrane from which fibers radiate in all directions. These are delicate collagenous fibrils called, by Sharpey, osteogenetic fibers. Upon these calcareous material and later osseous tissue are deposited by the enclosed mesenchymal cells that have become osteoblasts. In this way the bony spicules of the developing structure are formed. The osteogenetic fibers spread in all directions and almost as rapidly are covered and replaced by calcareous material and osseous tissues. As these spicules anastomose freely with one another spongy bone is produced. Some of the cells form an inner and an outer layer con-
STITUTING the periosteum (i.e., skull bones); other cells become much enlarged and secrete osseous tissue and are the osteoblasts. The periosteums now form periosteal lamellæ as in the shafts of long bones. As the bone increases in thickness the periosteal lamellæ in the center are removed and replaced by the spongy bone or are converted into this by the action of the osteoclasts.

Fig. 88.—Section of the Parietal Bone of a Fetus. Development of intra-membraneous bone. a, a, external and internal layers of the periosteum. (Photograph Obj. 16 mm., oc. 5 X.)

As the bone becomes vascularized the mesenchymal tissue enclosed within the bony meshes constitutes the primitive marrow. This consists of marrow cells, osteoblasts and a great number of osteoclasts. By the action of the latter, assisted by the osteoblasts, the internal portion of the bone is being constantly altered during the growth period. Upon the bony spicules the mesenchyme forms a thin membrane upon which is seen a layer or two of osteoblasts. This is the primitive endosteum.

Such bones increase, in thickness, as above, and laterally by the maintenance of a layer of fibrous tissue at their edges. This is the cambium layer that corresponds to the epiphyseal disc of long bones, and when full growth is attained this layer ossifies and the sutures of the skull result.
Bone readily *regenerates*, providing the periosteum is present. If a bone be broken a clot forms in the marrow cavity between the ends of the fragments and beneath the periosteum. The latter is rarely torn through completely, there usually being a bridge between the ends of the fragments of bone. The clot becomes organized through the proliferation of the various cells, especially endothelial cells, and fibroblasts are formed. This fibrous mass is invaded by osteoblasts from the marrow and deeper parts of the periosteum and these also proliferate. This fibroblastic mass becomes vascularized and constitutes *granulation tissue*. Then bone may be directly formed or a moderate amount of cartilage may first be formed. This represents *callus* and that portion in relation with the periosteum is likely to show cartilage development but the remainder usually becomes directly ossified. An absence of the osteoblasts leaves the callus fibrous, or cartilaginous. This may be the permanent result and this is due to the weak activity of the osteoblasts. When this fibrous mass holding the fragments of bone together becomes ossified then bony union is completed.

We might state that during the first week after the fracture there is the formation of a clot and organization thereof; during the second week this becomes greatly strengthened by dense fibrous tissue in and beneath the periosteum. During the third week ossification begins at points farthest from the ends of the fragments and usually by the sixth week ossification between the fragments is complete. This intervening new bone is a spindle-shaped mass and is spongy in nature.

The name *callus* is applied successively to the fibroblastic tissue, the granulation tissue, the fibrous tissue and the resultant bone. That portion in the marrow cavity is the *central callus*; that surrounding the bone beyond the general level of the old surface is the *ensheathing callus*. These two types constitute the *temporary callus*. The central callus may later be removed thus restoring the marrow cavity. It requires about a year to remove the temporary callus.

10. *Dentin* will be considered under the *teeth*.

11. *Blood* is the *only liquid connective tissue*. As it is part of the *circulatory system*, it will be considered when that is described.
CHAPTER V

MUSCLE TISSUES

Muscle tissue is a special tissue that produces the various movements of the body or organs whether under the control of the will or not. It consists chiefly of cellular elements in the form of fibers of varying shapes and lengths. Intercellular substance, or cement is absent. The muscles are all derived from the mesoderm with the exception of those of the sweat glands and iris. In lower animals they may be also of ectodermal and entodermal origin. Myoplasm, as yet undifferentiated into muscle fibers, is contractile as shown in the developing heart. As the primitive muscle cells, or myoblasts, are formed contractile myofibrils appear in them. Muscle cells, like nerve cells, are peculiar in that they do not reproduce after they reach their adult stage of development.

Muscle tissue constitutes the flesh of animals and is classified in three varieties: (1) voluntary striated, or skeletal, (2) involuntary nonstriated, or smooth, and (3) involuntary striated, or cardiac. These differ markedly in their cellular structure, arrangement, distribution and function.

Voluntary striated muscles are the most highly differentiated of the muscle tissues and are characterized by being under the control of the will. They constitute the skeletal muscles and even some of

FIG. 89.—SEGMENT OF A HUMAN VOLUNTARY STRIATED MUSCLE FIBER SHOWING DOBIE'S GLOBULES (INTERMEDIATE DISC) IN THE LIGHT BAND. (Sharpey.)
the visceral muscles. Their muscle cells are arranged in masses called *muscles* which are usually provided with a tendon at each end for attachment to the periosteum of the bones.

Each *fiber*, or *cell* is a long narrow cylinder and its cytoplasm constitutes a syncytium. A fiber averages about 1 inch in length though in the Sartorius muscle they may reach 5 inches. The diameter, usually 25 to 80 microns will vary in the same muscle. The largest fibers measure about 100 microns while the smallest are about 10 microns in diameter. In the male the fibers are thicker than in the female and in muscular individuals the diameter is greater (in the same muscle) than in other individuals. This same difference in thickness in different muscle is not apparent during infancy. Branched fibers are found occasionally among the muscles of the human tongue. Such fibers are numerous in the tongue of the frog.

Each fiber is composed of a large number of *fibrillae* imbedded in a substance called *sarcoplasm*. These fibrillae are surrounded by a delicate tubular sheath called the *sarcolemma*. This is composed of a tough, homogeneous substance that does not yield when the
MUSCLE TISSUES

Muscle substance ruptures. This sheath is more prominent, thicker and stronger in lower animals (fishes, amphibians) than in mammals.

The fibers show, when viewed longitudinally, light and dark bands, or lines running both transversely and longitudinally. The *longitudinal striations* are due to the alternation of the dark fibrillae and the lighter sarcoplasm in which they are imbedded. Each fibril or *sarcostyle*, consists of a series of smaller rod-like parts. These rods, or *sarcous elements*, are separated from one another at their ends by a clear space filled with sarcoplasm and containing a small body called *Dobie's globule*. This sarcoplasm is the passive sub-

Transition zone.

![Diagram](image)

**Fig. 92.—Longitudinal Section of a Part of a Muscle Fiber from a Human Internal Intercostal Muscle, Showing its Transition to Tendon. X750.** (Lewis and Stöhr.)

stance of the muscle fiber and contains the glycogen. Holmgren described a *trophospongium* in the sarcoplasm of voluntary striated muscle. The sarcous elements stain darkly and are doubly refractile, or *anisotropic*. The sarcoplasm stains palely, is semi-solid and is singly refractile, or *isotropic*. The sarcoplasm seems analogous to the hyaloplasm of the ordinary cells and serves as a vehicle for the chemical changes, and transference of nutrient and waste materials. The fibrillae correspond to the spongioplasm which in the muscle cells is peculiarly arranged and has the important property of powerful contraction.

The *cross-striations* consist of comparatively broad, uniform alternating *dark* and *light bands* that are usually more distinct than the longitudinal striations. The dark band is doubly refractile, or anisotropic and the light band is singly refractile, or isotropic.

Each band averages about 3 microns in breadth. The *dark band* (Bruecker's lines) consists of a row of sarcous elements (the rod-like parts of the sarcostyles) extending across the fiber and sepa-
rated from one another by sarcoplasm, so that each dark band exhibits longitudinal striations which are continuous with those of the other bands. Not infrequently the middle of this band is marked by a clear transverse line called the disc of Hensen. Upon careful examination each light band is seen to be crossed at its middle by a fine and usually dotted line. This is attached peripherally to the sarcolemma and is called Dobie's line, or the membrane of Krause. The parts above and below this membrane are referred to as the lateral discs. All parts of the fiber embraced between two successive membranes of Krause constitute a sarcomere.

The nuclei of a voluntary muscle fiber are very numerous (100 to 200). Each is somewhat oval in shape and contains a network of chromatin and one or two nucleoli. In mammals the nuclei lie just beneath the sarcolemma at the periphery of the sarcous substance. In the frog they are imbedded in the muscle substance. The nuclei are more numerous at the tendinous ends of the muscle than in the middle.

The sarcolemma is a delicate fibrous sheath that lies close to the fiber substance. It is transparent, homogeneous and tougher and thicker in lower vertebrates and represents a cell wall. It is not seen as a rule except in special preparations. If fresh muscle tissue be treated with water, the muscle substance ruptures, and the delicate membrane is shown spanning the interval.

Upon transverse section a muscle fiber is seen to be limited by the sarcolemmal sheath; beneath this are seen the nuclei located at the periphery of the muscle substance. The fibrillae are seen to be arranged in the form of small polygonal areas called Cohnheim's fields. These are separated from one another by a network of sarcoplasm. This
network of sarcoplasm is made very prominent by treating the muscle tissue with acid and gold chlorid after the method of Cohnheim.

There are two kinds of muscle fibers, red and white. The white fibers predominate in man and are poor in sarcoplasm and respond energetically when stimulated. The red fibers are rich in sarcoplasm, are usually thinner and respond more slowly to stimulation. These fibers also possess more nuclei that may even be imbedded in the fiber. In the rabbit these red fibers form entire muscles, while in man they are scattered among the white fibers in the Trapezius muscle.

During contraction the muscle as a whole becomes shorter and thicker. The changes in appearance of the fiber during contraction have been studied by a number of observers. Merkel believed that the muscle substance diffused itself over the entire muscle compartment at first and then accumulated at the membrane of Krause while the sarcoplasm passed to Hensen’s discs, the substances, thus,
becoming reversed. According to Englemann when contraction begins the membranes of Krause approach one another and the parts of each disc become indistinct, the striations are lost and the discs appear homogeneous. As the contraction progresses the striations reappear and the light disc becomes a dark band compared to the clearer disc of sarcous substance. In reality there has been no change of position of the discs, as Merkel believed, but a change in refrangibility accompanied by a decrease in volume of the dark disc at the expense of the sarcoplasm. McDougal advanced the theory that the shortening of the sarcomeres in contraction was due to the absorption of water causing the sarcomeres to swell, especially in the region of the dark discs. He later stated that he believed the absorption was due to the formation of lactic acid within or outside of the sarcomere. The contraction must be due to the movement within the sarcomere, that is from the membrane of Krause to the sarcous elements. Englemann later believed this movement to be

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**Fig. 95.—Muscle Showing Lateral Contraction Wave. (After Rollet.)**
due to heat developed during contraction. Another view is the electrical change occurring at the adjacent surfaces of the light and dark portions of the fibers producing a change of surface tension at these points. MacDonald believes that the changes in the muscle are due to the alteration in relation of the protein molecules and the electrolytes. He believes that the onset of the contraction is marked by the new appearance of potassium salts in the central portion of each sarcomere producing, thus, a difference in osmotic pressure.

A muscle consists of a definite collection of muscle fibers. The entire muscle is enclosed in a thin sheath of white fibrous tissue called the epimysium; this sends in septa that divide the muscle into large secondary bundles, or fasciculi. The secondary bundles are composed of a number of primary fasciculi, each of which is surrounded by a sheath called the perimysium. From the perimysium fibers extend into the bundles running between the individual muscle fibers, forming a network and supporting the capillary blood-vessels, lymphatics.
and nerves. This network is the *endomysium*. When the muscle fibers form the tendon, the muscle cells end abruptly and the nuclei are more numerous here. The tendon bundles begin abruptly and continue parallel to one another while the areolar tissues of the muscle and tendon are continuous.

Muscles are very vascular. The larger vessels pierce the epimysium and send branches along the septa between the primary bun-

![Fig. 97. — Trophocyte in Relation with a Muscle Fiber of the Human Tongue. The nutritive granules are being "fed" into the dark discs. (Nana Svartz, Anat, Anz., March, 1914.)](image)

dles; these vessels run parallel to the long axis of the muscle. Branches enter the primary fasciculi and form capillaries, that run parallel to the long axis of the muscle, forming a long meshwork between the fibers. At intervals transverse connections between the longitudinal capillaries are seen and these are the *ampullae* that serve to take the tension off of the capillaries during muscle contraction. As a rule the smaller the fibers the more abundant the vessels and the closer the capillary meshwork.

The *nourishment of muscle fibers* is not carried on in the usual way. Holmgren and Thulin, in their study of the tissue of insects, found
special cells, *trophocytes*, present; these took from the blood and lymph the various nutritive elements and, after modifying them, transferred the products to the tissue cells. These trophocytes are necessary to the specialized tissues (muscle and nerve). The relation of trophocytes and muscle cells has more recently been studied by Nana Svartz, in the human tongue. The trophocytes are large, granular elements that clasp the muscle cells. The granules are apparently nutritive in function resembling the tigroid bodies of the nerve cells. They are arranged in rows and are passed into the muscle cells and during the contraction of the muscle fiber the granules dissolve. The trophocytes exhibit peculiar and characteristic changes in appearance, number and arrangement of granules and the nucleus during the contraction wave of the fiber. This seems to indicate that they are not indifferent cells. The direct passage of substances from the trophocytes to the muscle cells is demonstrable. Yet it is stated that nutrition in muscle and nerve tissues is at its lowest. Apparently all that the muscle cells require is oxygen which when brought to the muscle cause the explosion of a contained compound thereby producing much energy.

**Lymphatic vessels** are said to be absent in voluntary muscles. The lymph spaces between the muscle fibers empty the lymph into the muscle sheaths and tendon.

The **nerves** are large and enter with the vessels. They pass between the fasciculi and anastomose with one another. After piercing the epimysium the nerve follows the septa to the primary fasciculi and separates into small groups of fibers. As such a nerve does not contain as many fibers as there are muscle cells each nerve fiber will give off a number of collaterals or branches so that ultimately there will be a nerve fiber for each muscle fiber, and one primary nerve fiber will supply a number of muscle fibers. As the terminal nerve fiber pierces the sarcolemmal sheath the neurilemma and myelin sheath blend with the sarcolemma and the naked axis cylinder alone enters the muscle substance. This passes to the *soleplate* which is a granular mass of nucleated protoplasm containing several nuclei. Within this the fibrillæ of the nerve fiber terminate in bulbous enlargements, which, with the sole-plate constitute the *end-plate*. There is but one organ to each muscle fiber.
The involuntary nonstriated, or smooth muscle tissue is less abundant than the preceding type and is not so highly differentiated. In most organs the fibers are arranged into distinct layers and not in the form of muscles. They form the muscle coats of hollow and tube-like organs. The fibers are said to be united to one another by a small amount of intercellular cement that can be brought out by the silver nitrate method of staining. When spaces between the fibers occur, delicate intercellular bridges are seen connecting the cells in the form of a syncytium. These bridges are the continuation of the peripheral fibrillar cytoplasm of the cells.

Each fiber, or cell is a small, spindle-shaped element measuring from 40 to 200 microns in length and 3 to 8 microns in thickness. Larger fibers are seen in the pregnant uterus where the length is often 500 to 600 microns and the thickness also increased in proportion (15 to 20μ). In the aorta and some of the larger blood-vessels these muscle cells are very irregular in shape. The ends of the fibers may be branched or forked as in the aorta and bladder.

The sarcous substance may show longitudinal striations (but no transverse) due to the presence of coarser peripheral fibrillae and deeper and more delicate fibrils. These are doubly refractile and are separated by varying amounts of sarcoplasm. In the developing fibers the fibrils arise from small granules that are apparently derived from the mitochondria and are called myochondria. The peripheral, or border fibrils are coarser and are the ones that form the intercellular bridges; they serve to connect the cells into a syncytium. Schaffer and v. Lenhossek state that what appear to be intercellular bridges are merely sections of fine connective tissue fibers that surround the muscle fibers. The deeper are the more delicate and seem to be the ones most concerned in the contraction of the cells. The sarcoplasm may contain granules at the poles of the nuclei and immediately surrounding the nucleus is of an undifferentiated character. This contains glycogen granules, lipoids and mitochondria.

The nucleus is usually long and rod-shaped and located in the center of the cell. It contains a distinct chromatin network and
A.—Longitudinal section of smooth muscle fibers: a, muscle fiber; b, nucleus; c, fibrous tissue between fibers. B.—Cross-section of smooth muscle fibers: a, perimysial connective tissue; b, blood-vessel; c, nucleated fiber; d, nonnucleated fiber. C.—Longitudinal section of voluntary muscle fibers: a, sarcolemma; b, nucleus; c, end of muscle fiber; d, dark bands; e, intermediate disc; f, nucleus; g, lateral disc. D.—Diagrammatic section of cross and long striations: a, dark disc; b, lateral discs; c, intermediate disc. E.—Cross-section of voluntary muscle: a, perimysium; b, endomysium; c, nucleus of perimysium; d, fibrillae; e, nucleus of muscle; f, sarcolemma. F.—Longitudinal section of cardiac muscle fibers: a, muscle fiber; b, nucleus; c, branch. G.—Cross-section of cardiac muscle fibers: a, perimysial sheath; b, nucleus of sheath; c, muscle fiber; d, nucleus; e, radial plates of fibrillae.
one or two nucleoli. During contraction of the cell the nucleus becomes shorter and thicker (or even a short spiral) and the chromatin seems to be forced towards its poles. A centriole is present at the side of the nucleus.

Although a sarcolemma is not present each cell is surrounded by a delicate membrane which may be a layer of peripheral, homogeneous cytoplasm. In contracted fibers this membrane may be wrinkled giving the appearance of indistinct transverse striations. The smooth muscle fibers are collected into fasciculi of varying sizes that are usually arranged parallel to one another forming layers. In some organs, however, these fasciculi interlace, as in the uterus, vagina and bladder.

This type of muscle is found in the hollow viscera as the lower part of the esophagus, the stomach and intestines, the trachea and bronchial tubes, the ureter, bladder, urethra, penis, the ovaries, oviducts, uterus and vagina, the ducts of glands, the skin, the blood-vessels, lymph vessels, the eyeball and in the capsules of certain organs as the spleen, lymph nodes and prostate.

The blood-vessels are less numerous than in the voluntary striated variety. The capillaries form plexuses around the fibers. Some organs, as the stomach and intestines, have abundant lymphatic plexuses between the layers. Other organs are not so well supplied.

The nerves are from the sympathetic system. In the stomach and intestines these amyelinated nerves form a prominent plexus between the layers of the muscle coat and another in the submucous coat. From these plexuses the terminal fibers pass to the muscle fibers. In other organs there may be more delicate plexuses or simply small ganglia in relation with the organs and from these the terminal fibers pass to the muscle fibers. Here the nerve fibers end as tapered or bulbous extremities that are applied to the surface of the muscle cells.

IN VOLUNTARY STRIATED OR CARDIAC MUSCLE

The cardiac muscle resembles both of the preceding in its characteristics. The fibers are cylindric in form and have both transverse and longitudinal striation, as in the voluntary type. Each
possesses usually a single nucleus, which is centrally placed, and no sarcolemma, the fibers are arranged in layers and are not under control of the will and in these they resemble the smooth type.

The cardiac muscle fibers are usually described as short stubby cylinders that measure 100 to 200 microns in length and 25 to 40 microns in thickness. These branch and anastomose freely so that there is a continuity of the fibers through both sets of chambers of the heart. As a result of this anastomosis and the continuity of fibrils from one so-called cell to another, heart muscle constitutes a syncytium. The cell boundaries are not clear, but for the sake of description the term cell or fiber will be used. Some observers maintain that septa do occur, indicating transverse segmentation, but the fibrils are seen passing through these septa continuing from one cell to the other.

The longitudinal striations are due to the presence of fibrillae or sarcostyles, imbedded in the sarcoplasm. Although there is no distinction between deep and border fibrils as in the smooth type, still the fibrils are specially arranged in rows that radiate from the central area. They are anisotropic. These fibrils are not con-

Fig. 99.—Section of Human Cardiac Muscle Showing Striations and Branches. (Photograph Obj. 4 mm., oc. 7.5 X.)
tinuous but interrupted at regular intervals so that as in voluntary striated muscle there is an alternation of light and dark bands producing the *transverse striations*. The light bands are chiefly sarcoplasm containing the mitochondria, glycogen, liposomes, lipid and albuminoid granules. This band is divided into the intermediate (Dobie's membrane) and the two lateral discs. The dark band (Bruecker's) is crossed by the *line of Hensen*.

![Muscle Tissue from the Adult Heart Showing the Intersegmental Septa and the Nuclei Lying in the Undifferentiated Sarcoplasm. (After Palczewska.)](image)

There is usually a single, large, oval and centrally placed *nucleus*, though two may at times be seen in one cell. The chromatin network is distinct and each nucleus is usually surrounded by the area of undifferentiated cytoplasm containing granules and fat droplets. A delicate limiting cell membrane is present and some call it a sarcolemma.

The muscle fibers of the atrioventricular bundle correspond to the Purkinjé fibers of the hearts of lower animals. The muscle fibers, less differentiated than those of the myocardium, are striated but the sarcoplasm predominates. The fibrillae are few and peripherally placed forming a circle, or groups that are irregular or triangular. The volume and size of each fiber are greater than in the ordinary
cardiac fibers. They are less branched and the intercallated discs are fewer in number. The cytoplasm is rich in glycogen and pigment granules may be present. Cell boundaries cannot be definitely located so that this tissue is a syncytium. This bundle is distinctly separated from the heart muscle and seems to appear early in development. It has to do with the conduction of the contraction wave.

According to some investigators the heart muscle represents a syncytium in which no distinct cell boundaries are to be detected. Others maintain that their individual cells as above described are shown by special stain methods. After treatment with special reagents, the muscle syncytium seems to be separated at fairly regular intervals by the intercallated discs; these may be straight bands, step-like or serrated. These are irregular as to form and position. These may extend across the fiber or only a short distance. They may be arranged annularly or in spiral form. They are merely peripheral in position never extending all of the way through a fiber or even in to the axial core of sarcoplasm. They are permanent structures and are composed of units corresponding to portions of a single fibril that may be granular or compact. They appear late in fetal life. Some believe them to be due to a "fixed phase of contraction wave" or due to an irresistible strain condition. The fibrillae continue through the discs from one so-called cell to another.

The blood-vessels are very numerous in the heart. The capillaries lie in close relation with the muscle substance and may even lie in grooves on the fibers. In some animals the capillaries are seen imbedded in the muscle substance.

The lymphatics are very numerous and follow the course of the blood-vessels. The lymph capillaries form a network throughout the intermuscular tissue forming vessels that pass toward the serous surfaces and ultimately toward the base of the heart.

Cardiac muscle is supplied by the sympathetic nerve system. These fibers may form delicate plexuses at the intersections of which are found ganglia of various sizes. Individual amyelinated fibers extend to each muscle cell and terminate upon its surface in one or more granules or bulbs. According to Huber and others the nerve fibers terminate in many fine fibrils that spread over each nucleated segment or cell.
Muscle tissues are derived from special portions of the mesoderm called myotomes, or muscle plates. The cells that form the muscle fibers are the myoblasts and they multiply very rapidly. In the formation of the voluntary striated muscles, the myoblasts elongate and increase in number. The myoblasts become separated from the mesenchymal cells, the latter forming the fascia and tendons. The protoplasm contains granules that are the mitochondria, according to Meves and Duesburg. The fibrils develop independently of one another. During the second month, in the human embryo, the granules form peripheral longitudinal striæ (the future muscle substance) and a delicate membrane appears derived probably from the mesenchyme. The nucleus lies in the central, undifferentiated cytoplasm. More striæ are formed and by the regular interruption of the fibrillæ the cross striations appear. By the sixth month of fetal life there remains but a small central core of undifferentiated cytoplasm containing the nucleus. Later the nuclei multiply and assume a peripheral location. In the trout embryo the first fibril, by a radial longitudinal splitting, forms a peripheral ring of fibrils and the central fibrils are formed by a splitting of those of the peripheral ring. As the central area becomes invaded by the fibrils the nuclei migrate to the periphery or occupy the deeper portion according to the cell. The remaining undifferentiated cytoplasm between the fibrils constitutes the sarcoplasm. Thus the white fibers are formed. In the red fibers fewer fibrils are formed and the sarcoplasm predominates. This variety represents an intermediate form between the myoblasts and the white variety.

Most of the smooth muscles are derived from the myoblasts of the mesoderm; the exceptions are the muscles of the sweat glands and the iris, which are of epithelial origin. In either case the cells elongate and become spindle-shaped while the nucleus elongates. The cytoplasm gradually shows the formation of fibrils that soon completely occupy the cytoplasm. These fibrils become differentiated into central finer and peripheral coarser ones; the latter are supposed to arise by the fusion of the finer ones and continue from one cell to another. These fibrils are continuous and uninterrupted so that transverse striations do not appear.
The early stages of the cardiac muscle are similar to the above. Later, however, the cells seem to join to form a syncytium.

After becoming completely developed voluntary striated fibers continue to increase in size to birth and from that time to adult life. They double their size in the last half of gestation and in the adult are about five times the size as at birth. The increase in the number of muscle cells is due to the presence of myoblasts in the muscles, even in the adult.

Although formerly it was believed that muscle tissue did not regenerate, it appears that diseased or cut areas are later joined by muscle tissue. Some consider this due to the presence of myoblasts but Schmincke states that the existing fibers bud at the ends. Pfitzner found that in artificially produced lesions of smooth muscle tissue regeneration occurs by the neighboring cells multiplying by karyokinesis.

The accompanying table gives a résumé of the general characteristics of the various types of muscle tissue.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Voluntary striated</th>
<th>Smooth</th>
<th>Cardiac</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape.</td>
<td>Long cylinder.</td>
<td>Spindle.</td>
<td>Stubby cylinder. (?)</td>
</tr>
<tr>
<td>Length.</td>
<td>1–5 inches.</td>
<td>25–500 microns.</td>
<td>100–200 microns.</td>
</tr>
<tr>
<td>Location.</td>
<td>Intermediate.</td>
<td>Rod. (Longitudinal.)</td>
<td>Oval.</td>
</tr>
<tr>
<td>Shape.</td>
<td>Cross and long.</td>
<td>None. (Occasional.)</td>
<td>Cross and long.</td>
</tr>
<tr>
<td>Sarcolemma.</td>
<td>Occasional.</td>
<td>Always.</td>
<td>As a syncytium.</td>
</tr>
<tr>
<td>Branches.</td>
<td>In masses called muscles.</td>
<td>Not by will.</td>
<td>Not by will.</td>
</tr>
<tr>
<td>Arrangement.</td>
<td>By will.</td>
<td>Not by will.</td>
<td>Not by will.</td>
</tr>
<tr>
<td>Control.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER VI

NERVE TISSUES

The nerve tissues are the most highly differentiated of all of the tissues. By means of these the various organs and structures are connected and associated so that they can work together and accomplish some definite object. By means of the nerve system the individual is made cognizant of his environments through his sense organs. Nerve tissues consist of cells and intercellular substance like the other varieties of tissues and, as in connective tissues, the intercellular substance predominates. Nerve tissues are derived from the ectoderm and adult nerve cells do not reproduce themselves.

There are two varieties, gray and white. The gray is characterized by a grayish color: in the cerebrum and cerebellum it is divided into layers while in the spinal cord, brain stem, and ganglia the arrangement is somewhat different. It consists of cells and their processes, myelinated and amyelinated nerve fibers and neuroglia, the special supportive substance of the nerve system. The white nerve tissue of the central nerve system consists chiefly of myelinated nerve fibers and neuroglia and a small amount of white fibrous connective tissue. The peripheral nerve system consists of nerve fibers supported mainly by white fibrous connective tissue, and some ganglia.

The nerve system consists of a series of interrelated and interconnected units that give a continuity of impulse from the central system to the periphery and vice versa. These units are called the neurons; each neuron consists of the nerve cell and its various processes. The nerve cell comprises the cytom, or cell body, the immediate dendritic processes and the proximal portion of the axone. The distal portion of the axone and the distal portion of the main dendrite, if it leaves the gray substance and becomes a nerve fiber as in the sensor system, constitute the nerve fibers. These fibers may
be but a few millimeters in length or several feet, as evidenced by those nerves of the extremities.

Nerve cells are found only in gray nerve tissue. A **typic nerve cell** consists of a cell body, from which a number of processes extend,

![Typic Nerve Cells](image)

**Fig. 101.—Typic Nerve Cells.**

*a.* From a human spinal cord; *b.* from the motor area of the human brain showing tigroid bodies. Drawn from slides.

a nucleus, nucleolus and centrosome. The whole structure comprises the **neuron**, or **neurocyte**.

The **cell-body**, or **cytom** is composed of a granular and fibrillar cytoplasm; the latter at the point of origin of the main process forms the **axis cylinder hillock**. The fibrillar network is of two kinds.
A fine meshwork, seemingly containing myelin, was found by Golgi. It stains darkly after prolonged exposure to osmic acid and is unconnected with the neurofibrils. The others are the neurofibrils that can be seen only after careful preparation after Golgi's method and must be examined under a high-power objective.

*Neurofibrils*, first described by Max Schultze, are seen passing into and through nerve cells without forming junctions with one another and extend also into all of the processes. These fibrils are of a semi-solid nature, apparently, as they easily become varicose in form; they vary, apparently, with functional activity. Cajal and Tello have found that in the hibernating lizard, during winter sleep, these fibrils are less numerous and thicker than in the active animals. These fibers pass from one cell to another and terminate there. These fibrils respond readily to the intravitam methylene blue and silver nitrate stains.

In the meshes of the fibrils are seen the granules and a homogeneous substance that stains but faintly. The latter is comparable to the hyaloplasm of the typic cell. The granules are of two kinds,
oxyphilic and basophilic. The oxyphilic granules are the more numerous and the smaller and are seen only after special stains have been employed. The basophilic granules, or corpuscles of Nissl, are large but inconstant.

The corpuscles of Nissl, or tigroid bodies consist of nucleoprotein containing organically combined iron, as pointed out by MacCallum. The tigroid nuclein is soluble in weak solutions of soda. They are usually large, flake-like bodies that respond readily to methylene blue, thionin, or toluidin blue stains. They are derived from the nucleus appearing first in the form of chromidia, sometimes called cytochromatin. The presence and position of these bodies depends upon the functional activity of the cell; they may be scattered or arranged in two groups, one near the nucleus and one near the periphery of the cell; they may be arranged concentrically around a well defined centrosome. Cells containing but few granules are called apyknomorphous while those containing many corpuscles

![Motor Nerve Cells from the Brain of a Dog](image)

**Fig. 103.—Motor Nerve Cells from the Brain of a Dog.**

*a.* Normal resting cell; *b.* fatigued cell. (Schäfer after Mann.)
of Nissl are called *pyknomorphous*. In fatigued cells they disintegrate and disappear, although Dollay has shown that if the activity is not excessive they first increase in amount. These changes are called *chromatolysis*, or *Nissl's degeneration*. Similar changes occur in these granules, if the axones of the cells be cut, twenty-four to forty-eight hours after section and being completed in fifteen to twenty-four days. Various poisons including toxins produce a like effect. With removal of the cause regeneration usually takes place. In disease, or section of the axone regeneration does not take place.

Crile believes that Nissl's substance is volatile and unstable and depends upon adrenalin for its existence. The thyroid bodies are seemingly nutritive in function.

It seems that the corpuscles of Nissl vary in size in cells of different functions. In the motor cells of the spinal cord the granules are few in number and large; in the sensor cells of the spinal and cerebral ganglia the granules are fine and evenly distributed through the cytom. In the cells of the sympathetic system the granules are mainly peripherally placed and intermediate in size.

In certain portions of the nerve system *other granules*, usually brownish-yellow, or black, are found in the cytoplasm. This is the *substantia nigra* of the locus coeruleus. This pigment contains lecithin and tends to increase with age, making its appearance at about the third year. It is more common in man than in the lower animals.

Schirkogoroff studied the *mitochondria* in the nerve cells of the rabbit and found them more or less abundant. They were best developed in the cells of the spinal cord, oblongata and Purkinje cells of the cerebellum, in the small cells of the basal ganglia of the brain they were small and few in number. Their presence in the axones is doubtful though some state that they are found in all of the cell processes. They have also been found in the spinal ganglion cells of man and are probably concerned with the metabolism of the cell.
Holmgren has found a fine network of *juice canals*, or *trophospongium*, in the cytoplasm of many of the nerve cells, especially those of the ganglia. He believes that these canals may undergo constant changes.

Golgi and others have described a reticular investment covering the nerve cell and extending for a variable distance upon the processes. Its nature and function are unknown. Some believe that it represents an interlacement of the terminal ramifications of the axones of other cells; others believe that it is of neuroglial origin. Around nerve cells, especially of the ganglia, there is a well defined lymph space that is lined with endothelial cells.

The *nucleus* is usually large, pale and eccentrically placed. The nuclear membrane is distinct and stains deeply. The chromatin is scant, the karyosomes few and small and usually attached to the inner surface of the nuclear membrane. At times chromatophilic granules are found in the nucleoplasm.

The *nucleolus* is usually very large and stains deeply. It is located near the middle of the nucleus and is usually readily discernible with the low power.

*Centrosomes* with attraction spheres have been found in the nerve cells of some mammals.

**Cell Processes.**—Extending from the cytom will be found one or more processes and cells are classified according to their number as unipolar, bipolar and multipolar. The main process is called the *axone* and the other the *dendrite*.

The main process is called the *axone, axis cylinder*, or *neurit* and represents a direct continuation of the cytoplasm of the cytom. It conducts the nerve impulse away from the cytom. It starts at the axis cylinder hillock and consists of a cylindric collection of neurofibrils imbedded in neuropasm and surrounded by a delicate membrane called the *axilemma*. The presence of this membrane is denied by some. The axis-cylinder hillock and the process are devoid of granules. The process is uniform in diameter, smooth in contour and may give off branches called collaterals; these are said to be more numerous near the proximal than the distal end of the axone. Near its termination the axone may bifurcate. Both axone and collaterals usually end in a brush-like mass of branchlets called
telodendria (better teloneurites). At times these terminals are knobs or plates called neuropodia. Occasionally an axone may arise from a dendrite. The axone extends a variable distance from the cytom and its course as to whether it remains in the gray substance or leaves it gives rise to a classification of nerve cells into first and second types.

A cell of the first type (Deiter's cell) is one in which the axone leaves the gray substance to become a myelinated nerve fiber, or a sympathetic nerve fiber. A cell of the second type (Golgi's cell) is one in which the axone does not leave the gray substance. In a unipolar cell the single process soon divides into two, one the axone and the other the dendrite.

The dendrites, or dendrons are secondary processes. As they arise from the cytom they are relatively thick, but as they branch repeatedly they taper rapidly. These branches do not usually extend far from the cell-body and terminate in fine branches, telodendria, that end in relation with the telodendria, or teloneurites of neighboring cells. Occasionally the dendrite does not branch until it is quite a distance from the cytom; this is the case in the sensor cells in the various ganglia connected with the sensor nerves, where the dendrites will be several feet in length and reach the periphery before they arborize. The network produced by the various telodendrites forms a considerable portion of the gray nerve tissue. The thorny appearance of dendrites in Golgi preparations is due to the presence of minute lateral projections called gemmules.

Unipolar cells possessing but one process, are found in the ganglia of the dorsal roots of the spinal nerves and in the ganglia connected with the trigeminal and vagal nerves and occasionally among the cells in the ventral horns of the spinal cord. The cells are usually spherical, or nearly so, in shape and the process close to the cytom is surrounded by a myelin sheath. At a short distance from the cell the process divides like a T or Y, one process entering the central nerve system (axone) and the other extending to the periphery (myelinated dendrite). Embryologically these are bipolar cells in which the cytom grew unequally so that gradually the two processes were thrown side by side; at the same time the cytoplasm became
A. Multipolar cell from cerebral cortex.  B. Multipolar cell from spinal cord.  
C. Pyramidal cell from cerebral cortex.  D. Unipolar cell.  E. Bipolar cell.  
from spinal cord of an ox, showing pigment granules.  K. Ganglion.  L. 
Sympathetic or amyelinated fibers.  M. Longitudinal section of myelinated 
nerve fiber.  N. Cross-section of osmicated nerve fibers.  O. Myelinated 
nerve fiber of a guinea-pig showing the reticulum.  P. Myelinated nerve 
fibers of a toad, showing reticulum (neurokeratin).  R. Motor neuron, 
showing nerve cell, dendrites, axis cylinder and ending of latter in a muscle.  
S. Cross-section of nerve trunk.
Fig. 106.—Cells from Cerebrospinal Ganglia Showing Intracapsular Knobbed Dendrites c, c; a, a, Axones. (After Cajal.)

Fig. 107.—Purkinjé Cell of the Cerebellum. 
a. Axone; b, collateral; c, d, dendrites and telodendrites. (Cajal.)
so extended as to form the undivided portion of the process. As a result this seemingly unipolar cell is bipolar functionally.

**Bipolar cells** are found in the cochlear and vestibular ganglia connected with the corresponding divisions of the auditory nerve; in the olfactory mucosa; as the rod and cone cells of the retina; as the Purkinjé cells of the cerebellum. Each possesses an axone and a single dendrite.

The **multipolar cells** are the most numerous and are found in the cerebral cortex and in the gray substance of the spinal cord and brain stem. These cells possess three or more processes, one axone and the remainder dendrites.

Nerve cells vary in size from 4\( \mu \) to 9\( \mu \) in diameter, for the smallest, to 75\( \mu \) to 150\( \mu \) for the largest. The former are the granule cells of the cerebellar cortex and the latter are those of the ventral horns of the spinal cord. The next largest are the large pyramidal cells of the cerebral cortex ("giant cells of Betz," motor area). Nerve cells *without an axone* are found in the retina and olfactory bulb. Neurons are unable to reproduce themselves; if the axone becomes destroyed it may regenerate but if the cytom is destroyed it is never replaced.

According to the neurone theory the nerve system consists of a series of closely related and physiologically correlated elements from
the central system to the periphery; in other words one neuron does not extend from the center to the periphery. At least two and a many as six are concerned in the various pathways. These related neurons are not directly connected to one another although the processes of one cell may end around the body of, or in contact with the processes of another cell. This has been shown by special stain methods, by the study of the nerve system in certain diseases and injuries and by the study of the development of the nerve cells and fibers. The cells and processes alike are affected by degenerative processes, but the preceding or succeeding neurons are not affected.

The ramifications of the axone of one cell about the body of another cell or its processes constitute a synapse. When the teloneurites surround the cell-body this form of synapse is called an investment; when the teloneurites come in relation with the telodendrites of another cell this constitutes an interlacement. Occasionally synapses may occur between the dendrites of two cells. Another peculiar form of synapse is that in which the axone does not branch at its termination but ends in a bulb-like enlargement upon the body of another cell, as in the trapezoid and ventral acoustic nuclei of the brain stem.

Another type is that in which the axone and its branches terminate by winding around the dendrites and telodendrites of the recipient cell, up to the next to the last telodendrites. Such are seen as the climbing fibers of the cerebellum and might well be termed an entwining synapse.

The neuroglia, or glial substance, is the peculiar supportive tissue of the nerve system. Like the nerve cells it is of ectodermal origin. Unlike the intercellular substance of other tissues it is not the result of the activity of the functionating (nerve) cells but the glial substance itself consists of cells and intercellular substance. The glial cells give rise to the glial fibers.

Glial cells are of two kinds ependymal cells and astrocytes. The ependymal cells are apparently some of the original elements of the neural tube. They represent the remainder of those indifferent cells that gave origin to the neuroblasts and spongioblasts. They are simple ciliated cells that are found lining the canal of the spinal cord and parts of the ventricles of the brain. Usually in adult
Fig. 109.—Spider Glial Cell. (After Andriesen.)

Fig. 110.—Mossy Glial Cell in Relation with a Capillary. (After Andriesen.)

Fig. 111.—Cross-section of Spinal Cord Showing Glial Fibers among the Nerve Fibers.

a, a, Glial fibers; a', same cut across; n, body of glial cell; t, cross-section of a myelinated nerve fiber; a, axone of same; t', small (sensor?) nerve fiber. (Schäfer after Ranvier.)
life the cells are not ciliated. The basal ends of the cells are usually branched; these branches extend into the surrounding gelatinous substance where they soon disappear. These cells multiply in the adult body and tend to occlude the spinal canal in part or as a whole.

The astrocytes are usually stellate elements with many processes. The mossy cells are those in which the processes are short and thick and are found chiefly in the gray nerve tissue. In some of the cells the processes are dendritic and do not extend far from the cell. The spider cells have fewer but longer processes and are found mainly in the white nerve tissue. These cells are both small and large; the smaller ones show merely a rim of cytoplasm around the deeply staining nucleus. In the larger cells the cytoplasm is greater in quantity and the processes are said to be more numerous.

The glial fibers are delicate filaments of protoplasm that form a network for the support of the nerve cells and glial cells. Some of the fibers have a very intimate relation with the glial cells passing close to the cell-body or even through its peripheral cytoplasm although they are distinct from the cell-body.

According to the investigations of Hardesty the glial fibers appear late, that is after some of the nerve fibers have become myelinated and long after the first connective tissue fibers have appeared. They are formed in the neural syncytium (neurospongium) in which they are formed directly by the cells or through their activity.

The white nerve substance of the central nerve system consists of myelinated nerve fibers supported by neuroglia and some white fibrous connective tissue; the latter is chiefly for the support of the blood-vessels. In the peripheral nerves the supportive substance is white fibrous tissue.

After the axone of a cell of the first type leaves the cell it becomes a nerve fiber. If the axone becomes invested with a myelin sheath it is then a myelinated nerve fiber such as constitute the cerebrospinal system. If no myelin sheath is present it is then called an amylminated nerve fiber, as is seen in the sympathetic nerve system.

An amylminated, or nonmedullated nerve fiber (Remak's fiber) consists of an axis cylinder surrounded by a delicate sheath called the neurolemma, and is said to be connected exclusively with the
sympathetic nerve system. Ranson, however, found that these fibers were more numerous in the ordinary nerves than had hitherto been supposed. These fibers are very numerous in the spinal nerves, and in the vagal nerves of the dog the amyelinated fibers predominate caudal to the diaphragm; these fibers are both efferent and afferent.

The axone arises at the axis cylinder hillock and consists of a bundle of neurofibrils imbedded in apparently homogeneous neuroplasm. It is continuous in its course and terminates in a set of branches called teloneurites. These sympathetic axones are the smallest measuring from 1.8 to 3.6 microns in diameter. The neurofibrils seem to converge from the dendrites to the axis-cylinder hillock. Although some investigators claim that these neurofibrils branch and interlace in the nerve fiber most observers hold that they are individual throughout their course. These fibers are semi-solid and readily become varicose. Under high magnification each fibril seems to be tubular in character, the center of the tubule being filled with the fluid conductive substance, as pointed out by Carlson. Surrounding the axone there is a delicate sheath that may be more pronounced in places and contain nuclei. This is the neurolemma. It is not always well developed and its nuclei appear to be imbedded in the peripheral portion of the axone.

The amyelinated nerve fibers are grayish in color. They terminate in the smooth muscles of the various organs (including the heart) and upon the epithelial cells of mucous membranes and glands. These fibers are also seen in several of the cerebral nerves and the ventral roots of the thoracic, most of the lumbar and some of the sacral spinal nerves. Through these they go to or come from the various organs and structures to which these nerves are distributed.

Amyelinated nerve fibers without a neurolemma consist of merely a naked axis cylinder. The fibers of the olfactory nerves belong to this class. Here are also placed the proximal and distal parts of the myelinated type that have as yet not become invested with this sheath or have lost it. It seems that this is a very trifling distinction as no myelinate nerve fiber receives its sheath directly upon arising from the cytom nor does the sheath ever continue to the termination of the axis cylinder.
A myelinated, or medullated nerve fiber is white in color and forms the bulk of the white nerve tissue of the cerebrospinal system; some of this variety are found even in sympathetic nerves. This type of fiber consists of axone, myelin sheath and neurolemma. The axone consists of a bundle of neurofibrils imbedded in a mass of homogeneous neuroplasm, apparently surrounded by a delicate membrane called the axilemma. The presence of this membrane is denied by some. These fibrillae are probably the conductive parts of the fiber though some are inclined to believe that the neuroplasm only has this property. The fibrils in mammals are very fine and almost evenly distributed in the axone although occasionally a narrow peripheral clear zone may be found. In lower animals, the fibrils are coarser and tend to form a mass in the center of the axone with a resulting clear peripheral area. The fibrils are considered by some merely a support for the neuroplasm. The largest axones (to the skeletal muscles) are 8 to 16 microns in diameter, though sensor fiber may be as small as 4 microns in diameter.

The myelin, or medullary sheath (white substance of Schwann) is, apparently an insulating sheath found mainly in the cerebrospinal

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**Fig. 112.—Cross-section of Osmicated Nerve.**

(Photograph Obj. 16 mm., oc. 10 X.)
NERVE TISSUES

This sheath is not continuous but is interrupted at regular intervals called the nodes of Ranvier. In fresh nerve fibers this sheath is homogeneous. After fixation it consists of a reticular substance and the myelin. The former is composed of neurokeratin and is arranged in the form of network that is invisible in fresh nerves. It seems to be a coagulation product as the meshes of the reticulum vary in size according to the strength of the reagent used. Alcohol and ether produce the best results and these results may be obtained with isolated myelin. Picric acid produces a different coagulation effect. When this agent has been used and transverse sections are made the myelin sheath has the appearance of fine delicate rods radiating from the axis cylinder to the neurolemma. The myelin substance is a phosphorized fat that is practically liquid at the ordinary temperatures for if the neurolemma of a fresh fiber be ruptured the myelin oozes out in the form of droplets. This substance responds readily to osmic acid solutions which turn it

Fig. 113.—Longitudinal Section of Osmicated Nerve. a, Node of Ranvier. (Photograph Obj. 4 mm., oc. 5 X.)
black, thus showing the presence of a fatty substance. It is also readily soluble in ether. It is probably nutritive in function.

In the degeneration of nerve fibers the myelin sheaths show the first signs. This is of importance in the study of diseases of the nerve system and in tracing the fiber tracts.

At regular intervals the myelin sheath is interrupted and the neurolemma dips into the axis cylinder. These regions are the constrictions of Ranvier and because the myelin sheath at these points may be somewhat bulbous, giving a nodal appearance, they are also called the nodes of Ranvier. These are seen only in longitudinal sections of osmicated nerve fibers. If a nerve fiber be treated with nitrate solution (Ranvier’s method) the solution penetrates at these nodes and makes a + -like stain. Those portions between the nodes are called the internodes. In osmicated preparations oblique, cleft-like spaces are numerous; these are the clefts of Lantermann (lines of Schmidt-Lantermann). The intervening parts of the sheath are the medullary segments. What they represent is still unsettled.

The neurolemma, or sheath of Schwann is the delicate sheath that limits the fiber. This is a thin, homogeneous membrane and in each internode there is a nucleus. Although the sheath seems continuous over the nodes it is thought that it really ceases here and that the successive nucleated segments, constituting individual cells, are connected by intercellular cement, as is seen in epitheloid cells. This sheath probably represents specialized ectodermal cells of the neural tube.

This type of nerve fibers is found in the peripheral nerve system. Myelinated nerves without a neurolemma are found in the brain and spinal cord. All of the white substance consists of nerves of this type. In these fibers the myelin sheath possesses no nodes of Ranvier and so continues uninterruptedly. Sheath cells are present and these are said to assist in the production and maintenance of the myelin. Myelinated nerve fibers conduct impulses more rapidly than the amyelinated fibers.

THE PERIPHERAL NERVE SYSTEM

The peripheral nerve system comprises the nerves and the ganglia connected with the spinal and the sensor cerebral nerves.
A nerve or nerve trunk consists of a variable number of nerve fibers collected into a compact mass and bound together by various sheaths. Upon the outside is a sheath of loose areolar tissue called the epineurium. This contains the larger vessel and lymphatics and also the nervi nervorum, the sensor nerves of the nerves. The epineurium is usually thin and sends in septa (for the support of blood-vessels) that divide the nerve into large secondary bundles; from these septa others extend in to surround individual bundles of nerve fibers called funiculi. The sheath surrounding each funiculus is called the perineurium and this is usually thicker in proportion than the epineurium. Although the perineurial sheaths seem compact their layers are readily separable from one another, indicating extensive tissue or lymph spaces that are continuous with the spaces around the brain and spinal cord. By this means the cerebrospinal fluid may pass into the nerves toward the periphery (Keyes). From the perineurial sheath bundles of fibers pass into each fasciculus forming here a delicate reticulum (endoneurium) which supports not only the nerve fibers but also the capillaries that nourish the nerve trunk. The endoneurium may even form partial septa.

The funiculi as well as the nerves vary greatly in size. A nerve, as the optic nerve, may consist of a single funiculus comprising 450,000 to 800,000 fine nerve fibers, or it may consist of many funiculi but few fibers, as the vagal nerve with its 10,000 nerve fibers. The nerve fibers in a funiculus rarely branch but the fibers themselves may start in one funiculus and cross over and join another. When a single nerve fiber runs individually to an organ it is usually sur-
rounded by a delicate sheath derived from the perineurium, called the sheath of Henle.

Nerves are quite vascular. The large arteries enter the epineurium and divide into branches that pass to the septa between the secondary bundles; from here branches are sent into the primary fasciculi where the arterioles form an extensive capillary plexus in the endoneurium. The blood is collected by the venules in the endoneurium and from here is conducted by small venous channels that lie along side of the arterial channels.

The lymph spaces of the nerve are very extensive as has been mentioned. Perivascular lymph vessels are said to be numerous in the epineurium and larger septa.

The nervi nervorum are numerous and small. They supply the blood-vessels (sympathetic) and some are sensor in function. The presence of the latter nerves is denied by some.

A ganglion is an isolated mass of nerve tissue in the course of a sensor nerve. Some consist of merely a few cells and are, therefore, microscopic; others are quite large and are easily found and recognized. The cerebrospinal ganglia all have the same general structure.

A ganglion consists of a sheath or capsule of white fibrous tissue that supports the structures within and serves to delimit it from the surrounding structures so that it may be readily isolated. This
sheath sends in trabeculae that form a delicate network in which are found the ganglion cells, myelinated and amyelinated nerve fibers, blood-vessels and lymphatics. The cells of the cerebrospinal ganglia are usually ovoid, or round and of the unipolar, or bipolar type. The unipolar cell is now looked upon as bipolar as the single process is considered merely an extension of the cytoplasm and not a mere process. The cells of the vestibular and cochlear ganglia of the acoustic nerve retain their bipolar character throughout life. The nerve cell is surrounded by a lymph space that is limited by a single layer of flattened epitheloid cells that is extended upon the processes and is continuous with the neurolemma. The spaces and capsules are absent in the vestibular and cochlear ganglia.

There are three types or varieties of cells in the spinal ganglia: (1) Large unipolar cells with thick processes that branch Y- or T-like become myelinated and leave the ganglion (first type cells). (2) Cells of the second type in which the delicate axones remain in the ganglion and divide into fine branches that penetrate the epi-

**Fig. 116.—Three Small Ganglia of the Submucous Plexus.** A, A nerve fiber passing through one of the ganglia but giving off collaterals to it. (After Cajal.)
theloid capsules and terminate about the previous cells. (3) Small cells of pyriform shape the process of which divides and leaves the ganglion as in the first variety. The processes of these last cells do not become myelinated however and Ranson believes them to be efferent in function. These amyelinated fibers are the ones previously mentioned as components of spinal nerves. In lower animals these last cells constituted, according to Ranson, two-thirds of the cells of the ganglion. A few multipolar cells are found in ganglia of the adult according to Dogiel.

![Diagram](image)

**Fig. 117.**—Perivascular Terminal Nerve Plexuses of the Sympathetic Nerve System. (*After Dogiel.*)

The nerve fibers are myelinated and amyelinated. The former are afferent and efferent. The afferent fibers come from the outside and terminate in the ganglion in delicate branches that penetrate the capsules of the cells and form an arborization about the bodies of the ganglion cells. The efferent fibers are those that arise from the first type cells (1 and 3). In the case of the axones of cells (1) they form a convoluted mass before leaving the cell capsule and after passing through the capsule soon become myelinated. The axones of cells (3) run a straight course and do not become myelinated. Other amyelinated fibers are those of the sympathetic system and the axones of cells (2).

In sympathetic ganglia the cells are multipolar in form. There are two types of cells. (1) Large spheroidal elements that possess from 1 to 16 dendrites. The axones of these cells pass to a nerve as a nonmedullated fiber but may later receive a delicate myelin sheath.
These are considered sensor in function. The dendrites are slender, long, enter the nerve and probably pass to a neighboring ganglion. (2) Smaller stellate, or spindle-shaped cells with 5 to 20 dendrites. The axone is also amyelinated when it enters the nerve but may later receive a delicate myelin sheath. The dendrites are short and thick and form synapses about other cells of the same ganglion. These are motor cells. The corpuscles of Nissl are of medium size and are grouped near the periphery of the cell.

The fibers in a sympathetic ganglion are both myelinated and amyelinated. The former are derived from the cerebrospinal system and constitute the white rami communicantes while the latter are the sympathetic fibers proper. The amyelinated nerve fibers predominate in sympathetic ganglia.

Sympathetic nerves have the same general structure as those of the cerebrospinal system but the sheaths are usually thinner and the nerves smaller. In the larger nerves are found many myelinated fibers that are derived from the cerebrospinal system.

Degeneration and Regeneration of Nerves.—If a living nerve be cut union between the cut parts is reëstablished by cicatricial tissue but the cut fibers themselves do not unite. The peripheral or distal portion of the process undergoes degeneration within twenty-four hours after the lesion in warm-blooded animals, but the changes are later in cold-blooded animals. The neurolemma becomes quite distinct, its nuclei increase in size; the myelin sheath undergoes changes and droplets of fat become abundant. The axis cylinder undergoes disintegration and disappears. The myelin is almost entirely removed (probably by the action of phagocytes) but fatty granules in the neighboring cells increase and stain more deeply with osmic acid solution than the normal myelin. This process is not limited to one part of the axone but occurs along its whole length at the same time. This change occurs earlier in the motor than in the sensor nerves. Regeneration also occurs more rapidly in motor than in sensor fibers.

The proximal portion (cell end) of the axone does not usually degenerate but regenerates. After the lesion the cut end usually becomes slightly swollen. The regeneration process is slow as changes are not noticed until nearly two months have elapsed. If
the nerves be then removed and sections made then the old neurolemmal tubes will be found to contain new axones, and new fibers, individual or in groups, are seen between these. These *new fibers* may be amyelinated or possess a thin myelin sheath. These fibers are seen to be continuous with the proximal ends of the original nerve fibers. The small groups noted may be the outgrowth of only one axis cylinder, or only one or two may arise from one axone but these will then branch and rebranch until quite a number has been formed. These new fibers arise from a node just above the area of section or injury and seem to arise as collaterals do in normal conditions. As a result there are more fibers in the healed nerve than in the original condition. The new fibers arise from the old one near a node and may enter the old neurolemmal sheathes or be independent of these. In the latter case they are at first amyelinated and later become myelinated and receive a neurolemma. The growing cut ends of the axones are bulbous and resemble the growing axonic process of the neuroblast. As this growth is slow, the function of the nerve is not resumed for many months after the lesion and only a few of the many new fibers assume the function of the fibers cut. In some instances the new connections are never established.

The new axones that do not enter the old sheath have a very irregular course. This is probably due to the fact that they have no original path to follow and must sort of seek their way. Regeneration occurs more quickly if the cut ends are placed in apposition. If a gap is left the process is slower. If a piece of the nerve be removed and the cut ends cannot be brought together then a piece of *guide material* should be placed in the gap. The best material is a piece of aseptic, dead nerve (Huber).

From the foregoing it will be seen that in the peripheral nerve system that the distal end of the cell process will degenerate while the proximal or cell end and the cell body usually do not. In addition the proximal end usually grows or regenerates and attempts to reestablish the former connection; under fairly favorable conditions the connection is established. If the cell body is undisturbed the nerve fiber will regenerate. On the other hand if the cell body is injured all of the processes will degenerate as their nutrition is controlled by the nucleus.
In the central nerve system conditions are different. The fibers crossing in the brain and spinal cord do not regenerate so that in lesions of these parts in which the fibers are cut regeneration and re-establishment of connections do not occur. Destructive injuries here are permanent.

NERVE ORGANS

Nerve fibers terminate either in the form of telodendrites (free) or in some special structure called a *nerve organ*; these may be comparatively simple or very complex. There are two varieties of organs *sensor* and *motor*.

The *sensor organs* are free, tactile *cells, corpuscles* and *spindles*.

The *free terminals* are found in mucous membranes (especially in stratified epithelium), serous membranes, cornea, skin and inter-muscular connective tissue. As the myelinated nerve fibers approach their termination they branch. In the epithelial structure when the basement membrane is reached the neurolemma and myelin sheaths disappear and the naked axone enters the epithelial relay. In this the terminal fibrillae, which are usually varicose, end in leaf-like expansions, or bulb-like enlargements upon the epithelial cells but not within them. In serous membranes and in the intermuscular septa the fibrils end in flattened expansions.

**Tactile Cells Are Simple and Compound.**—The simple variety consists of modified epithelial cells, each of which is composed of a disc-like structure, 6 to 13 microns in diameter, and a mass of clear cytoplasm. In each disc a naked nerve fiber (dendrite) terminates. These structures are found within the interpapillary portions of the epithelium of the skin and in the root sheaths of the hairs.

The *compound tactile cells* consist of two or more discs containing between them tactile cells which are nucleated masses of granular protoplasm. See Grandy’s Corpuscles.
The tactile corpuscles or bulbs are the more differentiated of these organs. They vary in complexity from the comparatively simple genital and conjunctival corpuscles to the more complex corpuscles of Meissner and Vater.

![Fig. 119.—Simple Tactile Cells in the Epithelium of a Pig's Snout. (After Ranvier.)](image)

![Fig. 120.—Compound Tactile Cells, with Two and Three Cells, from a Duck's Tongue. (After Isquierdo.)](image)

The conjunctival corpuscles or bulbs are spherical, oval, or pear-shaped bodies in which the cells are not regularly arranged. The nerve fibers, upon piercing the structure become amyelinated and pass through a central core of homogeneous protoplasm and terminate in a bulbous manner. The core is surrounded by a capsule that is composed of flattened cells. These organs average from 60 to 400 microns in length and may have as many as 10 nerve fibers connected with one organ.

The genital corpuscles or bulbs are more complex. Each is divided into two to six knob-like parts. The nerve fiber enters
the organ and divides into numerous branches each of which passes to a segment; here it may continue undivided, or form a series of branches. These are surrounded by the capsular cells. These measure from 60 to 400 microns in length and 40 to 100 microns diameter. They are found in the mucosa of the glans penis, glans clitoris and neighboring structures.

Other end bulbs both simple and complex are found in the peritoneum, around joints, in tendons and ligaments and even in nerves.

The corpuscles of Ruffini are cylindrical structures consisting

![Fig. 121.—Bulbous Corpuscle from the Human Conjunctiva. Methylene Blue Stain. (After Dogiel, from Böhm and von Davidoff.)](image1)

![Fig. 122.—Genital Corpuscle from the Human Glans Penis. Methylene Blue Stain. (After Dogiel, from Böhm and von Davidoff.)](image2)

of a central core of connective tissue, or according to some, granular material. This is surrounded by a sheath of connective tissue. The nerve fiber usually enters from the side, loses its sheath of Henle and within the structure becomes a naked process that forms a close ramification of fibrils around the connective tissue bundles, or in the granular material. One original nerve fiber may supply a number of these organs. These are found in the deeper portion of the stratum reticulare of the skin and are about as numerous as the Pacinian corpuscles.

The corpuscles of Golgi-Mazzoni are cylindrical, or spherical organs and consist of a large granular core surrounded by a capsule of connective tissue that consists of a number of layers. As the nerve
fiber penetrates the structure the sheaths blend with the capsule and the naked process enters the granular core and divides into a number of branches that terminate in flattened expansions. These are found in the derma of the external genitalia, the fingers and in the periosteum and conjunctiva.

The corpuscles of Grandy are really compound tactile cells. Each consists of a capsule of white fibrous tissue surrounding two or more tactile epithelial cells. These cells are flattened and their cytoplasm is striated. Between the cells are the tactile discs. When the nerve fiber enters the organ the sheaths are lost upon entering or by the time it has passed through the capsule. The naked axone then divides into as many branches as there are discs and one branch ends in each disc in a series of fibrils, which according to Dogiel, enter the adjoining cells. These organs are found only in the aquatic birds.

The corpuscles of Herbst resemble somewhat the Pacinian corpuscles. Each consists of a capsule in which the outer layers run longitudinally and the inner ones transversely. The core is composed of transversely placed cells and it is traversed by the naked fiber. These organs are found in the cere of aquatic birds.

The tactile corpuscles of Meissner are more complex. Each measure about 100 to 180 microns in length and 35 to 50 microns in diameter. It consists of a capsule of white fibrous connective tissue that encloses a number of flattened masses of protoplasm with transversely placed nuclei. One or more nerve fibers is connected with each organ and upon contact with the corpuscle the neurolemma is lost. The myelin sheaths soon leave and the naked fibers, after a spiral course, divide into a number of varicose fibrils that form a network and then terminate in small bulbous enlargement near the capsule. These are found throughout the skin of the body but are most numerous in the derma of the palmar surface of the finger tips (as many as twenty to the square milli-
NERVE TISSUES

meter). They are also found in the derma of the plantar surface, in the nipples, lips, glans clitoris and penis and the conjunctiva. They convey sensations of pain, pressure, warmth and cold. It is said that two sets of sensor fibers enervate them, one for light pressure and light temperature changes and the other for pain and extreme temperature changes.

Pacinian corpuscles (Vater) are also called lamellar corpuscles. Each consists of a capsule, inner bulb and end knob. The capsule consists of lamellae of connective tissue concentrically arranged and which are usually bound together by an intracapsular ligament. These lamellae are from forty to sixty in number and the outer ones are more widely separated from one another than the inner ones. Each lamella is said to consist of both white fibrous and elastic tissues and is covered upon both surfaces by endothelial cells forming a series of lymph spaces.
The inner bulb, or core, is a cylindrical mass of protoplasm that may show striations and nuclei. It is thought to consist externally of flattened nucleated cells surrounding the more homogeneous central portion. A single nerve fiber enters each corpuscle. As it pierces the capsule the neurolemma blends therewith and the myelin sheath is lost when the inner bulb is reached. The naked axone, showing its fibrillation, in properly stained sections, passes through the core at the end of which it expands into knob-like structure, the end knob. In this the terminal fibrils form a very dense mesh-work. If the fiber divides in the core the latter also divides. A small amyelinated nerve fiber has been found by Solokoff, passing to the core and terminating upon it in a reticular manner.

A small artery and vein accompany the nerve into the corpuscle. The artery forms capillary vessels that form loops between the lamelle; one capillary accompanies the inner bulb and courses along the outer surface of this for a variable distance. The blood is returned by a small vein that leaves at the nerve entrance.

These organs are visible to the unaided eye, measuring usually 2.5 mm. in length and 1 mm. in diameter. They are found in the deep part of the derma, along tendons, around joints, in the peritoneum, in the mesentery (especially in lower animals) and in the pancreas of the cat.
Muscle Spindles.—These organs are spindle-shape and consist of from 4 to 20 small voluntary muscle fibers, the *intrafusal fibers*, surrounded by a delicate white fibrous sheath called the *axial sheath*. External to this is the *capsule* composed of about six layers of white fibrous connective tissue concentrically arranged and separated from the axial sheath by a lymph space. In the equatorial region of the organ the muscle fibers consist chiefly of sarcoplasm and the striations are faint, while at the ends the striations are quite distinct. The muscle fibers are said to pass into tendon fibers at their ends and these fibers may continue into the intramuscular tissue, or if the spindle be near the tendon end of the muscle the fibers become continuous with those of the tendon. One or more nerves enter the organ near its equator and branch just inside of the capsule; these lose their sheaths and wind about the intrafusal fibers in the form of rings or spirals or may form a series of telodendrites. These all terminate in *flower-spray endings* upon the surface of the various intrafusal muscle fibers. Although these terminations resemble motor terminals they are sensor. Motor terminals have been demonstrated in these muscle fibers.

The spindles are numerous in some muscles (small muscles of the hands and feet), few in others (eye muscles), and absent in others. They measure from 1 mm. to 5 mm. in length and 0.1 mm. to 0.2 mm. in diameter. Each has its own blood-vessels that accompany the nerve through the capsule.

**Tendon spindles** resemble muscle spindles except that the intrafusal fibers are tendon fibers and the naked axones do not wind around the intrafusal fibers but branch into minute fibers that terminate in little plates upon the tendon bundles. They are most numerous near the junction of the muscles and tendons.

The **motor terminals** comprise those in voluntary striated muscles, those of smooth and of cardiac muscle tissues and those of glands.

The nerves of the *voluntary striated muscles* are of the myelinated type and are comparatively large. After passing through the epimysium the nerve divides into branches that form a plexus in the perimysial sheaths. From this plexus fibers enter the fasciculi and form a plexus in the endomysium. As such a nerve does not contain as many fibers as there are muscle fibers, usually, the fibers that are
"Medullated nerve fiber.

Terminal ramification. Tendon bundle.

Muscle fibers.

**Fig. 128.**—Tendon-spindle of a Cat. (*Stöhr's Histology.*)

**Fig. 129.**—Motor Nerve-endings in Intercostal Muscle of a Rabbit. 

- a, Sensor nerve fiber; b, muscle fibers; c, motor plates; d, myelinated nerve fiber; e, bundle of nerve fibers. (*Stöhr's Histology.*)
derived from the endomysial plexus give off branches or collaterals so that there will ultimately be as many nerve fibers as there are muscle fibers. As this terminal nerve fiber pierces the sarcolemmal sheath the neurolemma and myelin sheath blend with the sarcolemma and the naked axis cylinder alone enters the muscle fibers. This passes to the sole-plate which is a mass of granular, nucleated protoplasm. Within this the fibrillae of the nerve fiber terminate in bulbous enlargements, which, with the sole-plate constitute the end-plate. There is but one organ to each muscle fiber.

The smooth muscles are supplied by the sympathetic nerves. These form plexuses between the fasciculi or muscle layers and at

![Diagram of motor plates](image)

**Fig. 130.—Motor Plates.**

A, Surface view, from a guinea-pig. B, Vertical section, from a hedgehog. g, Granular substance of the motor plate; m, striated muscle; n, nerve fiber; t.r., terminal ramifications of the nerve fiber. (After Böhm and von Davidoff.)

the intersections of the meshes ganglion cells are to be found. Fibers (amyelinated) from this plexus may form a secondary plexus in between the muscle fibers and from this the terminal fibers pass to the muscle cells. Here they end as tapered, or bulbous extremities that are applied to the surface of the muscle cells. Some of the fibers of smooth muscle are of sensor function.

Cardiac muscle is also supplied by the sympathetic system. The fibers may form delicate plexuses at the intersections of which are found ganglia of various sizes. Individual amyelinated nerve fibers pass to each muscle cell and terminate upon its surface in many fine fibrils that spread over each nucleated segment or cell. Some of the fibrils may terminate in small granules or knobs. Occasionally terminals resembling those of voluntary muscle are found in the cardiac type. Sensor terminals seem to be present in the intermuscular septa.
In *secreting glands* the nerve fibers are amylinated and arise in sympathetic ganglia. In the gland the nerve fibers pass to the

![Fig. 131. - Termination of Secretor Nerve Fibers in the Tubules of the Submaxillary Gland of a Dog. (After G. Retzius.)](image)

secreting epithelium, divide into fibrils each of which terminates in a varicose manner between and upon the cells but does not pass into the cells. These are the *secretor fibers*. 
CHAPTER VII

CIRCULATORY SYSTEM

The circulatory system comprises the heart, arteries, capillaries, veins and the circulating fluid, the blood.

THE HEART

The heart is the most important member, as on its contractions depends the circulation. It is a thick-walled, hollow, muscular organ composed of three coats, the endocardium, myocardium and epicardium. These three coats are analogous to the coats of the vessels. Of these three the one that continues with the least change throughout the vessels is the internal coat; of this the endothelial layer continues in an unbroken line through the arteries, capillaries and through the veins back to the heart. The walls of the chambers have not all the same thickness and this is due to the different quantity of muscle tissue present. The reason for this difference is that in the two sets of chambers the muscular effort required of them is not the same.

The endocardium consists of a lining of endothelial cells which rest upon the subendothelial (fibroelastic) tissue. It is thicker in the atria than in the ventriculi. Although the endocardium is smooth, glistening and transparent it does not always run an even and regular course as in the blood-vessels, for in parts of the chambers the myocardium is very irregularly arranged. The endocardium lines every part of these chambers, covers the valves and chordæ tendineæ and is continuous with the intima of the vessels of the heart.

The endothelial cells are flattened, nucleated plates that have an irregular outline and are held together by a small amount of intercellular cement. They differ but slightly from those found within the vessels. The layer of cytoplasm may be so thin that the nuclei project somewhat. The cells are usually lanceolate or elongated
with serrated edges. These serrations fit into the neighboring cells so that with the intercellular cement a tight joint is formed.

The subendothelial tissue consists of delicate fibroelastic tissue. The outer part of this layer (next to the myocardium) contains less elastic tissue and the fibers are usually coarse. Frequently adipose tissue is found here; this is apparently more common in later life than in the young human adult and seems commoner in animals than in man. It may contain a few involuntary nonstriated muscle fibers. Here also are seen some partly developed heart muscle fibers, called Purkinje fibers; the fibrillae are few and form a peripheral ring in these muscle fibers. They are common in some mammalian hearts, and in man they are represented by the terminals of the Bundle of His.

Over the chordae tendineae and papillary muscles the endocardium is very thin and the elastic tissue is less in amount.

Guarding the atrioventricular orifices and the openings into the pulmonary artery and aorta are duplications of the endocardium called valves. Around the openings the fibroelastic tissue is condensed to form a ring-like mass, the annuli fibrosi. These rings serve as origins for the valves and muscle. In the larger quadrupeds cartilage may be present.

The atrioventricular valves consist of two layers of endocardium continuous at the free edges of the valves; the central part consists of a layer of tough white fibrous tissue containing but few elastic fibers. This central tissue is continuous with the rings and the chordae tendineae. At the bases of the valves there is a considerable quantity of smooth muscle tissue which may act as a constrictor of the orifice. The atrial muscle may extend for a short distance into the atrioventricular valves.

The chordae tendineae consist of cords of white fibrous tissue surrounded by a thin layer of the endocardium. Above they are attached to the valves where the endothelial surface becomes continuous with that of the valve and the central cord fibers pass to the central fibrous mass of the valve and join it in a radiating manner. Below they are attached to the papillary muscles where the endothelial surfaces are continuous and the central fibers blend with the endomysium of the papillary muscles.
The semilunar valves have the same general structure. They differ in several ways. No chordæ tendineæ are present and each valve possesses a marginal band, under the endocardium, in the middle of which there is an enlargement, the corpus Arantii. At each side of the corpus there is a small semilunar fold called the lunula. The band strengthens the free edge of the valve while the nodule probably ensures complete closure of the valves. These valves are thinner than the atroventricular valves. The atrial myocardium may continue into their bases. Blood-vessels extend into them as far as the muscle tissue penetrates. The aortic valves are more elastic on the ventricular surface than upon the aortic surface.

The atrioventricular bundle, or bundle of His, consists of a bundle of peculiar fibers that connects atria and ventricles. It arises in the interatrial septum and on the right side thereof, near the orifice
of the coronary sinus, and adjacent points; it then passes forward between the annulus ovalis and the atrioventricular orifice, the fibers converging to form a node (Tawara); from this node a single bundle is formed that turns down into the atrioventricular septum at the base of the median leaflet of the tricuspid valve; it passes into the pars membranacea septi, and at the beginning of the muscular portion of the interventricular septum it divides into two fasciculi, one for each ventricle. These bundles lie just beneath the endocardium, surrounded and insulated by fibrous connective-tissue sheaths. Passing toward the apex of the heart each bundle upon reaching the apical third sends branches to the papillary muscles and there forms a large number of twigs that extend in all directions over the ventricular surface and come into histologic relation with the cardiac muscle fibers. The main bundle is in relation with a bursa and the entire bundle is supplied by an artery from the right coronary. Other similar fibers form a network in the atrial wall near the entrance of the superior vena cava. These constitute the node of Keath and Flack and is also called the sinoatrial node. The cardiac contraction begins in the muscle tissue of the atrium in the vicinity of the node of Keath and Flack; the impulse is taken up by the node and transmitted to the atrioventricular bundle by means of which the impulse is transmitted to the musculature of the ventricles, causing their contraction.

The muscle fibers, less differentiated than those of the general myocardium are striated but the sarcoplasm predominates. The fibrillae are few and peripherally placed, forming a circle, or irregular or triangular groups. The volume and size is greater than in the ordinary cardiac fibers. The pigmentation is localized and not prominent. The cell-boundaries cannot be definitely located so that these cells form a syncytium. These fibers represent early stages of muscle development from undifferentiated protoplasm. The vagal and sympathetic nerves supply this bundle.

Johnson (Anat. Rec., Sept. '23) made a special study of the Purkinje fibers of the heart of the calf. In all parts of the atrioventricular bundle that lent themselves to teasing, the fibrillae in many preparations showed alternating dark and light bands in the presence of polarized light. Therein they resemble muscle tissue. The vascu-
lar supply of the Purkinjé fibers is also less than to the cardiac muscle. It seems possible that the property of transmitting the contraction wave from the atrium to the ventricle may be associated with a slight contraction of the fibrillae of the Purkinjé fibers. That the contraction is not extensive seems indicated by the scanty blood supply and the over abundant connective tissue between and around the Purkinjé fibers.

The myocardium consists of involuntary striated muscle. In the atria the fibers are arranged in two layers, inner and outer. The inner layer consists of two sets, one of which loops over each atrium from front to back; the other, annular fibers surround the appendages and form rings about the orifices of the veins and the fossa ovalis. In the outer layer the fibers run transversely from one atrium to the other predominating upon the ventral surfaces of the atria. In the ventricles the fibers cannot be separated so distinctly into layers. Some run longitudinally, others transversely, while the greatest number have an oblique, circular, or spiral course, forming even a figure eight. Owing to this arrangement distinct lamellae cannot be formed. Usually incomplete internal and external longitudinal layers are formed between which are seen the circular fibers that form the thickest layer. Besides the latter are found spiral and oblique fibers that are present chiefly in the upper and lower portions of the left ventricle. Most of the layers terminate in the papillary muscles.

A delicate meshwork, of areolar tissue is seen between the muscle fibers; this is the endomysium and it supports the numerous vessels and muscle fibers. In the endocardial and epicardial surfaces of the myocardium the fibrous tissue is a little more abundant and serves to connect these coats together. These layers of fibrous tissue constitute the internal and external perimysial sheaths, respectively.

The epicardium, or visceral layer of the pericardium, consists of a single layer of endothelial cells resting upon the subendothelial tissue. It differs from the endocardium in possessing no muscle tissue and is separated from the myocardium more or less completely by a thin layer of adipose tissue. The deeper fibers connect it with the external perimysium of the myocardium. It is thickest over the main branches of the coronary vessels where fat is usually found.
The pericardium consists of two parts, serous and fibrous. The serous pericardium is a continuation of the epicardium over the great vessels and upon the inner surface of the fibrous portion. The fibrous portion is a sac-like organ, consists of dense white fibrous tissue and serves as a protection to the heart. It is attached by its base to the diaphragm and its apex is continuous with the fascia of the neck.

The blood-vessels of the heart are branches of the coronary arteries; the capillaries form plexuses parallel to the long axes of the muscle strands and they may even lie in grooves on the strands. The venous capillaries attain a size of 0.25 mm. before continuing as venules. The endocardium is nourished by the blood that flows over it.

The lymphatics are superficial and deep. They are present in all of the coats but do not communicate with one another to any great extent. The lymph capillaries are numerous especially in the myocardium and epicardium.

The nerves are from both systems and sympathetic ganglia are numerous. The sensor nerve plexuses are subendocardial. The fibers end in direct contact with the endothelial cells of the endocardium and chordæ tendineæ. In addition end-plates are also present, especially in the atrial endocardium and in the epicardium.

The afferent nerves are derived from plexuses at the intersection of which are found ganglia of various sizes. Individual amyelinated nerve fibers pass to each muscle cell and terminate upon its surface in many fine fibrils that spread over each nucleated segment or cell. Some of the fibrils may terminate in small granules or knobs. The ganglia comprise four to five groups of ganglion cells upon the dorsal walls of the atria in the region of the interatrial septum.

The blood is sent from and returned to the heart by the vessels. Of these there are three varieties: (1) arteries, or efferent vessels; (2) capillaries, or connecting vessels; (3) veins, or afferent vessels.

The arteries carry oxygenated blood with the exception of the pulmonary arteries; the latter in that one particular resemble veins. Arteries, however, always carry the blood away from the heart, toward the periphery.
1. For convenience of description, the arteries or efferent vessels are classed as large, medium and small. The large are the aorta and pulmonary artery; the medium the remainder of the named arteries of the body, and the small, the unnamed branches that gradually become capillaries. All have the same general structure, consisting of three coats, tunica intima, tunica media and tunica adventitia; they carry the blood from the heart.

As the medium-sized artery is the type, its description will be considered first and then the differences between it and the others will be pointed out.
Medium-sized Artery.—The tunica intima, or interna, consists of three layers, the endothelial, subendothelial and an internal elastic lamina. It is elastic but easily broken in any direction so that it does not strip readily. It is usually corrugated or wrinkled due to the contraction of the artery after death.

The endothelial cells are elliptical, or irregular, elongated cells with clear outlines and prominent nucleus and nucleolus. The layer of cytoplasm is usually so thin that the nuclei form a bulge. The cells form a continuous surface and their serrated edges are held together by a small amount of intercellular cement. This is readily outlined by the silver nitrate method. These cells rest upon the subendothelial fibroelastic tissue in which numerous tissue spaces exist. The elastic fibers are delicate and this layer is usually thin.

Limiting this coat is a prominent wavy band (on transverse section of the artery) of elastic tissue, the internal elastic lamina. This is usually not solid but shows a number of perforations for which reason it is sometimes called a fenestrated membrane. It does not take the ordinary plasmatic stains well and therefore appears as a light band. It stains readily with the elastica stains.

The tunica media consists chiefly of circularly arranged involuntary nonstriated muscle tissue. The fibers are small and closely packed. At the origins of the branches of the abdominal aorta oblique and even longitudinally arranged smooth muscle may be found. The muscle fibers are held together by a small amount of white fibrous tissue and numerous yellow elastic fibers are present. Some of the latter run transversely and others course obliquely. Often a band of elastic tissue separates the media from the adventitia; this is the external elastic lamina but it is not so thick nor so prominent as the internal lamina. Some consider this lamina a part of the adventitia.

The media forms a considerable portion of the thickness of the arterial wall and it is usually thicker on one side than the other.

The tunica adventitia, or externa, is a thick fibro-elastic coat, and protects the vessel from undue dilatation. The elastic tissue is very abundant and consists of coarse fibers that are longitudinally arranged near the media. In some vessels, as renal and splenic arteries, longitudinal muscles fibers are found. It is about one-half
or two-thirds the thickness of the media. This coat contains the larger trunks that nourish the vessels, the *vasa vasorum*. The *nervi vasorum* are present also, and form branches that pass to the muscle coat.

**Fig. 134.**—**Cross-section of the Human Aorta.** Hematoxylin and Eosin Stain. (Photograph Obj. 16 mm., Oc. 7.5 X.)

The **large arteries** are mainly elastic tubes. The **intima** is not so distinct and gradually fades into the media. The **endothelial cells** are shorter. In the aorta an *internal elastic lamina* is not present but is often found in the common iliac arteries where it may be double. The elastic fibers usually fuse to form the *fenestrated membrane of Henle*. Although the **media** is very thick the muscle tissue is comparatively scant and the **elastic tissue predominates**. The
muscle fibers, which are often forked, are arranged in layers alternating with elastic tissue and some white fibrous tissue. In a well marked vessel the media consists of a thick elastic lamella, then a thin layer of fibroelastic tissue (delicate fibrils) and then a layer of smooth muscle tissue; this order is repeated until many layers are present. In the child at birth there may be forty or fifty elastic layers and a corresponding number of muscle layers; from childhood to the adult stage the number of each gradually increases to about seventy layers. The muscle fibers are from 160 to 250 microns in length and they are mostly circularly arranged. Toward the adventitia, however, some longitudinal muscle fibers are found.

This coat does not stain as deeply as the corresponding coat of the medium-sized arteries and from the above, the structure is markedly different. This coat is very elastic but not contractile. The same

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**Fig. 135.—Cross-section of the Human Aorta. Weigert's Elastica Stain.** (Photograph Obj. 16 mm., oc. 5 X.)
structure prevails in the large branches of the aorta. The adventitia is usually thin but otherwise resembles that of other arteries.

Dees (Anat. Rec., Sept. '23) found that the fenestrated membrane of Henle consisted of two parts. The outer, or peripheral portion is a solid film-like sheet that consists of a network of fine elastic fibers with numerous openings. Upon the internal, or intimal surface of this membrane is seen the second layer. This is an open meshwork of coarser elastic tissue, the fibers of which are arranged parallel to the long axis of the vessel. This network is fused to the surface of the perforated membrane. In sections the fenestrated membrane proper has the appearance of a homogeneous line. The inner meshwork part exists by itself in the adventitia. In the media of large arteries the felted and the meshed layers are very numerous.

In small arteries the muscle tissue predominates and these are contractile tubes. The intima is thinner but the elastic lamina is very prominent and thick. The media is proportionately thicker than in other arteries and consists entirely of smooth muscle tissue circularly arranged. Elastic tissue is practically absent although at times a thin external elastic lamina may be seen. The adventitia is thin.

From birth to old age the intima increases rapidly from 6 microns to 190 microns in thickness and the media from 650 microns to 1100μ while the adventitia decreases (at birth 1485μ and at 16 years 688μ). The increase in the intima is due at first to the addition of new white fibrous tissue and later to the addition of yellow elastic tissue. The intima shows a greater thickening upon one side for some peculiar reason. As old age advances the vessels lose their elasticity through the conversion of the elastic tissue into inelastic elacin. As the continued blood-pressure would tend to increase the caliber this condition is overcome by the special thickening of the intima.

The difference in structure may be explained by the difference in function of the arteries. The large arteries are practically elastic tubes, the main tissue being elastic. These vessels must be able to suddenly increase their capacity and return to the normal caliber without injury but they must not reduce their caliber to any appreciable extent. When the heart contracts a large volume of blood is
suddenly forced into the large arteries and they dilate to accommodate it. Through the natural recoil of the stretched elastic tissue and the removal of the resistance ahead (the flow of the blood into the smaller arteries) the blood in the large arteries is gradually forced onward and the vessels return to their normal caliber. They must not decrease this caliber for if that were to occur it would increase the resistance to the blood entering from the heart and cause this organ to hypertrophy to overcome the increased resistance.

![Small Arteriole Forming Capillaries](image)

**Fig. 136.**—Small Arteriole Forming Capillaries. The irregular outlines of the endothelial cells are shown. (From Schäfer after Mann.)

The medium-sized arteries are mainly contractile vessels and yet they have sufficient elastic tissue in their walls to permit of some dilatation. Their normal caliber is sufficient for the ordinary blood-supply and if more blood is required they can relax their muscle tissue and even be stretched some without injury. If the amount of blood be too great these vessels can contract and cut down the amount somewhat.

The small arteries and arterioles have no elastic tissue except an elastic lamina. These vessels are the ones that mainly control the supply of blood to a part and it is upon these that many drugs
given for that action have their effect. These are essentially only contractile tubes and are for the purpose of cutting down the amount of blood and to prevent congestion. If that amount is not sufficient then by the relaxation of the muscle tissue in their walls the vessel increases its caliber and so permits of more blood. The caliber of these vessels in the living condition is somewhat smaller than in the dead because under normal conditions all of the smooth muscles of the body are slightly contracted all of the time and this is called tonic contraction (due to adrenalin probably). If this tonic contraction be withdrawn then the vessels dilate somewhat through the relaxation of the muscle.

Variations in the structure of some of the arteries are to be found. The roots of the aorta and pulmonary artery usually contain a considerable amount of cardiac muscle tissue. The arch of the aorta may contain some smooth muscle tissue, longitudinally arranged, in all three coats. Some of the larger branches may have spirally directed muscles, especially those vessels that are bent. The arteries of the brain and its coverings are all thin-walled and the only elastic tissue present is in the lamina.

As the vessels become reduced, the intima is the first to suffer; the subendothelial tissue disappears, and the endothelial cells are seen to rest upon the elastic lamina. The media becomes attenuated so that only a single layer of muscle fibers is seen. This soon becomes reduced to a few stray fibers. The adventitia becomes greatly reduced and is represented by a few bundles of fibrous tissue. This is practically the precapillary vessel. It is succeeded by the capillary.

2. The capillaries or connecting vessels are merely delicate tubes consisting of a single layer of endothelial cells placed end to end, and held together by intercellular cement. These are readily outlined with silver nitrate. These cells are not so firmly united but that the leukocytes can force their way between them (diapedesis). The openings thus formed are the stomata but they are not permanent. The endothelium is held by some to be phagocytic. They are the smallest vessels, and anastomose freely to form loose or dense plexuses. At times they are very irregular, possessing dilatations. They are practically very thin animal membranes,
and through their walls the liquid portion of the blood and the ameboid white blood cells have no difficulty in passing into the surrounding tissues. Small capillaries average 5 to 7 microns in diameter, 500 microns in length, and cross-sections show that they are encircled by two endothelial cells. Large capillaries average 3 to 13 microns and are encircled by three to four endothelial cells. Stöhr claims that capillaries can contract as nerve endings are found in the cells.

Capillaries are found in practically all tissues except epithelium and adult cartilage. In the organs in general the capillaries are not in direct contact with the functionating cells but are separated by a space into which the lymph passes and bathes the cells. The meshes are long and narrow in tendons, muscles and nerves. In mucous membranes and the skin the capillaries form loops. In the lungs, glands and adipose tissue the meshes are close.

In certain tissues and organs the capillaries are peculiarly modified. In the skeletal muscles the capillaries run parallel to the course of the fibers and are connected to one another by cross-branches that
dilate readily. These are the (1) *ampullae* and during the contraction of the muscle are dilated with blood from the longitudinal vessels, and so take the strain from these.

(2) *Another type of ampulla* is that of the spleen. This form differs from those of muscle in being *larger* spaces or channels bounded by the endothelium; but of greater importance is the fact that the walls are *perforated*, or *porous*. This permits of the extravasation of all of the blood elements into the splenic pulp. This type occurs in no other organ, except possibly in red bone-marrow.

In the liver, adrenal, spleen and carotid gland the endothelium of the capillaries is in direct contact with the functionating epithelium or parenchyma of the gland. These capillaries are called (3) *sinusoids* (Minot) and the nutritional relation is of the closest. No spaces exist between the vessels and the epithelium and the nutritional elements pass directly into the cells so that any internal secretion may pass directly into the capillaries.
In parts of the cortex of the kidney arterioles break up into a series of capillary tufts from which the blood is again collected by the efferent arteriole; the tuft is a series of capillaries interposed between two arterioles and is called a (4) retia mirabilia.

In the penis and clitoris no regular capillaries exist in the corpora cavernosa. Here the arterioles pass the blood into large dilated cavernous spaces lined with endothelial cells and these are (5) sinuses.

![Figure 140: Sinusoids (Si) in the Liver of a Chick Embryo of Eleven Days. h.c., Cords and tubules of hepatic cells. (Lewis and Stöhr after Minot.)](x300)

In exposed regions, nose, ears, toes, kidneys and membranes of the nerve system, direct communications between the arterial and venule exist. These are (6) anastomoses and are not to be confused with the anastomoses that normally occur between arteries which form the anastomotic circulations of the extremities and certain organs.

The veins or afferent vessels have the same general structure as arteries but the coats are thinner. These vessels collapse readily when cut but they are nevertheless strong. They carry the blood toward the heart, are more numerous and larger than the arteries and anastomose more freely. The precapillary vessels are mere tubes of endothelium supported by a delicate network of fibroelastic tissue.
The coats are tunic intima, tunica media and tunica adventitia. The tunica intima is usually tougher than in the arteries and may be stripped more readily. The endothelial cells are short and broad; the subendothelial tissue is not well developed and the internal elastic lamina is not marked as the elastic tissue tends to form a sort of network and not a membrane. In some veins smooth muscle tissue longitudinally arranged is found in the intima.

At intervals this coat is thrown into folds called valves. These are duplications of the intima. Each valve is a semilunar fold of intima having a central mass of white fibrous tissue that gives it added strength. These are usually attached in pairs and opposite the points of attachment the vein is dilated forming pouches or sinuses. When filled with blood these pouches produce a marked bulge. The valves prevent a reflux of the blood but present no obstruction to the onflowing blood. Valves occur in all of the veins except the venae cavae, portal, pulmonary, hepatic, innominate, common iliacs, mesenteric, splenic, uterine, ovarian, cranial cavity, vertebral canal, cancellous bone and the renal veins.

The tunica media contains a relatively small amount of smooth muscle tissue that is circularly arranged. The bulk of this coat
consists of fibroelastic tissue but the white tissue predominates. In the veins of brain and bones and in the thoracic part of the inferior vena cava muscle tissue is wanting. In the crural, mesenteric and iliac veins some longitudinal muscle tissue is found near the intima.

The tunica adventitia is the most prominent coat. In some vessels as the abdominal part of the inferior vena cava, renal, spermatic, azygos, external iliac, splenic, hepatic and portal veins longitudinal smooth muscle tissue may be found in it. It consists of coarse bundles of white fibrous and yellow elastic tissues and contains the vessels and nerves of the vein.

Veins are merely conducting vessels and cannot assist in forcing the blood along as arteries do. They must be capable of considerable distention and no contraction, hence the presence of fibroelastic tissue in preponderance in the media and the small quantity of muscle tissue.

The blood-vessels are nourished by the vasa vasorum. These lie in the adventitia and from them small branches pass chiefly to the media, mainly for the muscle tissue. The intima has very few capillaries as it is nourished by the blood that flows over it.

**Table of Comparison of Arteries and Veins**

<table>
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<tr>
<th>Character</th>
<th>Arteries</th>
<th>Veins</th>
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<td>Coats.</td>
<td>Three.</td>
<td>Three.</td>
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<td>Size.</td>
<td>Thick.</td>
<td>Thin.</td>
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<tr>
<td>Intima.</td>
<td>Elastic lamina prominent.</td>
<td>Not prominent; may be absent.</td>
</tr>
<tr>
<td>Media.</td>
<td>Mainly smooth muscle.</td>
<td>Little muscle, mainly white fibrous tissue.</td>
</tr>
<tr>
<td>When empty.</td>
<td>Do not collapse readily.</td>
<td>Collapse readily.</td>
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<tr>
<td>Valves.</td>
<td>Absent.</td>
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<td>Course of the blood.</td>
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<tr>
<td>Character of the blood.</td>
<td>Oxygenated (with exception of that in the pulmonary artery).</td>
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<tr>
<td></td>
<td>Give off branches.</td>
<td>Receive tributaries.</td>
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Lymphatics are numerous. Blood-vessels are often the centers of extensive lymph channels that lie in the adventita, and constitute the perivascul ar lymphatics.

The nerves are chiefly sympathetic and are distributed to the media and adventita. These are the nervi vasorum and they form plexuses around the vessels. They are motor and sensor. The motor fibers ultimately terminate in the muscle tissue. The sensor fibers are connected with end-plates in the intima. Pacinian bodies are also found in the adventita.

**BLOOD**

**Blood** and **lymph** are the only liquid connective tissues. Blood is of an alkaline reaction, has a peculiar and characteristic odor due to a volatile fatty acid in combination with an alkaline base. The odor varies in different animals and is due to the different amounts of caproic acid and excrementitious substances in the blood. The alkalinity is due to sodium diphosphate, some of which is in the plasma and some in the red cells. Its saline taste is due to the presence of sodium chlorid. Its specific gravity (1.051 to 1.056) is diminished by liquid foods and increased by solid foods.

The temperature averages 38°C. This varies as follows: Inferior vena cava 36.7°C. (98.2°F.); hepatic vein 39.7°C. (103.4 F°). In lower animals the temperature varies as follows: Dog, 37.9° to 39°; mouse, 37° to 38°; fowl, 40.9° to 44.1°; in the frog the temperature closely follows its environment as say -5° in January to 30° to 40° in July.

It is composed of cellular elements, the corpuscles, and the intercellular substance, or liquor sanguinis. The quantity of blood seems to vary at different ages. In the infant it represents one-nineteenth of the body weight and in the adult one-thirteenth, although later investigation seems to give one-nineteenth also for the adult. The distribution is as follows: Liver and skeletal muscles a little over one-fourth each; heart lungs and great vessels together, about one-fourth; the remainder of the body about one-fifth. About one-eight of the kidney is blood and the same applies to the spleen; about one-fourth to one-third of the liver is blood; in the muscles about
one-thirteenth of their weight is represented by blood. Of course these amounts vary with the different stages of activity of the organs.

In lower animals the proportion of the blood to the body weight is as follows: Mice, one-thirteenth to one-twelfth; guinea-pigs, one-twenty-second to one-fourteenth; rabbits, one-twenty-second to one-fifteenth; dogs, one-eighteenth to one-eleventh; frogs, one-nineteenth to one-fourteenth; fish, one-fourteenth.

The cellular elements are of three varieties, the red cells, white cells and platelets. These are said to represent 328 parts and the liquor sanguinis 672 parts.

The red cells, or erythrocytes, are nonnucleated, bell-shaped elements varying from 5 to 9 microns and averaging 7 to 8.5 microns in diameter and 1.9 to 2.0 microns in thickness. The bell-shape is not seen unless the necessary precautions are exercised, that is, to fix the blood before it becomes exposed to the air (see Blood Technic, p. 47). These cells have been studied under various conditions by Weidenrich and Lewis and the author has found that they are to be readily studied in fetal tissues. Upon exposure to air these bell-shaped cells collapse and this accounts for the usual description as that of a biconcave disc. Schäfer and others maintain that the red cells are normally biconcave. When fresh normal blood is examined under the microscope these cells form rouleaux, and this is said to be due to the cells fitting into one another. When exposed to air these cells collapse and resemble rolls of coins on edge.
Under the microscope each cell is pale straw-colored or greenish. It consists of a framework, the *stroma*, that contains an organic iron compound that carries the oxygen; this is the *hemoglobin*. The presence of a cell membrane is still a matter of dispute.

Weidenreich states that the red cells are surrounded by a structureless and colorless membrane enclosing a colored semi-fluid mass that consists chemically of proteins, lecithin, cholesterol, inorganic salts and hemoglobin. A *stroma* does not exist in the adult stage of the cells. The *envelop* will stain with magenta and methyl violet. It is elastic and the cells can change their form and regain their shape.

Some cells average from 5.5 to 7.5 microns, and are called *microcytes*, while those over 8.5 microns are *macrocytes*. Bethe found the various red cells in the following proportions: 6.92 microns, 42 per cent.; 7.26 microns, 28 per cent.; 8.58 microns 16 per cent.; 6.6 microns, 8 per cent.; 9.24 microns, 6 per cent.

In normal blood, the cells tend to form rolls, or *rouleaux*. Under the same condition, 5,000,000 corpuscles are found, per cubic mm., in the male, and about 4,500,000 in the female. At birth the number is 7 to 8 millions. During the first seven to eight days there is a rapid decrease to 5 to 6 millions, the same in both sexes. With the advent of menstruation the number in the female becomes reduced 10 per cent. In an average male of 140 lbs. there are about 4.6 liters of blood and this contains 23 trillions of red cells. Red cells do not last very long so that every hour millions are disintegrating and these must be replaced.

*Nucleated red blood-cells*, or *erythroblasts* are found in the fetus, in red bone-marrow and in the spleen (at times). The cells of average size are called *normoblasts*, the smaller ones *microblasts* and the larger ones *macroblasts*.

In fishes, amphibians, reptiles and birds the red cells are nucleated and usually oval in form. In mammals they are nonnucleated and circular in outline, with the exception of the camel family; in these animals the cells are oval in shape. In the frog the red cells are very large, oval, biconcave nucleated cells and are far larger than the same cells in man, measuring about 24 microns in length and 14.5 microns in width.
The size of the red cell is by no means proportionate to that of the animal. The musk deer possesses one of the smallest (2.4 microns); in proteus the red cell measures 62.5 microns by 34.5 microns, while in amphiuma the red cells are about one-third larger. That of the elephant is but 9.2 microns in diameter and beside it stands that of the humming bird, with a diameter of nearly 9.4 microns.

The red cells may be decreased, or increased under other conditions. Cold baths may cause an increase of 2,000,000 due to capillary stasis. Athletes are said to have 5,500,000 normally. An increase may be caused by thirst, diuretics and purges and by the administration of iron and arsenic; red cells are also increased in number in starvation and fatigue.

![Fig. 143.—Turtle's Blood.](image)

Note some of the cells on edge. (Photograph Obj. 4 mm., oc. 7.5 X.)

The number of red cells is affected by altitude; at 314 meters above sea level the number is 5,322,000; at 700 meters 5,900,000; at 1800 meters 7,000,000; at 4392 meters 8,000,000. This increase is affected during two or three weeks and upon return to sea level the number gradually drops to 5,000,000 again (Köppe). The increase may be due to the concentration of the plasma or to an actual increase in the number of the cells. There is apparently no difference of number in the different races. This increase is termed polycythemia.

A decrease of red cells is called oligocythemia. There is a normal decrease in the adult after 40 years of age. A decrease may also result after the use of lead and mercury compounds. The red cells are also normally decreased after meals, during menstruation, lactation and child birth.
The red cells are more numerous in carnivorous than in herbivorous animals, while in birds they are larger in size. In the amphibians, where the size is great, the number is small. In the dog the red cells measure about 7 microns in diameter; in the sheep 5 microns; in the goat 4 microns; in birds 8.5 to 14.5 microns.

According to Malassez and Hayem, each cu. mm. of goat’s blood contains 18 to 19 millions of red cells; birds 2 to 3 millions; reptiles 0.5 to 1.6 millions; frogs 400,000; proteus 36,000; bony fishes 1 to 2 millions; torpedo 140,000.

The white blood cells, or leukocytes are large, pale, globular cells readily distinguished from the red cells. They consist of about 90 per cent. water and 10 per cent. of solids (proteins, lecithin, glycogen, fat and phosphorus). About 5000 to 8000 are found in each cubic millimeter of blood; there is a physiologic increase at certain times, as after meals, especially those rich in protein material. About 2 to 3 hours after meals the number is greatest. Fasting reduces the number and in total abstinence of food the number may fall to 1000 per cu. mm. At birth they number 17,000 to 20,000 per cu. mm. but by the end of the second week they begin to reduce so that there are about 5000 less by the end of the first year. After the first year the number gradually reduces to the adult number by the period of puberty. In the adult the number is as above, or 1 to every 700 red cells. In pregnancy during the ninth month the number may reach 18,000 especially in a primipara. The proportion in the splenic artery is 1 to 2260 red cells and in the splenic vein 1 to 60 red cells; in the portal vein the proportion is 1 to 740 and in the hepatic vein 1 to 170 red cells. Some of the leukocytes are actively ameboid and phagocytic.

The cytoplasm of the leukocytes is reticular even in the living cells; in addition granules of various types may be present. The nucleus varies from small to large and its stain reaction is not the same in all leukocytes. Some are multinuclear. A centrosome and attraction sphere are usually to be found near the nucleus.

They are classified as follows:

1. Lymphocytes (small lymphocytes), 4.5–7.5μ; 20–25 per cent.
2. Hyalin cells (large lymphocytes), 10–15μ; 2–4 per cent.
3. Polymorphonuclear leukocytes, or finely granular oxyphils (Formerly neutrophil), 7.5-10μ; 60-70 per cent.

4. Coarsely granular oxyphils (Formerly acidophil), 7-10μ; 1-4 per cent.

5. Finely granular basophils, 7.5-10μ; 0.25 per cent.

6. Coarsely granular basophils.

1. The lymphocytes, or microleukocytes, are the smallest of the white cells, average 4.5 to 7.5 microns in diameter and are the first to form. Each consists of a large darkly staining nucleus surrounded by a narrow rim of faintly staining cytoplasm that may be basophilic in reaction. The large nucleus is nearly spherical in form and the chromatin is prominent. This variety is formed mainly in the lymphoid tissues and organs and some arise in the red bone-marrow. This variety is both ameboid and phagocytic and constitutes about 20 to 25 per cent. of the white cells.

2. The hyalin cell, or macrolymphocyte, is the largest white cell and averages from 11 to 15 microns in diameter. It is said that they are derived from the lymphocytes which they resemble. Both nucleus and cytoplasm stain but faintly, hence the name. In the cytoplasm some basophilic granules are occasionally seen. The nucleus is large, eccentric, usually hazy in appearance and often kidney-shaped. In the latter condition the cell is called transitional and was given a special place but it is now considered simply a phase of the ordinary type. This cell is actively ameboid and phagocytic. They are found in lymphoid tissues and organs and some are formed in the red bone-marrow. They represent from 2 to 4 per cent. of the white cells.

3. The finely granular eosinophils, or finely granular acidophils (polymorphonuclear neutrophils) are the most numerous of the white cells and average from 7.5 to 10 microns in diameter. There are said to be several stages of this cell, the younger showing a centrosome and nucleus that contains little chromatin and fewer modifications of nuclear shapes, and older ones that have a dense chromatic network and more varieties of nuclear shapes. The latter may be U, V, W, etc., and may even be divided into a number of segments. The younger cells are said to be capable of reproducing to a slight
extent and the older ones not at all. The cytoplasm contains a large number of fine granules that usually take the plasmatic stains quite deeply. These granules were at one time thought to be neutrophilic and the cells were called neutrophils. These cells are increased in number after a meal and are formed in the red bone-marrow. They are actively ameboid and phagocytic and represent 60 to 70 per cent. of all of the leukocytes. They are the active infection fighters of the body and are the chief cells seen in such areas.

4. The coarsely granular eosionophil, or polymorphonuclear eosinophil is 7 to 10 microns in diameter. The cytoplasm contains a few large granules that take the plasmatic stains very deeply. Ehrlich suggests that these granules may be zymogen granules. The deeply staining nucleus may be horseshoe-shaped or lobulated. The younger cells contain a centrosome and are capable of division but the older ones are not. They are formed in the red bone-marrow and are actively ameboid but not phagocytic. They represent from 1 to 4 per cent. of the white cells in the child but rarely run over 2 per cent. in the adult.

5. The finely granular basophil (polymorphonuclear) resembles group 3 except that the granules take a basic stain. These are formed in the red bone-marrow and are present to the extent of 0.1 to 1 per cent., but are usually under 0.25 per cent.

6. The coarsely granular basophil is said to be absent from normal blood. They are relatively large cells and are also called mast cells. The cytoplasm contains a number of large coarse granules that respond well to the basic stains. The nucleus stains readily and varies in shape. They are said to be present to the extent of 0.5 per cent. Some consider these cells are eosinophils in a state of degeneration; the granules represent fragments of the nucleus and products that are the result of mucoid degeneration of the cytoplasm. Maximow considers them special leukocytes. They are formed in the red bone-marrow and are also found in areolar tissue where they probably end their existence. In certain diseases they increase in number in the marrow and spleen and are found in the blood in greater numbers.

The leukocytes are general scavengers as they remove foreign bodies, bacteria and disintegrating tissues. This process is called
phagocytosis. In their dissolution they contribute to the blood plasma certain proteins that assist in the coagulation of the blood. Some leukocytes are lost in the alimentary tract and some are destroyed by the phagocytes of the spleen, hemolymph nodes and even in lymph nodes.

The blood platelets, or thrombocytes are small, colorless, oval or circular, jagged discs the projections apparently representing pseudopodia. These are capable of ameboid movements and measure from 1 to 3.5 microns in diameter. The cytoplasm is homogeneous

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**Fig. 144.—The Blood Corpuscles.** (Wright’s Stain.) (E. F. Faber, from Da Costa’s Clinical Haematology.)

or finely granular. Each possesses a chromatin mass (*chromidium*) that apparently represents a nucleus. In drawn blood these elements collect in groups. They stain with basic dyes, especially methyl violet. They number 200,000 to 300,000 per cu. mm. They are formed in red bone-marrow and are said to be derived from the myeloplaxes or megakaryocytes, as broken off fragments of their pseudopodia. They are readily found in blood fixed in a 1 per cent. solution of osmic acid.

![Blood Platelets Showing Ameboid Condition and Chromidia.](After Kopsch.)

When these cells come in contact with a foreign body they rapidly throw out processes and adhere to it. In this way they form a plug and assist in stopping hemorrhages, forming a *white clot*, or *thrombus*. They are supposed to contain *prothrombin* which becomes converted into *thrombin* or *fibrin* ferment. The clotting power of blood is in direct proportion to the number of platelets. In certain diseases (anemias especially those following hemorrhage and pneumonia and chronic diseases) these elements are increased in number while in others they are decreased. From observation it seems that the fewer the platelets, the more acute, severe and threatening is the disease; therefore it would seem that there is a direct relation between the severity of the disease and the number of these elements. According to Helber blood platelets are not found in the blood of frogs or birds.
The intercellular substance, or liquor sanguinis, contains the salts of the blood. Its density is such that the cells retain their normal shape. It consists of 90 per cent. water and 10 per cent. of proteins, fats, sugar, inorganic salts, urea, cholesterol, lecithin, etc. It contains not only nutritious substances but waste products and the fibrinogen in solution. If, however, solutions are added that differ in density, the action upon the cells is characteristic.

Upon the addition of strong (hypertonic) salt solution, the cells become irregular in outline, and are crenated. If water or salt solutions under 0.5 per cent. (hypotonic) be added, it dissolves the hemoglobin, and the cells swell and become spherical. These are blood shadows. When these burst the particles constitute the blood dust or hemokonia of Mueller.

The action of acetic acid is important. The addition of a 0.3 per cent. solution decolorizes the red cells and renders the white cells more distinct. This is made use of in hematology for the purpose of counting the white cells, in a fresh condition.

An important property of blood is that of clotting, or coagulation. The fibrinogen is precipitated as fibrin and this entangles the cells. As the fibrin contracts the liquid portion of the blood and the salts are separated as a yellowish fluid which is the serum. This contains no fibrinogen. The clot contains the fibrin and the entangled cells and form in from two to eight minutes after the blood is drawn. The precipitation of the fibrinogen is due to some agent, called thrombin, that is formed by the leukocytes in their decomposition of dissolution and by the thrombocytes. Coagulation of the blood may be hindered by the addition of certain salts as magnesium sulphate and potassium oxalate, or by cold or by certain conditions as jaundice, scurvy, pernicious anemia, purpura and malignant diseases. Clotting is hastened by stirring, the addition of foreign bodies or by keeping the blood at a temperature of 38° to 50°C. It may also be hastened by certain conditions as pneumonia, yellow fever, typhus fever, malaria, septicemia and poisons. The lack of certain substances in the blood leads to difficulty of coagulation and such persons are known as bleeders; the condition is known as hemophilia.

Hemoglobin is an organic iron compound of a globulin and as it exists in the blood it cannot readily be studied. In the lungs the
oxygen forms an unstable compound called *oxyhemoglobin* and in the tissue spaces the affinity for or need of oxygen is so great that it is readily removed from the hemoglobin. The bright red color of blood of the arteries is due to this compound. It is probably in solution in the cytoplasm of the erythrocytes from which it may readily be removed by ether or it can be easily converted into a crystalline form. An increase of hemoglobin is called *hyperchromemia*; this may be due to an increase in the number of red cells, in changes from a lower to a higher altitude and in poorly compensated heart disease with cyanosis. A decrease is called *oligochromemia* and occurs in anemia and chlorosis.

**Fig. 146.**
1. Hemin crystals of man (X 560); 2. crystals of common salt; 3. hematoidin crystals of man. (Stöhr's Histology.)

**Fig. 147.**—Hemoglobin Crystals of a Dog (100 X); a crystal separating into fibers. (Stöhr's Histology.)

**Hemoglobin crystals** will be formed if a drop of defibrinated blood be mixed with a drop of Canada balsam, or clove oil, and covered with a cover-glass. They are large, red, rhombohedral crystals or elongated prisms in man.

**Hemin crystals** may be prepared by adding a small crystal of salt and two drops of glacial acetic acid to a little dried blood, and heating until the mixture boils. During this process it should be covered. When cool, small brownish crystals (*hemin chlorid*) will be found. These may be single or grouped in the form of rosettes, and are known as **Teichmann's crystals**. As these crystals will form as readily in old dried specimens of blood as in fresh specimens this test is of importance medico-legally.

**Hemosiderin** is a decomposition derivative of hemoglobin containing iron. These light brown granules are found in the bone-marrow and spleen and even in phagocytes. Iron in the tissues and iron pigments are no doubt derived from the same source.
**Hematoidin** is another derivative of hemoglobin but it contains no iron. It can be prepared as needle-like crystals of a yellowish color. It is found in the spleen, derived from the disintegrating red cells; from the spleen it is carried to the liver where it is utilized as bilirubin.

Among other blood-making organs are placed the **coccygea** and **intercarotid glands** and **hemolymph nodes**.

The **Coccygeal (Luschka's) gland** (2.5 mm. in diameter), is found in front of the tip of the coccyx, and is connected with the middle sacral artery. It is surrounded by a fibrous sheath, which sends in septa that divide the organ irregularly into *areas*, or *compartments*. The latter contains groups of polyhedral cells surrounded by dense plexuses of capillaries of the sinusoidal type. The cells are thought by some to be epitheloid and derived from the smooth muscle cells of the arterial channels, while others consider them modified endothelial cells. According to Stoerck chromaffin cells are not present in the organ at any stage. Amyelinated nerve fibers are numerous.

The **intercarotid gland** is found at the bifurcation of the common carotid artery, and its structure varies considerably. The cells may be diffusely scattered, arranged in scattered groups, or in ball-like masses. In man the cells are collected in scattered groups and were derived from the sympathetic elements. The cytoplasm is finely granular and the nucleus contains little chromatin. Many of the cells contain a yellowish pigment that gives the chromaffin reaction. The organ, no doubt, secretes adrenalin.

**Hemolymph (Hemal) Nodes.**—These organs vary in size from a pin head to a large bean and are found in abundance in the retroperitoneal and cervical regions and less numerous elsewhere. Each is surrounded by a capsule of white fibrous and yellow elastic tissues, containing a little smooth muscle tissue; trabeculae pass in and form the framework of the organ. In the framework are found *red* and *white* blood-cells. Of the latter, the lymphocytes are the more numerous; besides these hyalin, finely granular oxyphils and basophils are found in varying numbers. Megakaryocytes are also found here. In addition, mononuclear phagocytes that contain pigment and disintegrating red cells are seen. Beneath the
capsule and following the trabeculae to the hilus are seen sinuses, often very large, that do not contain lymph but blood.

These organs usually possess no lymphatics. The blood-vessels enter at the hilus and form capillaries within the organ; these capillaries communicate with the blood sinuses. The large veins are in the trabeculae and begin in thin-walled lacunae that possess perforated walls, by means of which they communicate with the blood sinuses.

Certain atypic organs possess lymphatics. Some of these structures resemble the spleen in structure, others the marrow and still others ordinary lymph nodes.

Nerves are present and probably pass to the smooth muscle tissue.

Parasympathetics, or Aortic Bodies.—These are two to four brownish bodies found in the neighborhood of the inferior mesenteric artery and closely related with the aortic sympathetic plexus. Each is surrounded by a capsule of white fibrous connective tissue that sends in trabeculae that form the framework of the organ. In the meshes of this framework are found the epithelium which consists of groups of polygonal or cuboidal cells closely packed and of the chromaffin type resembling the cells of the medulla of the adrenal. These structures are found only in childhood and are supposed to be accessory in function to the adrenals.

The blood-vessels derived from the aorta, or inferior mesenteric artery, follow the trabeculae and form a rich capillary plexus around the epithelial cell-groups.

The nerves are from the sympathetics and their relation and arrangement are similar to the nerves of the medulla of the adrenal.

HEMAPOIESIS

In the adult the formation of red blood-cells is carried on chiefly by the red bone-marrow; the lymphocytes are formed in the lymphatic tissues and organs and to some extent in the red bone-marrow while the granular leukocytes are formed chiefly in the red bone-marrow. In the fetal condition blood-cells are made in a number of places; the yolk-sac is the seat of origin of the first blood-cells; then the somatic mesenchyme and primitive endothelium of the vessels;
later the spleen, liver, developing lymphatic organs and the bone-
marrow.

Two theories are given as to the origin of the red and white cells; the monophyletic theory is that all the cells have a common ancestor, the hemoblast, or hemogonium; the polyphyletic theory is that the red cells have one ancestor and the white cells a different original mother cell. Later investigation seems to indicate that the monophyletic theory is the right one.

In the development and differentiation of these cells the primitive mother cell divides into two daughter cells; one of these cells continues its function as a mother cell and the other is an hemoblast. The hemoblasts are probably carried by the blood-stream to the organs that are to serve an hemapoietic function, where they proliferate. In certain organs they persist throughout life but in those that have only a temporary function of this nature they ultimately disappear therefrom when that function ceases.

According to Maximow the nucleated red cells are called erythro-
cytes and the nonnucleated cells, erythroplastids. According to him the erythrocytes are of two kinds; the primitive form that does not last long and soon disappears and the definite form that consists of cells a little smaller than the preceding and that persist and that give rise to all the red cells.

When the hemoblast divides, one of the daughter cells continues the function of the mother cell and the other undergoes mitosis. One of its daughter cells is the primitive erythrocyte and the other is called the primitive lymphocyte.

The primitive erythrocyte is about 11 microns in diameter and continues to divide for a while but dies out in early embryological stages.

The primitive leukocyte, or lymphocyte is about 9.5 microns in diameter and the cytoplasm contains some basophilic granules. Each divides and one of the daughter cells is the megaloblast, the ancestor of the continued red cells, and the other is the lymphocyte, the ancestor of the various leukocytes.

The megaloblast is about 8 microns in diameter and the cytoplasm contains only a small amount of hemoglobin; the large vesicular nucleus contains only a small amount of chromatin. This is the
ichthyoid stage of Minot. The daughter cells of the megaloblasts are called normoblasts. These cells are somewhat smaller than their mother cell, the hemoglobin is greater in quantity and the nucleus strains more deeply, due to a greater quantity of chromatin being present. This is the sauroid stage of Minot. The daughter cells of the normoblasts are called erythroblasts. These cells contain more hemoglobin than their mother cells (normoblasts) and the nucleus is smaller and denser. By a loss of its nucleus the erythroblast becomes the erythroplastid. According to some investigators the nucleus is absorbed (karyolysis); according to others it is extruded in mass or in fragments (karyorrhexis); in the pig the nonnucleated red cells are derived from the erythroblasts by a process of budding, the bud containing no nucleus.

The lymphocyte, or leukoblast, the other daughter cells of the primitive lymphocyte, is the ancestor of the white blood-cells. One of its daughter cells is called a premyelocyte (myeloblast) and the other a lymphoblast. The lymphoblast represents the large lymphocyte of the blood and is apparently only a slightly modified original lymphocyte. When these cells divide the small daughter cells are the small lymphocytes of the blood; as these grow they become the large lymphocytes. From the lymphocytes megakaryocytes are also differentiated. These giant cells are 14 to 20 microns in diameter, multinuclear and give rise to the platelets.

The premyelocyte gives rise to daughter cells which by differentiation become the myelocytes and the granular and neutrophilic leukocytes.

The accompanying diagram will show the derivatives of the hemoblasts.
Primitive erythrocyte

Primitive erythroblast

Soon disappear

Erythroblast

Erythroplastid (Nonnucleated red cells)

Megaloblast

Normoblast

Hemoblast

Lymphoblast

Large mononuclear and transitional forms

Small lymphocytes (these become)

Lymphocytes

Myelocytes

Premyelocyte, or myeloblast

Leukoblast, or lymphocyte

Premyelocyte, or lymphocyte

Myelocytes

Eosinophils

Neutrophils

Basophils

Large lymphocytes

Megakaryocytes

Eosinophils

Neutrophils

Basophils
CHAPTER VIII

THE LYMPHATIC SYSTEM

The lymphatic system includes the lymphatic and thoracic ducts, intermediate vessels, capillaries, lymph spaces, lymph and a number of organs, as lymph nodes (lymphatic gland), spleen, tonsils and thymus body.

The usual interpretation of lymph is that it comprises the fluids in the tissue spaces as well as that in the lymphatic channels. Some hold that this is wrong, that the fluid in the vessels is rightly named lymph but that fluid in the tissue spaces should be referred to as tissue juice. There is a marked difference in the composition between these two fluids, apparently, and this is given as a reason for the differentiation of terms. The older interpretation will be still used in the following description though the writer thinks the above differentiation should be recognized.

The lymph consists of 94 per cent. of water, 3 to 4 per cent. of proteins and the remainder of sugar, inorganic salts, fatty substances, urea, also free oxygen, carbon dioxide and water products. It is neutral in reaction and is derived from the blood by osmosis or diffusion and is returned to the blood. The lymph in the intercellular spaces carries oxygen and nutritious materials to the cells and receives the carbon dioxide and waste products. It then enters the lymph capillaries (passing through their endothelial walls), then into larger vessels and ultimately is emptied into the venous blood at the right and left subclavian-jugular vein junctions by the right lymphatic and thoracic ducts, respectively. The cellular elements are leukocytes; these are mainly small lymphocytes. They are passed into the blood in great numbers all of the time; some are destroyed and others are said to develop into other varieties of leukocytes. The leukocytes tend to adhere to the walls of the vessels in the circulating current. As lymph contains fibrinogen it may readily clot;
this clot is white and the leukocytes entangled in the fibrin are toward the surface of the clot (postmortem).

In the lymph vessels of the small intestine, after absorption, the lymph contains a great deal of fat in the form of small droplets; the lymph here has a whitish color and is called chyle.

The lymph starts in the **intercellular spaces**. These are merely the tissue, or pericellular spaces and they are not lined by endothelial cells; such spaces are found between the epithelial cells of mucous membranes and glands; in the connective tissues, as the lacunae of bone and cartilage and cornea, etc.; between the muscle fibers. They are readily outlined by the silver nitrate method.

The first vessels of the lymphatic system are the **capillaries**. These are much larger than those of the blood-vascular system, measuring from 30 to 60 microns in diameter; the diameter, however, is not constant as these vessels present successive dilatations and constrictions giving them a varicose appearance. The wall consists of a single layer of endothelial cells with very sinuous outlines. The layer of cytoplasm is thin and the nuclei project somewhat. These capillaries are closed at one end and continue into larger vessels at the other, so that the lymphatic system must be regarded as a closed system. Ordinarily the capillaries form a meshwork but in certain regions, as the villi of the small intestine, they are individual, straight, blind tubules and called the **lacteals**.

As the lymph capillaries increase in diameter the endothelial tube becomes strengthened by the addition of a delicate fibro-elastic network. When they reach a diameter of from 0.2 to 0.8 mm. they have three coats, resemble venules and constitute small lymph vessels. The **tunica intima** consists of a single layer of endothelial cells resting upon the fibroelastic subendothelial connective tissue. In this the elastic fibers have mainly a longitudinal direction but interlace somewhat. If the surrounding tissue contains a considerable amount of elastic tissue then this tissue may be absent in the vessel. The thin **media** contains some circularly arranged smooth muscle tissue. The **adventitia** is the thickest coat and consists of a network of fibroelastic tissue in which there may be some smooth muscle tissue longitudinally arranged.
The large vessels, or lymphatic ducts, resemble veins more than they do arteries. The tunica intima is like that of the smaller vessels but the elastic tissue is usually prominent. The tunica media consists of fibro-elastic and muscle tissues; the muscle tissue consists of smooth muscle (more than in a vein) circularly and obliquely arranged. The elastic fibers are mainly circularly directed. The adventitia is quite thick and the elastic and muscle fibers are chiefly longitudinally arranged.

![Figure 148: Diaphragmatic Pleura Showing Part of a Lymph Vessel](image)

Blood-vessels and nerves are abundant in the medium and large-sized lymph channels.

Like veins the lymphatic vessels, including the lacteals, possess valves. These valves have the same structure as those of veins but are placed at more frequent intervals. They are numerous in the vessels of the mesentery.

Lymph vessels are found in all vascular structures except the eyeball, internal ear and the central nerve system; they are also absent from nails, hairs, muscles and cartilage.

The lymphatic structures comprise lymphoid tissue, including the lymph nodes, the spleen, thymus and tonsils.
Lymphoid tissue is arranged in two forms, diffuse and nodules. Diffuse lymphoid tissue is an indefinite collection of leukocytes in an organ. It is found in the tunica propria of the alimentary, respiratory and urinogenital tracts. It forms the medulla of the lobules of the thymus body and the bulk of the spleen and tonsils. In the

![Image](image-url)

**Fig. 149.—Section of the Mucosa of the Jejunum of the Cat.**

a. Simple columnar and goblet cell layer separated from the core of the villus b; the latter is filled with diffuse lymphoid tissue. c. Simple tubular glands with the intervening tunica propria filled with diffuse lymphoid tissue. (Photograph Obj. 16 mm., oc. 7.5 X.)

former places it consists merely of the leukocytes scattered in the areolar tunica propria. The number is usually so great that this tissue has a dark appearance and the connective-tissue portion is hidden. Under a low magnification the tunica propria has a granular appearance. In the spleen, thymus and tonsils the supportive tissue is the reticulum of the organ. The cellular elements are mainly small and large lymphocytes, only a few of the other varieties of leukocytes being present.
Nodules are small dense collections of small and large lymphocytes sharply outlined, usually, from the surrounding tissue. The supportive tissue is said to be reticulum, the meshes of which are larger in the germinal center than at the periphery. The center of a nodule is usually lighter and is called the germinal center; here the cells are fewer in number, more widely separated and younger.

**Fig. 150.—Solitary Nodule of the Spleen of a Monkey.**
The light area is the germinal center. The nodule is surrounded by diffuse lymphoid tissue. (Photograph Obj. 16 mm., oc. 7.5 X.)

This is the area where the cells undergo mitotic division. As the new cells are formed the excess cells are crowded and packed at the periphery of the nodule. As they form a dense mass they give to the periphery of the nodule a darker appearance. In general appearance the lobules of the thymus body are merely very large and irregular solitary nodules. The lenticular and splenic varieties of nodules have been described in the section on Lymphoid Tissues.

These structures are found in the submucous coat of the alimentary and respiratory tracts and in the spleen and tonsils. These and the diffuse variety are transient in character.

The agminate nodules, or Peyer's patches, are more or less regular collections of solitary nodules forming an individual mass, sharply
outlined from the surrounding tissues. Each patch is from 1 to 5 cm. in length and consists of from ten to sixty nodules, each of which shows a germinal center. Each nodule is partially or completely surrounded by a delicate capsule of white fibrous tissue, although usually the nodules merge more or less into one another. They are located in the submucosa of the ileum opposite to the attachment of the mesentery. Some state that they are also found in the jejunum. The long axis of each is directed parallel to the long axis of the bowel. They are visible to the unaided eye. Although they are said to be located in the submucosa, more com-

monly they are seen invading the mucosa, having broken through the muscularis mucosae. Usually in those areas where the nodules approach the epithelial surface, the glands are absent. At the edges of the nodules the glands are seen arranged in the form of a circle. Often the villi are absent over such an area.

Each nodule has a thin-walled *artery* that passes to the center and forms a capillary plexus of wide meshes. These extend to the periphery where the blood is collected by two or more small veins.

**Lymph nodes**, or **glands**, are bean-shaped organs placed in the pathways of the lymph vessels so that the lymph must filter through one, or usually more, of these structures before it ultimately enters the blood stream. They vary in size from a few millimeters to several centimeters in length. They are found distributed over the body but are more numerous in the trunk. They are most numerous in mammals, a few are found in birds, but none are found in the lower

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**Fig. 151.—An Agminated Nodule of the Ileum of a Cat.**
(Photograph Obj. 48 mm.)
vertebrates. Each is surrounded by a capsule, has a hilus and consists of cortex and medulla.

The capsule consists of a thin layer of white fibrous connective tissue containing yellow elastic fibers and smooth muscle tissue. Between it and the parenchyma is seen a lymph space, the sinus, exhibiting a network of reticulum, that is continuous with the reticulum of the organ, on the one hand, and attached to the capsule, on the other. At regular intervals the inner surface of the capsule sends into the peripheral portion of the organ trabeculae, or partial septa, covered with endothelial cells. These divide the outer part of the parenchyma into a number of nearly uniform masses called the secondary nodules; these and the trabeculae constitute the cortex of the node. The lymph sinus continues along the trabeculae. Within the organ the trabeculae continue into the central part or medulla where they form a large coarse meshwork for the support of the larger vessels. Throughout the organ the spaces between the trabeculae and capsule contain a delicate meshwork of reticulum.

Fig. 152.—Longitudinal Section of a Lymph Node.

a, Hilus; b, arteriole; c, venous sinuses; d, adipose tissue; e, secondary nodule of cortex; f, vein in medulla; g, subcapsular lymph sinus; h, germinal center of secondary nodule; i, i, trabeculae; k, capsule; l, lymph sinus; m, medullary cord.
that constitutes the fine framework of the organ. This is for the support of the capillary vessels and the functionating cells of the organ. The reticulum cells are attached to the reticulum fibers and are said to be phagocytic and contain pigment granules and even erythrocytes. The trabeculae contain some smooth muscle fibers.

The cortex comprises the secondary nodules, the trabeculae and the peripheral portion of the lymph sinus. The secondary nodules are from 0.5 to 1 mm. in diameter and are just beneath the capsule and are separated from one another by the trabeculae and the sinus. Each is a solitary nodule presenting a germinal center and a darker peripheral zone where the lymphocytes are closely packed. The central lymphocytes show mitotic figures. The germinal centers are not distinct in very young or old animals. Laterally the nodules may connect with one another. The medullary side of each nodule continues as a cord-like mass into the center of the organ where they anastomose or join one another. These are the medullary cords. The cells are chiefly lymphocytes, which are arranged in concentric layers around the periphery of each nodule. Other cells of the hyalin variety are found in the center of each nodule. During gestation nucleated red blood-cells may be present.

The medulla consists of the medullary cords, the trabeculae and a continuation of the sinus. It is best developed in the mesenteric and lumbar lymph nodes.

The medullary cords are the cord-like continuations of the cortical nodules. Within the reticular and trabecular network of the medulla these cords anastomose and join one another to form a darkly staining coarse meshwork of dense lymphoid tissue. They consist of a reticulum supporting the lymphocytes and blood-vessels. Between the medullary cords the tissue is lighter. Here are seen the band-like trabeculae continued from the cortex. Each consists of rather dense white fibrous tissue containing some smooth muscle tissue. Between the trabeculae and the medullary cords is seen a delicate reticulum that marks the position of the sinus continued from the cortex. As has been shown the sinus is not a clear-cut space but a series of fine spaces between the trabeculae and the parenchyma of the organ.
At one side of a lymph node is a scar-like depression called the hilus. Here the cortex is absent and the medulla, mainly white fibrous tissue, comes to the surface. It is also the region where some of the vessels enter and most of them leave.

The cells are mainly small lymphocytes and then the hyalin cells are next. Both of these varieties are seen undergoing mitosis especially in the germinal centers of the nodules. A few finely granular oxyphils, eosinophils and mast cells occur in these organs but they are probably not formed here in any great numbers. Many of these cells may contain fat, red cells, pigment granules and bacteria.

The arterial vessels enter at the hilus and divide into branches some of which continue into the trabeculae to the cortex where they pass to the nodules and form a capillary plexus in these structures. Others pass directly to the capsule for its nourishment. Other branches leave the trabeculae just within the hilus and pass to the medullary cords where a capillary meshwork is formed. The blood is collected by veins that carry the blood to the hilus where one or more vessels leave. A few small arterioles may enter at the capsule.

The afferent lymph vessels all enter at the surface and open directly into the capsular lymph sinus. The lymph then filters through the reticulum of the sinus and its medullary extensions toward the hilus where the lymph is collected into one or more efferent vessels.

The nerves are not numerous. Myelinated and amyelinated nerve fibers form plexuses around the vessels and supply the muscle tissue of these and the trabeculae. They have not been demonstrated in the nodules or cords.

Lymph nodes are the highest form of lymphoid tissue. They are often collected into groups as in the axilla, femoral and inguinal regions. They are said to be somewhat inconstant as they may disappear early or change from place to place. They make certain kinds of white cells, filter the lymph and are the centers of cell destruction, and in the female, during pregnancy they may form red blood-cells.

Hemolymph nodes are probably just lymph nodes that have temporarily taken over the function of making red blood cells.
Huntingdon believes that they are of the nature of accessory spleens, forming red blood cells from endothelium and having phagocytic function as well.

**THE SPLEEN**

The **spleen** is the largest of the lymphoid structures and is located in the abdominal cavity. It is a soft organ of a dark-red color and its shape depends upon the state of the organs surrounding it. It is surrounded by a capsule that is invested with peritoneum; within this is the splenic substance consisting of the splenic pulp and the splenic corpuscles.

The **capsule** is a rather thick layer of dense white fibrous tissue containing elastic fibers and a considerable quantity of smooth muscle tissue. Externally the capsule is covered by the peritoneum which is a serous membrane. This consists of a single layer of endothelial cells that rest upon a thin layer of fibroelastic tissue.

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**Fig. 153.—Section of Spleen.**

*a*, Capsule; *b*, trabeculae, longitudinal section; *c*, pulp; *d*, splenic corpuscle; *e*, germinal center of corpuscle; *f*, eccentric arteriole in corpuscle; *g*, trabecula, cross-section; *h*, blood-vessel.
This is thinner than the capsule proper. From the inner surface of the capsule beams of white fibrous tissue extend into the organs and form a coarse meshwork. These trabeculæ contain smooth muscle tissue and blood-vessels. The arterial vessels are thicker-walled and smaller in caliber than the veins. Within the large meshes made by the trabeculæ there is a delicate network of reticulum.

![Reticular Tissue Seen in a Frozen Section of a Dog's Spleen Which Had Been Injected with Silver Nitrate. X 250. (Mall.)](image)

A, Artery with its ampullæ (a); V, vein.

This is for the support of the splenic substance and the smaller vessels. Upon this reticulum phagocytic reticulum cells are found.

The splenic substance comprises the pulp and the splenic corpuscles.

The splenic pulp consists of diffuse lymphoid tissue comprising lymphocytes, hyalin cells and polynuclear cells; the large cells are the most numerous. In addition there are a few nucleated red cells, a great many thrombocytes, erythrocytes and many disintegrating red cells. The large number of red cells in the pulp gives
the color to the spleen. The presence of nucleated red cells in the adult condition is denied by some. In fetal life and sometimes early childhood nucleated red cells may be numerous. The splenic phagocytes are large mononuclear cells that are ameboid as well as phagocytoplastic; their cytoplasm usually contains many pigment granules and often erythrocytes that are undergoing disintegration. Some giant cells, or megakaryocytes are present. These are especially numerous in the fetal condition and some claim that in the adult they are absent from the spleen. The large number of disintegrating red cells in the splenic pulp has led some to call the spleen

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**FIG. 155.—Diagram of the Blood-vessels of the Human Spleen.** (Lewis and Stöhr.)

At x is shown the direct connection of terminal arteries with terminal veins (the existence of such a connection has been questioned). At xx and xxx are the free endings of the terminal veins in the pulp and near the nodules respectively.
the graveyard of the erythrocytes. The uneven mixture of nucleated and nonnucleated elements gives the stained sections of the spleen a characteristic mottled appearance.

The *splenic*, or *Malpighian corpuscles* are dense collections of lymphoid tissue. Each is really a solitary nodule in which is usually seen an eccentrically placed arteriole. These vessels are not found in the ordinary solitary nodules and so this is characteristic of the structure of the nodules of the spleen. Each nodule usually shows a germinal center. It represents a collection of lymphocytes in the adventitial sheath of the arteriole.

The *circulatory system* of the spleen is peculiar in being an *open one*. Capillaries as such do not exist and the arterioles and venules are connected to each other by blood-spaces or ampullæ. The walls of these vessels are said to be porous.

The *blood-vessels* enter and leave at the hilus. The splenic artery divides into six or more branches. As these arteries enter the spleen they branch and of these divisions some enter the pulp almost immediately while others follow the trabeculae to their smallest divisions and to the capsule. The adventitia of the small arterioles
in the pulp contains some lymphoid cells and is then called the *lymphoid sheath*. At frequent intervals the lymphoid tissue becomes very abundant forming spherical, or oblong masses called the *splenic corpuscles*. These corpuscles receive capillaries from the enclosed arteriole. The arterioles after leaving the corpuscles divide into branches which are said to be surrounded by the *ellipsoidal sheaths*; these are said to be condensations of the reticulum, without leukocytes, surrounding the terminal arteriole branches. These branches then end in the *so-called capillaries* that are really dilated channels the walls of which are not complete. Some state that the capillary tubes end by opening directly into the pulp and that the terminal cells of these capillaries have branched processes that join those of the reticulum cells of the pulp. The blood is thus emptied directly into the pulp spaces. The *veins* start in this manner as venous sinuses and these are surrounded by ring-like collections of reticulum fibers and some longitudinal fibers that cause a ribbing of the sinus walls. The small veins quickly enter the trabeculae and through them join to form larger vessels that proceed toward the hilus to form the single splenic vein.

According to Mall the spleen is divided into circulatory lobules, about one mm. in diameter, each one of which is further subdivided into *histologic units*, one for each terminal artery, or *ampulla*. These terminal vessels are covered by a lymphatic sheath, the *ellipsoidal sheaths*. The terminal ampullae are *porous*, and continue as veins. The endothelial cells are long and slender, resembling smooth muscle cells, and are contractile. Their edges are not closely approximated. In the splenic vein the leukocytes are said to be 70 times as numerous as in the splenic artery.

The spleen is subject to *rhythmic contractions*, one per minute, and about 18 per cent. of its volume is lost at each contraction. These are produced by the involuntary muscle in the capsule and trabeculae. When the cardiac impulse sends the blood into the arteries, the blood passes into the ampullae, and through the porous walls into the pulp spaces. When the rhythmic contractions occur, the blood is forced into the veins, and, at the same time, the arteries are closed. This shows an open circulation (Mall).
The lymphatics are trabecular and perivascular. The trabecular vessels are in the trabeculae and in the capsule; they start in the latter and get larger toward the hilus. The perivascular lymphatics arise in the lymphoid sheaths of the arterioles and after leaving the corpuscles two vessels are usually formed and these accompany the artery and frequently anastomose around it. As these vessels reach the hilus they join the trabecular vessels and the efferents from the spleen carry the lymph to the splenic nodes.

The nerves are chiefly amyelinated and are derived from the solar plexus of the sympathetic system. Plexuses are formed around the arteries and their branches and fibers pass to the muscles of the vessels and the smooth muscle of the capsule and trabeculae.

The spleen is an important blood-cell-making organ throughout life. In fetal life it is an important center for the production of erythrocytes but by birth that function is usually lost. In certain blood diseases it may resume that function. At all times it is an important center for the formation of lymphocytes and some of the other leukocytes, though in lesser quantities. It acts as a blood filter and from the number of disintegrating red cells present in the pulp it must also be intimately concerned with the destruction of the useless erythrocytes. The hemoglobin derived from these cells is probably utilized by the liver in the manufacture of bilirubin and biliverdin. Removal of the spleen, in dogs, seems to increase the formation of red blood-cells in the red bone-marrow. Others have found that the removal of the spleen caused the yellow marrow to become red again.

THYMUS BODY

The thymus body is essentially a lymphoid structure, though it undergoes peculiar changes in its life history. It weighs from 5 to 11 grams at birth, increases in size and weight to puberty (40 to 50 grams) and by some is considered active until the fortieth year, losing its function after that time.

It originates as a true gland (epithelial organ), but soon leukocytes enter it, and cause the disappearance of the epithelium except small islands. After the sixth year, it generally undergoes further change or involution. The lymphoid tissue is gradually replaced
by adipose tissue, so that an old thymus will show but little lymphoid tissue.

This organ is surrounded by a capsule of white fibrous tissue that sends in septa, which divide the organ into lobes and lobules. Within the lobule there is a delicate reticulum meshwork for the support of the parenchyma and the blood-vessels, nerves and lymphatics. Each lobule consists of cortex and medulla.

![Fig. 157.—Section of the Thymus Body of a Child.](image)

The cortex consists of dense lymphoid tissue and stains deeply owing to the large number of leukocytes present. The cortex may be subdivided into secondary nodules like a lymph node, by trabecular septa from the interlobular connective tissue. Germinal centers in such nodules are, however, not present.

The medulla consists of diffuse lymphoid tissue, and takes, therefore, a lighter stain; the lymphoid cells are chiefly small lymphocytes and hyalin cells and a few eosinophiles and giant cells. The supportive tissue is reticulum, which is coarser than in the cortex. Cortex and medulla are not always sharply differentiated from each other. At times band-like extensions of the medulla may pass from one lobule to the other. These are called medullary cords.
In the medulla, are found small, peculiar bodies, consisting of concentrically arranged epithelial cells; these are the thymic corpuscles, or corpuscles of Hassal. These are at first 12 to 20 microns in diameter and increase even to 180 microns. The larger ones are usually compound. New ones are constantly forming from the reticular tissue. The nucleus of a cell disappears and hyalin substance develops in the cytoplasm. The peripheral cells are usually keratinized. The center may calcify or fat may deposit. The formation of these bodies is considered a degenerative process. They are supposed to represent the remains of the epithelium, though some hold that they represent endothelium of blood-vessels. These bodies are encapsulated, and may be compound.

The numerous arteries pass through the capsule and branch in the interlobular connective tissue. From these vessels branches pass into the cortex of the lobules and form a plexus of capillaries from which capillaries proceed to the medulla. The blood is collected into venous channels that pass to the interlobular connective tissue where they join to form larger veins that ultimately pass through the capsule and empty into the left innominate vein.

Small lymphatic vessels are found in the medulla and cortex of the lobules. These communicate with larger vessels in the interlobular connective tissue in which these vessels anastomose extensively. The lymph is collected into one or two vessels for each lobe and conducted to the nearest lymph node.

The nerves are small and chiefly sympathetic; these supply the blood-vessels.

According to Hammer the corpuscles of Hassal seem to represent the essential functional changes and form the morphologic expression of antitoxin activity. There is no conclusive evidence of an internal secretion. All of the change after thymectomy are explained as the result of injuries of a toxic nature which are neutralized in the intact animal. He also believes that the organ functions to old age; at puberty its parenchyma begins to reduce but this age involution does not check the antitoxin activity of the organ. In 32 of 37 thymic deaths the gland was apparently normal in size and structure. The gland is never found normal after death from disease or in extreme inanition. Roentgen radiation disintegrates the lympho-
cytes and the thymus is changed to a pure epithelial structure for a time.

The function of the thymus is unknown. It is a center for the formation of lymphocytes and believed by some to give rise to an internal secretion that has to do with normal growth and sexual development. Its change from epithelial to lymphoid occurs early in fetal life. The change from lymphoid to adipose tissue is variable; although its involution occurs usually from the sixth year to puberty it may retain its essential lymphoid character until after middle life and even to old age. Castration delays its involution and removal of the thymus in young animals hastens sexual maturity especially in the male. It is also stated that its removal ultimately proves fatal.

THE TONSILS

The tonsils comprise the palatal, or faucial tonsils, the lingual, pharyngeal and tubal tonsils. The palatal tonsils will be considered here and the others with their respective organs.

The palatal tonsils are located at the beginning of the pharynx one on each side of the base of the tongue, between the glossopalatal and glossopharyngeal folds. They are essentially lymphoid in structure but being so intimately related with the alimentary tract they will be described here. Each is about 2 to 2.5 cm. long, 18 mm. wide and 12 to 15 mm. thick.

Upon the pharyngeal surface each is covered by a continuation of the mucosa of the oral cavity. This consists of stratified squamous cells that rest upon a thin basement membrane beneath which is the tunica propria consisting of areolar tissue. Laterally the organ is surrounded by a capsule of rather dense white fibrous tissue that separates it from the surrounding tissues. This capsule sends in trabeculae that form the gross framework of the organs; within this there is a delicate meshwork of reticulum that supports the functioning cells, small blood-vessels, nerves, and lymphatics. In the trabeculae are found the larger vessels and nerves. Upon the pharyngeal surface of the organ are noted a number of openings that are the orifices of the tonsillar crypts. These crypts are usually long and tortuous and those of the upper portion of the structure are said to
pass downward and laterally. These crypts are lined with stratified squamous cells continued from the pharyngeal surface, and in this epithelial layer are seen varying numbers of leukocytes called *salivary corpuscles*. These are ameboid leukocytes that wander through the epithelium into the crypts. When examined fresh the granules of the cells may exhibit Brownian motion. The epithelium in areas may often show degenerative changes.

![Diagram of a human palatal tonsil](image)

**Fig. 158.—Vertical Section of a Human Palatal Tonsil.**

- a, Stratified epithelium;
- b, basement membrane;
- c, tunica propria;
- d, trabeculae;
- e, diffuse lymphoid tissue;
- f, nodules;
- h, capsule;
- i, mucous glands;
- k, striated muscle;
- l, blood-vessel;
- q, pits.

Within the reticulum is seen the *parenchyma* that is composed of lymphoid tissue of the diffuse and solitary nodule varieties. The cells are chiefly small and large lymphocytes. The solitary nodules all show germinal centers and these structures are arranged in a single row around the crypts; the remainder of the intercrypt reticulum is filled with the diffuse lymphoid tissue which will also fill in such spaces as are not occupied by the solitary nodules. The ducts of small mucous glands are said to empty into the crypts at times.
Under the palatoglossal fold there seems to be an area that corresponds to a hilus as the larger vessels seem to enter here. Other arterial vessels enter at different points on the capsule. These vessels all branch and the larger divisions follow the trabeculae; from these vessels smaller branches extend into the substance of the organ and form capillary plexuses in the diffuse tissue and around the nodules. The blood is then collected and returned by venous channels.

The lymphatics are also numerous. The lymph channels form plexuses that surround the nodules and empty into a peripheral vessel beneath the fibrous capsule.
CHAPTER IX

ALIMENTARY TRACT

The alimentary tract starts at the lips, and extends to the anus. It receives the food, digests it and casts off that which is undigested. The various portions perform different functions, and the lining cells differ accordingly. The inner coat is a mucous membrane that gives rise to glands, which are devices of nature for increasing the secretory surface. The absorptive surface is increased by prolongations of the mucosa into the lumen of the organ (villi of the small intestine).

The lip is covered externally by skin, and internally by mucous membrane. Between these, are found connective tissue and muscle. The skin consists of two portions, the epithelial or epidermis, and the connective tissue portion, or derma.

The epidermis is composed of stratified squamous cells, of which two layers, the stratum corneum and stratum Malpighii are distinct. The stratum corneum is the outer, and consists of nonnucleated scales; the stratum Malpighii is the genetic portion. Its lowest cells rest upon a basement membrane, and are columnar in shape. Those above are polyhedral which become more flattened as the corneum is approached. The derma consists of white fibrous connective tissue supporting blood-vessels, nerves and lymphatics. Beneath the epithelium it is thrown into projections called papillae.

The mucous surface is also lined by stratified squamous cells, that differ from the outer, however, in being larger and less readily stained. The cells rest upon a basement membrane beneath which is the tunica propria, composed of papillated, delicate fibro-elastic tissue.

Between the tunica propria and skin, are found connective tissue and voluntary striated muscle. Near the tunica propria are to be seen small, compound tubular glands that open upon the mucous surface. At the margin of the lip these two surfaces join, and this is the mucocutaneous junction; here the epithelial layer is quite thick,
and the cells are larger and bladder-like, resembling the epitrichial cells of the fetus.

Blood-vessels are found in great abundance, and form dense plexuses, especially around the glands.

The mouth is lined by a mucous membrane, consisting of stratified squamous cells resting upon a basement membrane and tunica propria. The superficial epithelial cells are not keratinized and the nuclei may be distinct. The tunica propria consists of delicate areolar tissue that supports the smaller blood-vessels, nerves and lymphatics. In addition diffuse lymphoid tissue and even solitary nodules are met with. That portion next to the basement membrane is thrown into delicate projections called papillae; as a result of this the basal epithelial cells have a very uneven course and the tunica propria is referred to as papillated.

Small salivary glands are very numerous in the mucosa and even in between the muscles; these are named according to the region in

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**Fig. 160.—Section of the Lip of a Child at Birth.**

*a*, Skin surface; *b*, mucous surface. (Photograph Obj. 32 mm., oc. 5 X.)
which they are found, as buccal (cheek), labial (lips), molar (opposite the molar teeth in the cheeks). These are either tubular, or tubulo-alveolar in structure. The tubular glands are mostly pure mucous glands while the mixed glands are mixed in secretion also. The mucous portion of the glands stains lightly with the ordinary plasmatic stains and the serous acini stain deeply under the same conditions. They are readily distinguished from each other under the microscope. Their appearance is also different in the different stages of secretion (rest and activity) and this will be considered with the large salivary glands.

The gums represent that portion of the oral mucosa covering the alveolar processes of the maxillae and mandible and the necks of the teeth. It is dark red in color, very vascular and sensitive. It consists of stratified squamous cells resting upon a basement membrane that is very thin and indistinct. Beneath this is the tunica propria that consists of flattened bundles of white fibrous tissue that are arranged parallel to one another; these fibers are arranged in three ways. The vertical fibers extend from the basement membrane to the periosteum; the horizontal fibers run parallel to the surface; the radiate fibers are arranged fan-like around the alveolar margins and include fibers derived from the alveolodental membrane. Some elastic fibers are present between the bundles of white fibrous tissue which are quite dense and almost tendinous and with the fibers derived from the periosteum serve to bind the gum firmly to the alveolar periosteum.

Over the palate the mucosa consists of the stratified squamous cells, basement membrane and tunica propria. Over the front of the hard palate the epithelial layer and the entire mucosa is thinner than over the back portion; the tunica propria is also less papillated in front. The fibers form flat bundles that make a denser and tougher layer than in the tunica propria in general. These fibers pass from the alveolar borders toward the center of the palate in a radiate manner and are also firmly attached to the periosteum.

The soft palate consists of a double layer of stratified squamous cells, continuous at the free edge of the organ, enclosing between them the fibrous aponeurosis of the palate. The epithelial cells rest upon the thin basement membrane beneath which is the tunica
propria consisting of a network of white fibrous and yellow elastic tissues. The white fibers are arranged in three directions, horizontally (side to side) longitudinally and obliquely. The latter fibers extend into and blend with the fibers of the aponeurosis. This is a dense layer of white fibrous tissue that forms the center of the soft palate and it is attached, in front, to the periosteum of the back edge of the hard palate and, behind, it extends toward the free edge of the soft palate and forms the core of the uvula. The tunica propria varies in thickness depending upon the number of salivary glands present. These glands are usually small and of the mucous variety. The mucosa is thickest at the free edge of the soft palate. The pharyngeal folds have the same general structure but the elastic tissue is more abundant.

Beneath the mucosa of the oral cavity there is a submucous layer that varies in thickness in different regions. It serves to connect the mucosa to the underlying structures and also for the support of vessels and glands. On the gums and hard palate it is thin and relatively dense. In the cheek and soft palate it is looser and comparatively thicker owing to the salivary glands present.

The blood-vessels are quite numerous and enter the submucous layer from which arterioles pass to the mucosa and form a plexus of capillaries parallel to the surface. From this plexus capillaries extend into the papillae. The blood is collected in a similar venous plexus and returned from the mucosa in a corresponding manner.

The nerves are very numerous and terminate in various ways. The vasomotor nerves are sympathetic and pass to the blood-vessels. The sensor nerves are myelinated and terminate in free endings or special end organs. In the case of the free endings the nerve fiber loses its sheaths as it enters the epithelial layer and the naked axis cylinder then divides into a series of telodendrites that surround the epithelial cells and end in fine granules, or end-discs. Some free endings are found in the adventitia of the blood-vessels. The organs are corpuscles of Krause and are found in the papillae. Other tunica propria and are similar to those of the conjunctvillae of the sympathetic fibers pass to the epithelium of the glands.
THE TEETH

The teeth are the chief organs of mastication and are adapted for cutting, grinding, holding, etc. Each consists, anatomically, of crown, that portion above the gum; root or fang, that portion in the jaw; neck, the narrow portion between the preceding, covered by the gum.

Histologically considered, there are the enamel that covers the crown; the dentin that forms the bulk and gives the shape of the tooth; the cementum that covers the dentin of the fang; the peridental membrane that surrounds the root and holds the tooth in place; the pulp that occupies the pulp cavity and is the nutritive and sensitive portion of the organ. In the root of the tooth is a canal that leads into the pulp chamber called the root canal.

The enamel is the hardest substance in the body and forms a cap-like covering, of varying thickness, of the dentin. It is thickest at the cutting or occlusal surface of the teeth and diminishes in thickness as the neck is approached. It is said to consist of 97 per cent., or more, of inorganic matter and 3 per cent., or less, of organic matter. Bibra gives the composition as follows: Earthy material 96.6 per cent.; animal material 3.5 per cent. The former includes phosphate of calcium (with traces of calcium fluorid) 89.8 per cent.; calcium carbonate 4.4 per cent.; magnesium phosphate, etc., 1.3 per cent. Berzelius found only 2 per cent. of animal material and 8 per cent. of calcium carbonate.

**Fig. 161.**—Longitudinal section of an incisor tooth. A, Crown; B, neck; C, fang; 1, enamel; 2, dentin; 3, pulp cavity; 4, cementum; 5, root canal. (After Stöhr's Histology.)
The enamel consists of hexagonal enamel prisms that are arranged perpendicular to the surface of the dentin, and represent modified epithelial cells. The surface of the enamel is marked by delicate stria
tions which indicate the enamel prisms. Each *enamel prism* or *fiber*
is about 5 microns in diameter, has a wavy or tortuous course with
its inner end fitting into a slight depression in the dentin. The prism

![Enamel rods](image)

**Fig. 162.—Human Enamel.** Transverse ground sections. (*Broomell and Fischelis, after Gysi.*)

is of the same diameter throughout, though the sides may not be
straight and even. They are arranged in bundles in which the
constituent prisms are parallel to one another. The various bundles
are not always parallel to one another. As a result, near the surface
of the tooth shorter additional prisms are found and these are the
*supplemental prisms*. The prisms seem to be held together by a
transparent cement which is apparently inorganic in composition.
In a prepared section of the tooth are seen some *brown striations* that
run almost parallel to the surface of enamel or dentin and in the latter instance may run the entire extent of the crown. These are the "brown striæ of Retzius." The cause of these striæ is still in dispute. Tomes believes that they represent successive positions of the enamel cap. Minute fissures may exist between the enamel bundles in the deeper portions of the enamel. At times large fissures are found that extend downward from the depressions between the cusps of the molar teeth.

When studied with reflected light the "radial lines or prism stripes of Schreger" are seen in the enamel. These are apparently due to various directions taken by the different bundles of enamel prisms, and are well marked near the surface of the dentin and less so toward the surface of the enamel. The enamel prisms are best studied in the newly formed or still growing teeth. When these are subjected to the action of acids the enamel prisms are readily dissociated or broken up.

Dentin.—This portion forms the bulk of the tooth and gives it its shape. It is yellowish-white in color, harder than bone, and represents ivory. It is everywhere covered by either enamel or cementum. It is composed of about 72 per cent. of inorganic matter and of about 28 per cent. of organic matter.

The parts of importance are the dentinal sheaths, matrix, and dentinal fibers. The dentinal sheaths, or Neumann's sheaths, are delicate tube-like masses of dense dentin that seem indestructible and will persist when the matrix has been destroyed. They extend in a curved or spiral course from the pulp cavity to the enamel or cementum, diminishing in diameter as they pass outward. Within the sheaths are spaces called dentinal tubules, or canaliculi. They radiate from the pulp cavity to the periphery and have the same curved or spiral course of the sheaths. They diminish in diameter from within outward, and terminate at the enamel or cemental surface either by anastomosing with one another, ending bluntly or opening into the interglobular spaces. Some are said to penetrate into the enamel and cementum; in the latter they communicate with the canaliculi. The pulp cavity end is usually funnel-shaped (5.5 microns), and the tubules here are closely packed so that there is very little matrix. The tubules are from 2 to 4 microns in diameter.
at the beginning and 0.5 to 1 micron at the peripheral end. The tubules branch toward the enamel or cementum; the branches are most numerous in the fang. These tubules may show constrictions at intervals. The curvatures of the tubules are long and short, or primary and secondary, respectively. As these occur regularly they produce the *incremental lines of Schreger*. These are lines that are parallel to the surface of the dentin.

The *dental fibers*, or *Tome's fibers*, represent the processes of the odontoblasts and they occupy the dental tubules, branching as the latter do and diminishing in size as the tubules become smaller. Some claim that they do not belong to the odontoblasts, but represent nerve tissue surrounded by connective tissue.

The *matrix* occupies the space between the dentinal sheaths. It consists of a more or less homogeneous dentin that is not so hard as that surrounding the canaliculi in the form of the dentinal sheaths.
Upon decalcification it can be separated into lamellae parallel to the pulp surface. Fibers are also said to be present. It is less abundant near the pulp cavity, as the sheaths here are very close together. Farther out, as the sheaths become smaller in diameter, the matrix increases and along the margin of the dentin near the enamel, a varying number of small irregular spaces, the *interglobular spaces*, are seen; these represent areas of imperfect calcification and are filled with a gelatinous substance. Between dentin and cementum these spaces are smaller, and under low power give a granular appearance to the area; this represents "Tome's granular layer."

**Osteodentin** may be deposited in the pulp cavity. This resembles bone and contains pulp and vessels. The dentinal substance may be arranged like an Haversian system and numerous tubules may radiate from the central canal.

**Repair dentin** may be formed in the pulp cavity, opposite to an injury upon the surface of the tooth (crown or neck). The dentinal
tubules here are then blocked and if the injury be extensive the repair dentin may fill the pulp cavity.

**Cementum.**—The **crusta petrosa** is a bone-like substance that covers the root of the tooth. It consists of about 66 per cent. inorganic matter and 34 per cent. organic matter. It is thickest at the apex of the tooth and becomes gradually thinner as the cervix or neck is approached and ends at the lower margin of the enamel.

It resembles bone very closely, contains **lacunae**, **canaliculi** and **lamellæ**. According to Schäfer Haversian systems are at times found where the cementum is thick. The **lamellæ** are about the same in number but thicker at the apex than near the cervix. This applies to young teeth. In older teeth the layers are not only much thicker near the apex but are also more numerous, the shorter added lamellæ constituting **supplemental lamellæ**. The layers may or may not run parallel to the dentin. Passing through the lamellæ
at varying intervals are fibers of Sharpey. Between the lamellæ are irregular spider-like lacunæ that vary in size but resemble in shape and number of canaliculi, those of bone; they lie partially in one layer and partially in another and their long axes are parallel to the surface of the tooth. Extending out from the lacunæ are the canaliculi which usually are directed peripherally, though some are seen extending in all directions.

The cementoblasts occupy the lacunæ. They are oval, stellate, or elongated elements and usually correspond in direction to the lacunæ. The processes vary in length and form, and most of them extend toward the periphery, following the canaliculi.

Dental Pulp.—The pulp is the highly vascular and sensitive mucous connective tissue that occupies the pulp cavity, or chamber and root canals and is concerned with the nutrition and growth of the tooth. It is composed of cells and intercellular substance and contains blood-vessels and nerves.

The cells are of various varieties, the most important of which are the odontoblasts. These cells are found upon the surface of the pulp and form a continuous layer of cells one layer deep. They are elongated flask-shaped elements, about 40 microns on height, from which three sets of processes extend. These are dentinal, pulpal and lateral. The dentinal process, or processes, arise from the peripheral end of the cell and extend into the dentinal tubules, and they have been described under the dentin. The lateral processes pass from the sides of the cells to the neighboring cells, while the pulpal processes extend from the central ends of the odontoblasts to the deeper cellular elements of the pulp. The nucleus occupies the end of the cell next the pulp reticulum. Beneath the layer of odontoblasts there is a narrow layer of tissue almost devoid of cells, then an area of which the cells are quite numerous, and again a region, the center of the pulp, in which there are very few cellular elements. The cells are spindle-shaped, stellate and spheroid in form and possess many or few hair-like processes that pass in all directions.

The arteries, apical, of the pulp are derived from a branch that enters the root canal of the tooth; as this vessel passes toward the pulp chamber it gives off branches that form plexuses parallel to
the long axis of the tooth; ultimately forming rich capillary plexuses in the neighborhood of the odontoblastic layer. The blood is collected by venous channels that anastomose freely and empty into one channel that leaves through the root canal.

The nerves, one or more, pass through the root canal giving off a few fibers here; in the pulp chamber branches are distributed in every direction forming arch plexuses, after losing their myelin sheaths, beneath the layer of odontoblasts. From this plexus fibers are said to pass between the odontoblasts to end in bulbous enlargements within the central ends of the dentinal tubules. Magitot claims, however, that the dentinal fibers are continuations of the nerve fibers. Mummery states that two nerve fibers from the plexus around the odontoblasts enter each tubule and this accounts for the extreme sensitiveness of the dentin. Sympathetic motor fibers supply the muscle tissue of the pulp vessels.

The peridental, or alveolodental membrane, is a highly vascular and sensitive white fibrous tissue membrane that lines the alveolar processes of the jaw and covers the roots of the teeth. It is thickest at gum and apical portions and thinnest in the middle. The fibrous elements are bundles of white fibrous tissue that pass into the cemental layers on the one hand and into the bony tissue of the jaw on the other hand, resembling Sharpey’s fibers. In general, around the apex of the tooth the fiber bundles are arranged fan-like and are directed upward and outward. In the body of the tooth the fiber bundles pass directly outward from the cementum to the alveolar wall and are largest and strongest here. At the gum margin the fiber bundles pass outward and are lost in the fibrous tissue of the gum, or pass toward the adjacent tooth as the case may be.

Upon the inner surface of the membrane are found the cementoblasts; these are irregular flattened elements possessing a clearly defined nucleus and numerous delicate irregular processes that extend in various directions. They are evenly distributed. Upon the opposite (alveolar) surface of this membrane are the osteoblasts that form the bone of the jaw. In the meshes of the fiber bundles are found fibroblasts or connective-tissue cells and some osteoblasts or bone-destroying cells. The latter are large, fairly regular, oval or round cells that possess several nuclei and usually have no processes.
The arteries are derived from the apical artery and pass up parallel to the long axis of the tooth, giving off branches at intervals, these form capillary plexuses beneath the alveolar and cemental side of the membrane. The blood is collected by venous channels that ultimately empty into the apical vein.

The veins are tributary to those at the apex and are distributed somewhat like the arteries.

The functions of the alveolodental membrane are physical and sensor. It holds the tooth in place, returns it to its normal position when slightly rotated or displaced; upon one side it forms cementum and upon the other it forms bone.

Nasmyth's Membrane.—This enamel cuticle is a thin indestructible membrane covering the enamel of the unworn tooth. It is said by some to be the remains of the enamel organ, while others claim it is a continuation of the cementum. The former seems the more probable origin. It forms a protective covering and is horny in nature. It resists the action of strong acids and also prolonged boiling. With silver nitrate outlines like those of pavement epithelium are produced. It is made up of short, uncalcified prisms that are flattened in shape and represent the last formed portions of the enamel prisms before calcification takes place.

THE TONGUE

The tongue, like the teeth, occupies part of the mouth cavity. It is covered by a mucous membrane that consists of stratified squamous cells, basement membrane and tunica propria, which, along the sides and base, is papillated. The superficial surface of the epithelium of the sides and under surface of the tongue is regular and even in its course and the tunica propria is thick throughout. The upper surface, or dorsum, is characteristic. It is continuous with the mucosa lining the oral cavity. Its apical two-thirds is covered by minute projections, called papillae; of these there are three varieties, filiform, fungiform and vallate. The central portion consists chiefly of voluntary striated muscle that forms the bulk of the organ.

The filiform papillae are cone-shaped projections of the tunica propria, covered by the stratified squamous cells, the outer ones of which
are hard and horny. They vary in height from 0.5 to 2.5 mm. The central part of a papillæ consists of white fibrous tissue, which is thrown into small *secondary papillæ* that are not visible externally. These papillæ are the most numerous, and are scattered over the whole of the apical two-thirds. They are directed backward, and are the ones that produce the scratching sensation when the hand is licked by a lower animal. In these animals these papillæ are very long and the amount of keratinized epithelium is great.

![Image: From a Longitudinal Section of the Dorsum of a Human Tongue. X 12. (Lewis and Stöhr.)](image)

The *fungiform papillæ* are flat-topped, table-like structures, in which the sides are parallel. They have secondary papillæ, and are scattered like the filiform variety, but are less numerous. Each consists of a large central core of tunica propria that usually has secondary papillæ. In the stratified squamous cells covering these papillæ taste-buds are occasionally found. They are usually not over 1.5 mm. high.

The *vallate papillæ* are the most important. While the top is flat, the sides usually converge and give this variety a narrow base. *Secondary papillæ* are found only on the upper portion. Each papilla is surrounded by a little *vallum*, or *ditch*, hence the name; this is
due to the fact that these papillae are beneath the general surface level of the mucosa of the tongue.

These papillae are the least numerous, and are found only in one area. Ten to fifteen arrange themselves like a letter V, with the apex at the foramen cecum, a little depression that lies at the boundary of the apical two-thirds and basal one-third of the tongue. These papillae contain taste-buds along their sides.

The taste-buds are the organs of taste and lie in the epithelial layer of the vallate papillae as well as in the epithelial layer of some of the fungiform papillae, in the epithelium of the soft palate, uvula, papillae foliatae and the ventral surface of the epiglottis. They are ovoid or barrel-shaped structures. The superficial extremity is narrow and extends nearly to the surface of the epithelial layer; the deeper part is broader and rests upon the basement membrane. At the superficial end there is a small opening called the gustatory
pore, that leads through a short canal to the surface of the papilla. Each bud consists of two kinds of cells, the outer, stave-like elements called the sustentacular cells; the inner, neuroepithelial cells.

The sustentacular, or supporting cells, are elongated elements the outer ends of which are pointed and form the boundary of the taste-pore. The basal extremities of these cells, are broad and irregular and rest upon the basal cells, to which they may be connected by protoplasmic processes.

The gustatory cells are of the neuroepithelial type. They are so thin that the nucleus forms a large bulge near the center of each cell. The basal extremity of each cell is usually branched and connected to the basal cells by delicate protoplasmic processes. The outer extremity is continued as delicate hair-like process that extends into the epithelial canal beyond the taste-pore and almost to the surface of the epithelium of the mucosa of the papilla. The finely granular cytoplasm contains a deeply staining, rod-shaped nucleus.

The basal cells are flattened elements that lie at the base of the taste-bud. The cytoplasm is small in amount and extends as many processes that connect with the sustentacular cells of the taste-bud. The nucleus contain but little chromatin. These cells are supposed to be supportive in function.

The nerve fibers arise from the subepithelial plexus of nerve fibers. These terminal fibers end in three ways. Some enter the organ (intragemmal) where they divide into fibrils that are varicose and end in small knobs between the neuroepithelial cells. Others surround the taste-bud (circumgemmal) and the fibrils terminate upon the sustentacular cells. Others end between the neighboring epithelial cells of the mucosa (intergemmal).

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**Fig. 168.—Golgi Preparation of the Nerve Fibers of a Taste-bud.**

a, Intragemmal fibers; i, i, intergemmal fibers; c, circumgemmal fibers; n, nerve fibers. (After Retzius.)
Fig. 169.—Cross-section of Tongue.

a, Stratified squamous cells; b, basement membrane; c, tunica propria; d, serous glands; e, mucous glands; f, venule; g, longitudinal muscle fibers; h, vertical muscle fibers; i, transverse muscle fibers; l, septum; m, filiform papilla; n, secondary papillae; r, adipose tissue. A, Filiform papilla. B, Fungiform papilla. C, D, Circumvallate papillae—m, m, taste-buds; n, n, glands. E, Taste-bud—o, nucleus of neuro-epithelial cell; r, nerve fiber; s, gustatory hair; t, sustentacular cell; v, neuro-epithelial cell.
Beneath the mucosa is found the **musculature** of the tongue. This consists of the voluntary striated variety, arranged *longitudinally, vertically* and *transversely*. The longitudinal fibers are arranged in bundles that lie beneath the tunica propria and extend around the tongue. They are separated by small bundles of vertical fibers. In the center, the fibers are vertical, oblique and transverse, and are separated in the middle line by a little partition, or *septum*. This consists of white fibrous tissue, and arises at the base, but does not reach the tip. It varies in height, being higher in the middle than at either end. In the muscular portion, small salivary-glands are often found. Occasionally, branched muscle fibers are found.

The mucosa of the true base of the tongue, basal one-third, possesses *no papillae*. The epithelial surface, however, is not smooth and regular but presents a large number of little rounded elevations each of which shows a small central opening. These elevations indicate the presence of the *lingual tonsils* and the openings are the orifices of the crypts.

The *epithelium* is of the stratified squamous variety and these cells rest upon a *thin basement membrane* and a rather thick *tunica propria* that consists of areolar tissue. The *crypts* are tubular extensions of the epithelium of the surface of the tongue and these epithelial cells are the lining cells of these tonsillar crypts. In the tunica propria surrounding each crypt there is a solitary nodule. It is this nodule of lymphoid tissue that bulges the epithelium and forms the rounded elevations upon the surface. Lymphocytes pass through the epithelial layer and enter the crypts of the lingual tonsils.

The basal one-third of the tongue represents an extensive, widespread but shallow tonsil, a part of the tonsillar ring surrounding the pharyngeal orifice. This *lingual tonsil* consists of scattered groups of lymph nodules especially near the foramen cecum, but scattered nodular elevations may be found over the greater part of the base of the tongue. Each group has its crypt which may be greatly branched; this is lined with stratified squamous cells and in the tunica propria surrounding the crypt are the solitary nodules and diffuse lymphoid tissue, the ducts of mucous glands may open into these crypts. This tonsil may form a distinct and discreet mass
that is encapsulated upon its deep surface and may thus readily be removed in the case of undue enlargement.

Minute salivary glands are very numerous in the tongue and are called lingual glands. These are usually buried in between the muscle bundles and their ducts pass to all surfaces. Upon the ventral (under) surface near the tip, under the mucosa, are two of the largest glands and these are called the apical glands. The glands are espe-

![Cross-section of an Injected Tongue](https://example.com/tongue-cross-section.png)

**Fig. 170.—Cross-section of an Injected Tongue.**

Note the abundant vessels in the papillae. (Photograph Obj. 32 mm.)

cially numerous at the root of the tongue. These glands are of both the mucous and serous types.

The tongue is very vascular and is supplied by the lingual artery chiefly. This artery and vein are deeply buried and from the artery branches pass to the deeper parts of the tunica propria and form a plexus of vessels. From this plexus of capillaries others are given off that pass to the superficial portions of the tunica propria and in the papillae form loops that are characteristic. From the deeper
side of the plexus vessels supply the musculature and glands. The blood is returned by venous channels that have a corresponding course.

The lymphatics are superficial and deep. The former start in the intercellular spaces beneath the epithelium; around the lingual tonsils these lymphatics are very numerous and the capillaries form plexuses around the nodules. The deep set is located near the surface of the musculature and receives the lymph from the superficial set and also from the deep structures of the tongue. The efferents from this plexus carry the lymph to the lingual and deep cervical lymph nodes. The two halves of the tongue are drained separately there being no intermingling of lymph from the two sides. This is important especially in early stages of certain malignant conditions.

The nerves are from the cerebrospinal and sympathetic systems. The cerebrospinal nerves are sensor and motor. The sensor are for general sensibility and special sense of taste. The former terminate in free endings in the tunica propria of the papillae and the deeper connective tissue; some terminate in muscle spindles. The nerves of special sense of taste pass in small bundles of fibers to the bases of the papillae containing the taste-buds. These form a plexus beneath the epithelial cells and from this plexus fibers are distributed to the interior of the taste-buds, to the surface of the taste-buds and to the surrounding epithelium. In the latter instance the naked fibers end between the epithelial cells.

THE PHARYNX

The pharynx is a musculo-membranous bag that connects the oral cavity with the esophagus. It communicates also with the larynx, the nasal cavities and on each side with the middle ear through the auditory tube. There are three divisions, the nasopharynx, the oropharynx and the laryngopharynx. It consists of three coats mucous, fibrous and muscular.

The mucous coat of the nasopharynx is lined with stratified ciliated cells that rest upon a delicate basement membrane beneath which there is the areolar tunica propria. Goblet cells are also numerous in the epithelial layer. In the tunica propria there are usually some small mucous glands and lymphoid tissue. The latter is of
the diffuse form and solitary nodules are very numerous, especially on the dorsal wall. When these hypertrophy in the child they are called adenoids. This lymphoid tissue represents the pharyngeal tonsil. The tunica propria is firmly adherent to the bony dorsal boundary of the pharynx, but laterally and ventrally it is loosely attached to the muscles of the pharynx and palate.

At the side of the nasopharynx the epithelial cells are continuous with those of the auditory tube. The tunica propria of the pharyngeal extremity of the auditory tube contains a considerable quantity of lymphoid tissue that constitutes the tubal tonsil.

In the oropharynx and laryngopharynx the epithelium is of the stratified squamous variety. These rest upon a basement membrane and a rather thick tunica propria that contains thin-walled blood-vessels and the ducts of some mucous glands that lie deeper. The epithelial surface of the tunica propria is usually papillated.

The fibrous coat is the middle portion of the organ; this consists of large bundles of connective tissue fibers and numerous yellow elastic fibers that are longitudinally directed. Some of both kinds of fibers extend into the tunica propria and muscle coat. This fibrous coat takes the place of a submucosa as it supports the larger vessels and nerves.

The muscle coat of the pharynx is the same throughout. It consists of voluntary striated muscle, the various constrictors of the pharynx, that have an oblique direction. In places the muscle tissue is intimately attached to the periosteum of the adjacent bones but in other places it is not and here there is considerable loose areolar tissue that serves to connect the pharynx to the neighboring tissues or organs. In the connective tissue between the muscle bundles are the mucous glands above mentioned.

The blood-vessels and lymphatics are numerous; the main vessels lie in the fibrous coat and from this smaller vessels extend into the mucous and muscle coats and form plexuses of capillaries in these, especially around the glands.

The nerves are also numerous. Those from the cerebrospinal system are both motor and sensor. The former pass to the voluntary muscles and the latter to the mucous membrane. Sympathetic fibers are also present and these pass to the blood-vessels and glands.
ESOPHAGUS

The remainder of the alimentary tract is tubular, and possesses four coats, mucous, submucous, muscular and fibrous. The mucosa is further subdivided into four layers, epithelium, basement membrane, tunica propria and muscularis mucosae.

In the esophagus, the mucous coat is lined by stratified squamous cells which upon the lumen surface run an even course. These rest

Fig. 171.—Section of Mucosa of the Human Esophagus. This is a Typic Mucous Membrane.

a, stratified squamous epithelial cells; b, genetic layer of epithelium and basement membrane; c, tunica propria; d, muscularis mucosae. (Photograph Obj. 16 mm., oc. 10 X.)

upon the basement membrane, beneath which is the papillated tunica propria. These papillae are tall and slender and extend for quite a distance into the epithelial layer. The tunica propria consists of yellow elastic and white fibrous tissues, in which the capillary vessels form a delicate network beneath the epithelium; the ducts of the glands pass through this layer on their way to the surface. These ducts are lined by tall columnar cells at first but in the epithelial layer these cells are replaced by several layers of flattened elements. Diffuse lymphoid tissue and even solitary nodules may be present. The muscularis mucosae consists of involuntary, nonstriated muscle fibers, circularly and longitudinally arranged. In the upper portion
of the esophagus, this layer is often wanting, but in the lower part it is always present. In the resting condition, the mucous and submucous coats are thrown into *longitudinal folds*.

Although the general epithelium is of the stratified squamous variety occasionally patches of *ciliated*, or *columnar epithelium* are found in the upper third. These may be retentions of fetal cells as in fetuses up to birth, such patches are frequently found in the esophagus. In the resting condition the walls of the esophagus are in contact and the lumen almost obliterated. In this condition the mucosa and submucosa are thrown into extensive longitudinal folds.

Some short branched tubular glands, resembling those of the cardiac end of the stomach, are found in the upper part of the

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**FIG. 172.—CROSS-SECTION OF ESOPHAGUS.**

*a*, Stratified squamous epithelium; *b*, basement membrane; *c*, tunica propria; *d*, muscularis mucosae; *e*, esophageal gland; *f*, blood-vessel; *g*, submucosa; *k*, outer longitudinal muscle; *l*, fibrous coat; *n*, inner circular muscle.
esophagus. These tubules are lined throughout with simple columnar cells as well as the neighboring esophageal surface. In addition the secretory portions may contain some parietal cells. Although they do not respond to stains as the deep mucous glands they are considered mucous in type. These glands involve only the mucous coat and are called the upper cardiac glands or the superficial glands of the esophagus.

The lower cardiac glands are found at the lower part of the esophagus close to junction with the cardiac portion of the stomach. These glands are similar to the preceding and are continuous with the gastric glands.

The submucous coat is composed of coarser bundles of white fibrous tissue, which forms a loose network for the support of the large blood-vessel trunks. In this coat are seen a number of glandular structures, the esophageal glands, which are apparently mucous, as they stain lightly with ordinary stains but respond well to the mucin stains. They send their ducts through the mucous coat. As the stomach is approached, these glands become more numerous, and may even be found in the mucosa. They are of the compound alveolar type; crescents are absent in these glands in man. In herbivorous animals these glands are absent. In carnivorous and omnivorous animals they are very numerous seeming to indicate that they are important in the chemistry of digestion.

The muscle coat consists of muscle fibers arranged in two layers, inner circular and outer longitudinal. It is said that the layers are thicker here than in any other part of the alimentary tract with the exception of the caudal end of the intestine. In the upper third these fibers are of the voluntary striated variety, in the lower third smooth and in the middle portion, mixed. The involuntary non-striated variety continues throughout the remainder of the tract. In the upper part of the esophagus the longitudinal muscle is arranged in three bands, one ventral and two lateral. Occasionally some voluntary fibers are found in the lower third in man, while in some animals these fibers predominate throughout the esophagus.

The fibrous coat consists of fibroelastic tissues, and connects the organ with surrounding tissues. It sends in bundles between the muscle bundles, of which they are said to form the perimysium.
The main blood-vessels lie in the submucosa and form a longitudinal network. From this smaller branches pass to the mucosa, the muscularis mucosae and the muscular coat. In these extensive capillary plexuses are formed. In the submucosa special plexus surround the glands. The blood is returned by venous channels in a corresponding course.

The lymphatics are mucous and submucous. The mucous vessels start in the papillae and connect with the channels in the submucosa which also receive the lymph from the muscle coat. The solitary nodules present are usually surrounded by sinus-like lymph vessels.

The nerves are both myelinated and amyelinated. They form two plexuses, one between the layers of the muscle coat and the other in the submucous coat. In these plexuses there are many large ganglia containing large ganglion cells. From the myenteric plexus myelinated nerve fibers (from the vagus) pass to the voluntary striated muscles where they terminate in motor end-organs. Other amyelinated nerve fibers pass to the smooth muscle tissue of the muscle coat and the muscle of the vessels. From the submucous plexus amyelinated fibers pass to the muscularis mucosae and the glands and epithelial lining of the organ where they terminate in free endings.

STOMACH

The stomach is the first part of the tract in which the food rests for any length of time, and in which active digestion and possibly some absorption occur. Although very large, it still represents a tube, and has the four coats above mentioned. It is divided into three portions, the cardia, fundus and pyloric end. They pass into one another insensibly, and the structure of the first two parts is practically the same.

The mucous coat is rather thick and presents a great change over that of the esophagus, showing a higher degree of specialization. The epithelial change is abrupt. In it are seen, with the naked eye, a number of minute depressions, the gastric crypts, or pits, from which the gastric glands extend into the deeper portions. The crypts are 0.12 to 0.25 mm. in diameter and the larger and deeper ones are near the pyloric portion. Between or bounding the pits, are the inter-
glandular projections (plicae villosae). Each gland consists of mouth, neck and fundus, or secretory portion, and is lined by simple epithelial cells.

The cells rest upon a basement membrane, which in turn, rests upon the tunica propria. The latter forms the core of the interglandular projections that form the boundaries of the pits. Between the glands, the tunica propria consists of narrow bands of the areolar tissue, which contains a great deal of diffuse lymphoid tissue, bundles of smooth muscle fibers from the muscularis mucosae, and capillaries, both vascular and lymphatic, in great numbers. In places, the lymphoid tissue is collected into solitary nodules that are lens-shaped, and are called the lenticular nodules. These are numerous in the pyloric end. The mucosa is bounded externally by the muscularis mucosae, which consists of two layers of smooth muscle fibers, arranged as inner circular and outer longitudinal layers.

In the cardiac and fundal portions, the secretory portions of the glands are chiefly of the simple tubular variety. The mouth is short, with the neck and fundus of about the same length. In the neck and fundus, are found two varieties of low columnar cells, the chief, peptic, or adelomorphous cells, and the large delomorphous, acid, or oxyntic cells.

The surface, or true lining cells of the stomach are tall and narrow elements that line the mouths of the glands, the gastric pits and cover the interglandular projection, or parts intervening between the pits. In the resting stage the basal part contains the nucleus and the cytoplasm is granular; the distal cytoplasm is clear and stains lightly. They are mainly goblet cells and secrete a mucous substance that is probably of a protective nature. Cuticular borders are not prominent and terminal bars are to be found at their distal extremities. These cells form a broad band of palely stained protoplasm in which the basally placed, darkly staining nuclei form a row of closely placed bodies. The lateral boundaries of the cells are not distinct, but the nucleus of each indicates the breadth of the cell. Altogether they give a feather-like appearance to the interglandular projections.

The peptic cells are low columnar, or pyramidal elements and are more numerous in the fundi than the necks of the glands. The
nucleus is usually circular or oval and contains considerable chromatin. The granular cytoplasm has an affinity for hematoxylin and appears bluish when characteristically stained. During the

resting stage the cells become so swollen as to occlude the lumen of the gland. The granules increase in number in the distal portion of the cell, forming a broad zone. These are zymogen granules and are derived from the prozymogen granules that occupy the basal
portion of the cell. These prozymogen granules are in the form of small rods and are so placed as to give a striated appearance to the basal part of the cell. These are said to respond readily to toluidin blue or iron hematoxylin. After secretion these cells are greatly reduced in size and are less granular.

The acid or oxyntic cells are readily distinguished from the others by their size, shape, and affinity for acid stains. They are very large, oval, or triangular elements, most numerous in the necks, but also scattered in the fundus. They are found along the wall of the tubule, and usually beneath the peptic cell, hence the term parietal, or wall, cell. The nucleus is quite large (there may be two) and centrally located.

These cells are most numerous in the neck of the glands where they are more oval in shape. In the fundus of the gland they are somewhat triangular in form while in the intermediate part of the gland tubule they are said to be sort of wedge-shaped, or pyramidal in form. The homogeneous, or finely granular cytoplasm contains an elaborate, basket-like system of secretory canals that carry the secretion of these cells to the lumen of the tubule. This canalicular system can be outlined by the silver nitrate method.

The appearance of the parietal cells alters with its stages of rest and activity. During fasting the cells are much smaller and more angular in outline, and may leave their position against the wall of the tubule. During digestion these cells increase greatly in size.

Although these are called the acid cells and are supposed to secrete the hydrochloric acid of the gastric juice this seems improbable as the reaction of the cytoplasm is neutral or alkaline and contains chiefly chlorids. It is thought that an organic chlorid is formed by the cells and when this is passed to the lumen of the gland the
hydrochloric acid is liberated. The recent work of Hammett leads him to believe that hydrochloric acid is present in the parietal cells.

In some animals the parietal cells are placed in special depressions of the basement membrane and communicate with the gland proper by only a narrow opening. In some amphibia the glands of the fundus of the stomach contain only the acid cells; their pepsin forming cells are apparently located in glands in the esophagus. In birds the main tubules of the glandular stomach are lined only with peptic cells and the acid cells line the secondary, or offshoot tubules alone.

The affinity for acid stains is pronounced. With eosin, they are distinctly red, while with acid fuchsin they are colored a very much deeper red.

In recent special\(^1\) studies of the acid cells of the adult stomach, by the author, it was found that these cells cease abruptly at different points along the various curvatures of the stomach. Along the lesser curvature they extend 63.09 per cent. of the distance from the cardia to the pyloric orifice; along the greater curvature, 81.55 per cent.; along the ventral curvature, 76.48 per cent.; along the dorsal curvature 80.54 per cent. It will readily be seen that the acid cells do not stop at the same points in all parts of the organ. In the rabbit the acid cells extend even farther along the lesser curvature but to about the same extent as in the human along the other curvatures. It was noted, however, that nowhere did the distribution agree with the general anatomic divisions of cardiac and pyloric portions.

The thickness of the mucosa is generally given as 0.5 mm. at the cardia, 1 mm. intermediate and 2 mm. at the pylorus. In the above studies no such constant increase as stated was found; in some instances the cardiac mucosa was thicker than that at the pylorus, in others about equal and in some few the pyloric mucosa was less than twice as thick as that of the cardiac portion.


2. The Distribution of Acid Cells along the Dorsal Curvature and the Possible Relation to the Occurrence of Gastric Ulcer. Jour. of Surgery, Gynecology and Obstetrics, Jan., 1923.
The average measurements were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Cardia, mm.</th>
<th>Fundus, mm.</th>
<th>Intermed., mm.</th>
<th>Pylorus, mm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater curvature</td>
<td>0.85</td>
<td>0.83</td>
<td>0.85</td>
<td>0.78</td>
</tr>
<tr>
<td>Ventral curvature</td>
<td>0.64</td>
<td>0.71</td>
<td>0.80</td>
<td>0.81</td>
</tr>
<tr>
<td>Dorsal curvature</td>
<td>0.57</td>
<td>0.69</td>
<td>0.69</td>
<td>0.90</td>
</tr>
<tr>
<td>Lesser curvature</td>
<td>0.71</td>
<td>0.70</td>
<td>0.72</td>
<td>0.88</td>
</tr>
</tbody>
</table>

In the first portion of the **fundus**, the glands are chiefly of the simple tubular variety. As the **pyloric** end is approached, the branched tubulars appear suddenly, so that they form the predominating variety in this end. There is also a marked change in the lining cells. The acid cells become rapidly fewer in number, and, in the pyloric end, are but seldom seen. One can, therefore, be safe in saying that a section containing a number of acid cells is from the **fundus**, or **cardia**.

Around the cardiac orifice is a zone 5 to 40 mm. wide where the special tubulo-alveolar **cardiac glands** are found. The cells of these glands are chiefly of the mucous type; other cells similar to the chief and acid cells of the fundus glands and the peptic cells of the pyloric glands are found. These glands represent retrogressive fundus glands (Bensley). According to Ellenberger and others the true cardiac glands contain acid cells and secrete an **amylolytic ferment**.

In the **pyloric canal** the mucosa is thicker and the glands are of the branched tubular variety. The gastric crypts are deeper, the mouths of the glands are longer and the fundi and necks are comparatively shorter. Into each mouth or crypt a number of secreting tubules pour their secretion and these tubules are all the branches of one duct. The fundal or secreting portions may be coiled. These pyloric glands are said to occupy the pyloric fifth of the stomach, according to Piersol.

The **interglandular projections** are covered and the pits and gland ducts are lined with the same kind of tall, slender columnar and goblet cells seen in the cardiac portion. This variety of cell is more
extensive, however, on account of the greater amount of surface covered. The *secretion portions of the glands* present an entirely different appearance than the corresponding portions of the fundal glands. In the first place, they are not straight as in the cardia and fundus; in the second place, the branches of one duct are usually grouped closely together and seem to be distinctly separated from their neighbors by denser tunica propria resembling septa, or tiny capsules; thirdly, the cells are different in form and different in stain reaction than those of the cardia and fundus; lastly, the cells are usually of only one variety and the lumen of the secretory tubules is broader than in the other glands of the stomach.

The cells are said to be of the *peptic* variety but they differ from those of the cardia and fundus. Each cell is taller and broader than the ordinary peptic cell and represents a distinct columnar element. They are sharply delimited and differentiated from the cells of the ducts and interglandular projections. The cytoplasm is clear and responds only faintly to the ordinary stains. In the resting stage
the cytoplasm is finely granular. The oval nucleus stains readily and occupies a basal location. As the pyloro-duodenal junction is reached, the glands become shorter and less numerous, and some may even extend into the submucosa. Intestinal crypts have been found in the stomach. The interglandular projections become longer, and resemble, somewhat, the villi of the small intestine but they are not true villi. The pyloric glands may extend from 6 to 14 cm. from the pyloro-duodenal junction.

The mucosa and submucosa are thrown into large, longitudinal folds, the rugæ, in the empty contracted stomach. These folds and glands increase greatly the absorptive and secretory surfaces. As the stomach fills these folds become reduced in size and when the stomach is fully distended they are gone. This provision permits of great distension of the organ without injury to the mucosa.

In addition to these glands crypts of Lieberkühn have been described in the stomach. These crypts are more numerous in the transition zone (between fundus and pyloric canal), although some have been found scattered in other parts. These resemble the glands of the mucosa of the small intestine; they are simple tubular in form and are lined with simple columnar cells with striated borders and occasionally goblet cells are seen. In the fundi of these glands cells of Paneth are said to be present.

The submucous coat consists of areolar tissue. The fibers and bundles are usually coarser than those found in the tunica propria and the meshes formed by these bundles are also larger. This is because the larger blood-vessels and lymphatics are here and the submucosa might readily be called the vascular coat. This coat stains lightly because diffuse lymphoid tissue is absent. In this coat is located the submucous plexus of nerves that supplies the muscularis mucosae and the epithelium of the organ. The sub-
mucosa forms a loose distensible coat connecting the muscular and mucous coats and forms the central portion of the rugous folds.

The **muscular coat** consists of smooth muscle tissue arranged in *three layers*. Of these the *inner* is *oblique*. These fibers are continuous with the circular fibers of the left side of the esophagus but they do not form a complete layer. The *middle, circular fibers* form a complete layer and are continuous with the circular fibers of the esophagus. The circular fibers form ring-like masses that start at the fundus becoming at first larger and then smaller as the pylorus is approached. At the pyloric orifice they form a very thick ring called the *sphincter pylori muscle*. The outer, *longitudinal layer* is continuous with the corresponding layer of the esophagus. These fibers radiate from the cardiac orifice and are most numerous along the curvatures. Although they form only a thin layer on the surface they become increased in number toward the pylorus and become continuous with the longitudinal layer of the intestine. Between the circular and longitudinal layers is the myenteric plexus of nerves for this coat.

The *external, or fibroserous coat*, consists of a layer of the *peritoneum*, a serous membrane. This consists, externally, of a single layer of endothelial cells resting upon the fibroelastic subendothelial tissue. It invests all but a very small part of the stomach. At the curvatures it continues away from the organ forming the omenta and it is at these regions that the vessels gain access to the stomach. Beneath this is a thin layer of areolar tissue that constitutes the *fibrous coat*. Some of its fibers pass in between the bundles of muscle fibers of the longitudinal layer and blend with the perimysial sheaths.

The *blood-vessels, lymphatics and nerves* will be considered with those of the intestinal tract.

**SMALL INTESTINE**

The **intestinal tract** consists of two main portions, the *small* and *large intestines*. These each have their subdivisions, which usually differ from one another.

The *small intestine* is divided into *duodenum, jejunum* and *ileum*. They all have the same general structure. This will first be described, and then the differences studied,
There are four coats, *mucosa*, *submucosa*, *muscularis* and *fibrosa*, or *serosa*.

The *mucosa* has four layers, *epithelium*, *basement membrane*, *tunica propria* and *muscularis mucosae*. As is the case with the mucosa of the stomach, the epithelium is evaginated in the form of an immense number of tiny glands that are all of the simple tubular variety. The tunica propria and epithelium between the glands are invaginated into the lumen of the intestine in the form of simple, finger-like projections, the villi, that resemble the interglandular projections of the stomach but are a little different in structure and entirely different in function. Through the formation of the glands and plicae circulares, to be described later, the secretory surface of the tubular intestine is enormously increased. Through the formation of the villi and the plicae circulares the absorptive surface is also enormously increased.

The *epithelial cells* are columnar in type but vary in structure, those covering the villi differing from those that line the glands. These cells rest upon a thin basement membrane, of a reticular nature, which is supported by the tunica propria. The basement membrane like the epithelial cells has a very sinuous course passing in a continuous manner over the villi and down into the glands.

The *tunica propria* consists of areolar tissue. This fills in the space between the glands and the muscularis mucosae and forms the core of the villi. It contains a great deal of diffuse lymphoid tissue and the amount varies at different times as the leukocytes come and go. Occasionally Peyer’s patches project through the muscularis
mucosæ into the mucosa. The abundance of the leukocytes gives the tunica propria a dark appearance and hides the areolar tissue. In addition vascular and lymphatic capillaries are very numerous. The nerves from the submucous plexus pass through the tunica propria to their terminations.

Fig. 178.—Longitudinal Section through the Apex of the Villus of a Dog. × 360.
The goblet cells contain less mucus as they approach the summit of the villus.

The muscularis mucosæ consists of smooth muscle tissue arranged into two layers. The inner layer consists of circularly arranged fibers and the outer of longitudinally directed fibers. It runs an unbroken course usually but in the ileum it may be broken in places by the nodules of a Peyer's patch that is invading the mucosa. The
muscle fibers found in the villi are said to be derived from the muscularis mucosae.

The intestinal crypts, or glands of Lieberkühn are of the simple tubular variety and involve only the epithelium, basement membrane and tunica propria. These are evaginations of the epithelium and basement membrane that measure 0.2 to 0.3 mm. in depth and extend in a straight course almost to the muscularis mucosae. The tunica propria that surrounds them and separates one from the other is filled with diffuse lymphoid tissue.

Lining the mouths of the glands and then continuing over the villi are goblet cells in various stages of secretion. When these cells have discharged their secretion they are tall columnar elements with cytoplasm that stains fairly darkly; when they are full of secretion they are goblet-shaped and stain very lightly. A cuticular border is distinct. In the necks and parts of the fundi of the glands the cells are of the simple columnar type. The cytoplasm of these cells is slightly granular and contains neither mucin nor fat. A cuticular border is not well developed. They are supposed to be indifferent cells which by mitosis produce daughter cells that may become differentiated into the goblet cells of the neck and villus or the glandular cells in the fundus of the glands. The remaining portion of the fundus of each gland is lined by these simple columnar cells but in the bottom of the fundus are the cells of Paneth. These are low columnar, or pyramidal elements in which the cytoplasm is coarsely granular; in some of the cells these granules respond to the plasmatic stains and in others to the nuclear stains. These are no doubt secretion granules in the various stages of elaboration. These cells have lately been found in all parts of the intestines including the great bowel. Other granule cells have recently been described. One of these, the acidophilic cell, has fine granules that respond to the acid stains; the other, the chromaffin cells (called yellow cells by Schmidt) contain fine granules of chromaffin. These cells are found both in the glands and upon the villi and are apparently independent of all of the other cells. Cells resembling the chromaffin cells have been found in the glands of Brunner of the duodenum. Between the various cells of glands and villi leukocytes are frequently seen.
The villi are little finger-like projections of the tunica propria covered by the basement membrane and simple columnar cells. They are enormous in number and extend throughout the length of the small intestine and constitute one of its most important characteristics. They increase greatly the absorptive surface of this organ and vary somewhat in number, shape and height in the different divisions of the intestine. The base of the villus is at the level of the mouths of the glands and its tunica propria core is directly continuous with the tunica propria that lies between the glands. The tip of the villus extends into the lumen of the intestine.

Each villus is from 0.2 to 1 mm. in height. The center consists of tunica propria that consists of delicate areolar tissue containing a great deal of diffuse lymphoid tissue. Although the amount of this is constantly variable there is usually enough present to hide the areolar tissue and the other structures. In addition there are numerous blood capillaries, smooth muscle fibers and a dilated lymph capillary in the center called a lacteal. The smooth muscle fibers are longitudinally arranged around the lacteal and serve to retract the villus. Those fibers near the tip of the villus are attached to the basement membrane, the muscle fibers branching to make this attachment. The lacteal is the starting point of the lymphatic vessels of the small intestine. They are simply large lymph capillaries and extend through the villus toward the muscularis mucosae where they empty into a plexus of lymph vessels. By contraction of the muscle of the villus this structure is shortened and the lacteal pressed upon and emptied. The valve at the end of the lacteal, where it connects with the plexus, prevents regurgitation of the lymph. Occasionally two lacteals may be found in one villus.

The basement membrane is a thin reticulated structure that supports the epithelial cells. These cells consist of a single layer of columnar elements that are really goblet cells in different stages of secretion. The discharged cells are narrow columnar cells, the cytoplasm is slightly granular and stains more darkly than in later stages. The nucleus is near the basal extremity of the cell and is usually thicker than the band of cytoplasm. In the resting stage the secretion makes its appearance in the form of fine granules, mucinogen, which increase in number and size and respond to special
stains. These form a goblet-like mass that crowds the remains of the cytoplasm and the nucleus to the basal part of the cell. When secretion occurs these granules absorb water, swell and run together to form a single droplet of mucin that is discharged into the lumen of the intestine. Each goblet cell possesses a diplosome that lies near the middle of the peripheral half of the cell. It is in this region that the mucus is formed.

The villi of the duodenal portion of the small intestine are from 0.2 to 0.5 mm. in height, flat and leaf-like in form and most numerous. In the jejunum they are 0.5 to 0.7 mm. in height, club-shaped. In the ileum they are short and filiform and fewer in number. According to Piersol the number per square millimeter is as follows: Duodenum and jejunum, 24 to 40; ileum 15 to 30. The shape and height are said, by Johnson, to vary according to the state of distension of the intestine.

The mucosa and submucosa are thrown into folds that have a circular direction and are called the plicae circulares, or valvulae conniventes. These extend usually about two-thirds of the way around the bowel though some form complete circles and others form spirals of one or more turns. The spirals may occur individually or in groups of two or three. At their highest points these folds are about 8 mm: in height. They increase the absorptive surface and are permanent, that is no matter how much the bowel is distended within the normal limits these folds are always present. These folds do not begin to appear until a short distance from the pyloric orifice so that the first part of the duodenum is practically smooth. They are quite large just beyond where the conjoined bile and pancreatic ducts open and are nearer one another here. Here they are about the height of a fold apart. In the middle of the jejunum and on they become smaller and more widely separated and ultimately disappear in the lower end of the ileum.

The duodenum shows the general characteristics of the small intestine and in addition possesses the glands of Brunner, or duodenal glands that are characteristic of this division of the small bowel. These are branched tubular structures that are located in the submucosa. Each is small and according to some tubuloalveolar; they are most numerous in the first part of the duodenum and may
sometimes break through the muscularis mucosae and lie partly in the mucosa. The secreting cells stain very lightly giving the idea of a mucous gland. A mucin reaction can be obtained. In the resting condition, just after discharge, the cells appear small, shrunken and granular. During the accumulation of the secretion the cells become larger, swollen and clear. As the ducts leave the gland they run a somewhat irregular course through the submucosa and muscularis mucosae and mucous coats and empty their secretion at the bases of the villi.

The ileal portion of the small intestine is characterized by the presence of the agminated nodules, or Peyer's patches. These are a
form of lymphoid tissue. Each patch is usually located in the submucosa but at times one may break through the muscularis mucosae and some of the nodules lie in the mucosa. In the areas over such nodules the glands are usually absent but those at the edges of the nodule may form a circle about it; the villi may also be absent here. Each patch consists of from ten to sixty solitary nodules in one distinct group. Each solitary nodule shows a germinal cen-

![Fig. 180.—Cross-section of Duodenum.](image)

1, Mucous coat; 2, submucous coat; 3, muscular coat; 4, fibrous coat; 5, 6, villi; 7, epithelium of villus; 8, muscularis mucosae; 9, glands of Brunner.

ter and may be surrounded by a partial or complete delicate capsule of white fibrous tissue. Each patch may be 4 cm. in length, 12 to 25 mm. in width and is usually placed opposite to the attachment of the mesentery. They are most numerous in the lower part of the ileum and are closer together here. Some state that they are found also in the jejunum and in the caput coli. There are said to be twenty to thirty of these on the average though as many as forty-five have been found in young individuals. They are most marked in the young, gradually decrease in number toward middle age and in the aged may be almost entirely absent. They are the seats of the ulcers in typhoid fever.
**Fig. 181.**—CROSS-SECTION OF ILEUM.

*a*, villus; *b*, epithelium; *c*, tunica propria of villi; *d*, intestinal gland; *e*, tunica propria; *f, f*, muscularis mucosae; *g*, blood-vessel; *h*, submucosa; *i*, circular muscle layer; *k*, longitudinal muscle layer; *l*, peritoneal layer; *m*, fibrous coat; *n*, nodules of the Peyer’s patch.

**Fig. 182.**—AN AGMINATED NODULE OF THE ILEUM OF A CAT.

(Photograph Obj. 48 mm.)
Absorption takes place after the ingested food has been acted upon by the various juices of the stomach, small intestine, pancreas and liver. This process of absorption is carried on chiefly by the villi of the small intestine. By the "selective action" of the simple columnar cells covering the villi the water and inorganic salts are passed through and ultimately reach the blood-vessels. All of the sugars, except possibly lactose, are converted into levulose and dextrose and as such are taken into the epithelial cells and transferred to the blood-vessels. In whatever form the carbohydrates are absorbed they never leave these cells except in the form of levulose or dextrose. Proteins are converted into peptones by the digestive fluids and as such are absorbed by the epithelial cells of the villi. Native proteins are also absorbed by the mucosa of the large intestine. After absorption the epithelial cells convert these peptones into plasma-albumin and as such are given over to the blood-vessels. The end products of protein digestion are not peptones but less complex bodies, as polypeptids, peptids and amidoacids. It is these simple products that the epithelial cells convert into plasma-albumin and plasma-globulin.

Fats are believed, by some investigators, to be converted into an emulsion during digestion and from this emulsion the fat globules are taken by the epithelial cells and passed through them to the lymph vessels. Others believe that as a result of digestion, fats are converted into soaps and glycerin. The epithelial cells take these and reconstruct fat within the cell bodies and the fat is then passed to the lymph vessels where with the lymph they constitute the chyle.

If parts of the small intestine of animals fed upon rich fatty foods be fixed in osmic acid solutions and sectioned, the fat in the tissues will be seen stained black. In the epithelial cells of the villi the fat droplets are most numerous and larger in the ends of the cells toward the lumen of the bowel. This would seem to indicate the second theory and that the cells had taken these saponification products and reconstructed fat. These droplets are then said to be passed by the epithelial cells into the intercellular spaces of the tunica propria. Here the fat is seen between and in the lymphocytes and also in the lacteals. It is supposed that the
lymphocytes assist in the transference and passage of the fat to the lacteals; possibly the endothelial cells of the lacteals assist also in this process. Disintegrating leukocytes with fat in their cytoplasm are found in the lacteals.

The *muscularis mucosae* consists of two layers of smooth muscle fibers arranged (inner) circularly and (outer) longitudinally. From it bundles are sent up into the villi.

**LARGE INTESTINE**

This consists of *cecum, colon, rectum* and *appendix*. The structure of all is practically the same.

![Figure 183](image)

**Fig. 183.—Cross-section of Segment of Colon.**

*a*, Mucous coat; *b*, submucous coat; *c*, muscular coat; *d*, fibrous coat; *e*, columnar cell; *f*, goblet cell; *g*, basement membrane; *h*, tunica propria; *i*, inner circular layer of muscularis mucosae; *k*, outer longitudinal layer of muscularis mucosae; *l*, inner circular layer of muscular coat; *m*, outer longitudinal layer of muscular coat.

The *mucosa* contains *simple tubular glands, crypts of Lieberkühn*, which are usually longer, broader and more numerous than those of the small intestine, measuring 0.4 to 0.6 mm. in depth. The cells lining these are *goblet* cells. The tunica propria contains a great deal of diffuse lymphoid tissue that is often collected into solitary nodules that show germinal centers. *Plicae circulares and villi are*
absent. Smooth muscle fibers may extend from the muscularis mucosae to the basement membrane.

The outer three coats are like those of the small intestine, except for difference in the muscular coat. The longitudinal fibers are usually thin except where they form the three bands, the *taeniae coli*, which are about one-sixth shorter than the bowel. These act as a purse string to the intestine, and cause it to be thrown into a number of *sacculations*. If the bands be removed, the sacculations disappear. They extend from the cecum to the beginning of the rectum.

Along the colon and the first part of the rectum the serous coat has the *appendices epiploicae* attached to it. These are small tabs of adipose tissue that vary in size from a few millimeters to a centimeter or more. Each pad of adipose tissue is covered with peritoneum which is continuous with that of the bowel in the form of a delicate *pedicle*. The fibers in this adipose tissue do not respond well to the ordinary stains and give a hazy picture unlike the ordinary adipose tissue. At times leukocytes, almost in sufficient numbers to constitute diffuse lymphoid tissue, are found in the adipose tissue.

The *rectum* has its mucous and submucous coats formed into folds called the *rectal valves*. These contain a continuation of the muscular coat, by means of which the valves may be protruded into the lumen. At the lower end, the *anus*, *stratified squamous* cells replace the simple columnar, and this marks another *mucocutaneous junction* as in the lips. The circular fibers are more numerous in the rectum and especially at the anal extremity where they form the *internal sphincter muscle*. This is about 4 mm. thick.

The *appendix* is a continuation of the cecum. It has the four coats, *mucosa*, *submucosa*, *muscularis* and *fibrosa*, or *serosa*. 

---

**Fig. 184.** — *Section of Human Colon*

*a*, Mucosa showing simple tubular glands; *b*, submucosa; *c*, muscularis; *d*, fibroserous coat. (Photograph Obj. 32 mm., oc. 7.5 X.)
The mucosa is usually irregular, and consists of simple columnar epithelial cells that rest upon a basement membrane; beneath the latter lies the tunica propria, which is bounded by the muscularis mucosa.

In the mucosa are a large number of tube-like depressions, the glands of Lieberkuhn. These possess an equal diameter throughout, and are quite regularly distributed. The cells of the mucosa are the simple columnar variety, interspersed with many goblet cells. They are quite distinct, and usually possess a basal border. The cells in the base of the glands supply the parts higher up, and are consequently the youngest. The glands are about 25,000 (Kelly and Hurdon) in number, and are absent where the solitary nodules are found.

The tunica propria consists of a delicate fibro-elastic stroma containing many capillaries, considerable diffuse lymphoid tissue and solitary nodules (often 300 to 400 in number). The solitary nodules contain germinal centers, and may extend into the submucosa. Immediately over them, the glands are usually absent.

The muscularis mucosa is not always present. It consists of smooth muscle fibers forming a thin band separating the mucosa from the submucosa.

The submucosa consists of loose white fibrous tissue, and supports the larger blood-vessels. In older subjects, it becomes thicker and denser, and passes into the tunica propria.

The muscular coat is usually separable into two distinct layers, inner circular and outer longitudinal. The former is the more prominent, and extends to the blind end, where the fibers form a dome-like collection of interlacing fibers. The longitudinal fibers are less prominent than the circular. Both layers are pierced, at intervals, by large vessels. Such an opening, of which one especially exists at the blind end, is called an hiatus (Kelly and Hurdon).

The serous coat consists of white fibrous tissue, surrounded by the peritoneum.

The lumen tends to disappear more frequently than supposed; this change occurs during the ages ranging from 20 to 80. The older the individuals, the higher the percentage of occlusions. The glands are gradually destroyed by the thickening of the submucosa,
this process beginning at the blind extremity and proceeding toward the bowel. Occasionally, in this process of occlusion, quite an abundance of adipose tissue is seen in the submucosa.

Fig. 185.—Cross-section of Human Appendix.

- a, Lumen
- b, epithelium
- c, basement membrane
- d, glands
- e, tunica propria
- f, diffuse lymphoid tissue
- g, muscularis mucosae
- h, solitary nodule
- i, adipose tissue
- k, submucosa
- l, circular muscle fibers
- m, longitudinal muscle fibers
- n, fibrous coat

The blood-vessels of the gastrointestinal tract pass between the layers of the mesenteries, or omenta, to the organs where the large trunks enter the submucous coats. In the case of the stomach the vessels enter from along the curvatures and represent branches from the aorta, hepatic and splenic arteries. From their anastomoses along the curvatures main trunks enter the organ and in
passing through the muscle coat give off small branches thereto; the main vessels continue into the submucosa where they anastomose freely; from this plexus branches complete the supply to the muscle coat. Other branches pass to the mucous coat; these arterioles are at first coiled and then straight giving off numerous capillary branches that pass between the glands toward the epithelial surface where these capillaries form a coarse meshwork around the gastric pits. From this plexus the venous capillaries form a fewer number of larger venules that after a straight course between the glands unite near the muscularis mucosae to form a venous plexus. The vessels derived from this plexus pass into the submucous coat where they again anastomose; from this second plexus vessels carry the venous blood to vessels beneath the serous coat and from here to the portal, splenic and superior mesenteric veins.

In the small intestine the terminal loops formed by the branches of the superior mesenteric artery, in the mesentery, send branches to
the bowel; these branches reach the organ at the mesenteric attachment and each usually divides into two that separate and encircle the bowel, giving off branches in this course and anastomosing after the circuit is completed. These vessels lie under the serous coat.

The branches ultimately enter the submucosa, supplying part of the muscular coat on the way, and form a plexus of vessels in the submucosa; branches pass to the muscular and mucous coats. In the mucous coat another plexus is formed and from this numerous capillaries form a meshwork around the glands and individual capillaries extend straight into the villi to their tips, forming a mesh-
work of capillaries just beneath the basement membrane. The blood
continues into venules that start near the tips of the villi and after a
straight course through the mucosa and submucosa empty into the
submucous plexus of veins. This plexus receives also the blood,
through venules, from the deeper (glandular) portion of the mucosa
and from the muscle coat. From this plexus the efferent vessels
have a course corresponding to that of the arteries.

In the large intestine, owing to the absence of villi, the vessels
are arranged somewhat as in the stomach. The terminal portion
of the large bowel differs though. In the anal end of the rectum the
vessels of the submucosa are longitudinally arranged; in the anal
canal they lie in longitudinal folds of the mucosa. The veins of
these parts are very large and form the internal and external hem-
orrhoidal plexuses; the internal plexus has for its efferent vessel the
inferior hemorrhoidal vein while the efferent of the external plexus
is the superior hemorrhoidal vein.

The nerves supplying the gastrointestinal tract are the two vagi
and the sympathetic system. These nerves form two great plexuses,
one in the muscle coat and the other in the submucous coat; at the
intersections of the fibers of the plexuses there are sympathetic
nerve cells in greater or lesser numbers forming large, or small
terminal ganglia.

In the stomach the two vagal nerves and branches from the solar
sympathetic plexus are the sources of the nerves. These enter the
organ and between the circular and longitudinal muscle layers form
the myenteric plexus (plexus of Auerbach) from which fibers supply the
muscle fibers of this coat. Other fibers continue into the submucous
coat where they form the submucous plexus (plexus of Meissner)
from which branches go to the muscularis mucosae and to the
epithelium of the mucosa.

In the small intestine the nerve fibers that form the corresponding
plexuses just described are derived from the right vagal nerve and the
celiac plexus and superior mesenteric ganglion. These nerves at
first follow the larger vessels toward the intestine, anastomosing
with one another in this course, and near the intestine leave these
vessels and enter the walls of the organ. In the muscle coat the
myenteric plexus is formed and in the submucous coat the submucous
plexus is formed. The distribution is the same as in the stomach except the villi are also supplied, some of the fibers going to the muscle fibers in the villi and others to the epithelial covering.

In the large intestine the nerve fibers are mainly from the second and third sacral spinal nerves and from the superior, inferior and hypogastric plexuses of the sympathetic system. These nerves form plexuses that are distributed in the foregoing manner.

The numerous lymph spaces of the stomach surround the vessels and glands. The lymph capillaries lie in the mucosa well below the surface and between the glands and receive the lymph from the intercellular spaces. At the region of the muscularis mucosae these capillaries form a plexus the efferents of which pass into the submucosa to form the coarser submucous plexus, the vessels of which possess valves. Another plexus lies between the muscle coat layers. The efferents from these two plexuses follow the blood-vessels and leave the stomach and carry the lymph to nodes around the stomach.

In the small intestine the intercellular lymph spaces are likewise extensive. The first vessels are the lacteals, which are closed at the tips of the villi and run a straight course toward the muscularis mucosae where they all terminate in the mucous plexus. At their junctions with the plexus the lacteals have valves. The vessels of the mucous plexus are mostly valveless. The efferents from the mucous plexus carry the chyle to a plexus of larger vessels in the submucosa; these have valves. A third plexus lies between the layers of the muscle coat. The efferents from the submucous and muscular plexuses carry the lymph to the fourth, or subserous plexus, which is most prominent at the mesenteric attachment. The efferents from the subserous plexus follow the vessels and in the mesentery, at frequent intervals, the chyle is filtered through numerous lymph nodes before it ultimately reaches the common intestinal trunk.

The cells lining the various portions of the alimentary tract are as follows.

LIPS.......................................................... Stratified squamous.
MOUTH........................................................ Stratified squamous.
TONGUE...................................................... Stratified squamous.
PHARYNX..................................................... Stratified squamous.
ESOPHAGUS.................................................. Stratified squamous.
The differences between the small and large intestines are as follows:

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<tr>
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<th>SMALL</th>
<th>LARGE</th>
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<tr>
<td>GLANDS.</td>
<td><strong>LONG AND NARROW.</strong></td>
<td><strong>BROAD.</strong></td>
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<tr>
<td>CELLS.</td>
<td>CHIEFLY GLANDULAR</td>
<td>CHIEFLY GOBLET.</td>
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<td>VILLI.</td>
<td>PRESENT.</td>
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<td>PLECT.</td>
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<td>BRUNNER'S GLANDS</td>
<td>PRESENT.</td>
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<td>PEYER'S PATCHES</td>
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<td>LONGITUDINAL BANDS</td>
<td>ABSENT.</td>
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<td>SACCUCTIONS.</td>
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<td>APPENDICES EPIPOICA.</td>
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CHAPTER X

THE DIGESTIVE GLANDS

The digestive glands are the liver, and salivary glands, the parotid, pancreas, sublingual and submaxillary.

LIVER

The liver, the largest gland in the body, is compound tubular in structure. In the child at birth it represents one-eighteenth to one-twentieth of the body weight, while in the adult it represents about one-fortieth, weighing from 48 to 58 ounces in the male and 45 to 50 ounces in the female. It is surrounded by a sheath of white fibrous tissue, the capsule of Glisson, which is covered by peritoneum. On the under surface of the organ, the capsule follows the blood-vessels at the portal or transverse fissure into the gland, and forms the interlobular connective tissue and intralobular reticulum. Folds and bands forms the various ligaments as the suspensory, coronary and lateral. The round ligament is formed by the persistent, closed umbilical vein.

The liver is divided into lobes and lobules, of which the latter represent the units. A description of a lobule will suffice for that of the whole liver.

Each lobule is about 1 mm. in diameter and Mall states that there are about 480,000 in the liver. Each consists of a collection of anastomosing and radiating chains of hepatic cells, the tubules, that start from the central, or intralobular vein, which represents a large sinusoid. These chains are separated from one another by reticulum, which supports the cells and the intralobular blood capillaries; these capillaries are of the sinusoidal variety; that is, the endothelium is attached to the epithelium of the tubules. As a result the material for secretion is transferred directly from the blood to the liver cells and the internal secretion is transferred
directly from the cells to the blood without the intervention of the lymph or lymph vessels. Each chain consists of two or three cells side by side, enclosing a small capillary space called the bile capillary. Peripherally, the lobules are not separated from one another by connective tissues, except in the pig and camel. In these animals, the lobules are sharply outlined by bands of connective tissue. This occurs somewhat imperfectly in the human liver under pathologic conditions (chronic interstitial hepatitis).

According to Mall, the lobule, as now considered, is not the structural unit of the liver; the structural unit refers to all the tissue that surrounds each terminal branch of the portal vein and is supplied thereby.

From the capsule of Glisson large bands or trabeculae pass into the organ forming the coarse framework of the liver and supporting the larger vessels, ducts and nerves. From the interlobular trabeculae the intralobular reticulum is derived. This is a very delicate meshwork of fine fibrils that support the functioning hepatic cells and the intralobular capillaries. Owing to the fineness of the reticulum,
Fig. 189.—From a Cross-section of a Human Hepatic Lobule. × 300.

(Lewis and Stöhr.)

Golgi preparation. The boundaries of the hepatic cells could not be seen. The black dots are precipitates of the silver. 1, Bile capillary in the anastomosis between two hepatic trabeculae; 2, nucleus of an endothelial cell of a sinusoid; 3, nucleus of an hepatic cell; 4, nuclei of hepatic cells.
but especially to the extremely close relation of the blood capillaries and the epithelial cells this reticulum is practically invisible or hidden in the ordinary section 10 microns thick. In order to see this it is best to prepare digested preparations. In special preparations stellate cells with two or three processes are seen in the lobules. These are the cells of Kupfer. These cells may have one or two nuclei; they are uniformly distributed in the lobule and are said to be phagocytic. In certain regions, at the junctions of several lobules,

![Fig. 190.—Reticulum of a Liver Lobule.](image)

Fig. 190.—Reticulum of a Liver Lobule. c, Central vein; i, interlobular area. (Schäfer after Oppel.)

large masses of the interlobular connective tissue are seen. Upon examination these masses usually contain a branch of the portal vein, hepatic artery, and bile duct and are called the portal canals, or systems. In pigs and camels the interlobular connective tissue is so abundant as to form a complete investment of each lobule, so that in sections, each lobule is separated from its neighbor by a complete wall of white fibrous tissue. The portal canals are present here as above.

The hepatic cells are large mononuclear masses of protoplasm; occasionally two nuclei may be present in one cell. The cytoplasm
is finely granular and an exoplasmic zone may be differentiated. These cells are traversed by a network of fine canals, the *secretory capillaries*, that may communicate, on the one hand, with the bile capillaries between the cells, or on the other hand, with the sinusoidal blood capillaries that surround the epithelial cells. It has been shown that these capillaries extend to the periphery of the hepatic cell and are in such close relation with the sinusoid that the *internal secretions* of the liver (from its glycogenic and urea-forming functions) are readily poured into the blood-vessels.

![Fig. 191.—Intracellular Canaliculi of the Liver Cells Communicating with the Sinusoid. (After Schäfer.)](image)

One of the important functions of the liver is that of forming *glycogen* and storing it until it is required. This substance is in the form of granules of different sizes and the quantity present varies at different times. After meals rich in carbohydrates the glycogen is great in quantity; after meals poor in these substances there is less. After periods of abstinence from carbohydrates glycogen is almost absent from the liver cells. It can readily be demonstrated by means of special stains. It is readily soluble in water and dilute alcohols so that strong alcohol is one of the best fixing agents for its demonstration.

A few *fat globules* are normal in hepatic cells; these are usually small in size and are distributed mainly in those cells at the periphery of the lobule. After a meal rich in fatty foods the number of fat
globules is greatly increased. If large quantities of fat-forming foods are constantly taken then fat is found in abundance in all of the cells. The fat globules usually coalesce to form one or more large droplets and the condition is that of fatty infiltration. In fatty degeneration of the liver cells the fat globules are numerous but small in the degenerating cells and they do not coalesce. Fat may be readily demonstrated by means of osmic acid solutions or any other special stain for fat.

Pigment granules are often found in hepatic cells especially those near the central vein. This is an iron pigment and is present in the form of small granules that are not numerous in normal conditions. Mitochondria are also found in hepatic cells.

The bile capillaries that lie between the cells of the tubules or chains, are merely notches in the opposed cells and start blindly near the central vein. These capillaries are small and some consider them true secretory capillaries. They correspond, however, to the lumen of the alveolar or ordinary tubular glands but differ in the fact that they form an anastomosing set of capillaries throughout the entire lobule and do not empty into intralobular ducts as there are no such ducts present in the liver. In some instances three cells form the chains and all participate in the formation of the capillary; in the frog five cells are said to form the tubules and then each one would participate in the formation of this channel. At the periphery of the lobule these capillaries empty into the delicate interlobular ducts. The first of these ducts consists of a lining of low columnar epithelial cells that rest upon a delicate basement membrane that is supported by a small amount of areolar tissue, the tunica propria. These soon join larger ducts that lie in the interlobular tissue and receive the bile from a considerable area; these larger ducts have three coats and are lined with tall columnar cells that rest upon a delicate basement membrane and tunica propria; outside of this is a muscle coat consisting of circularly arranged smooth muscle tissue supported by the fibrous coat. These ducts are the ones noted in the portal canals. The largest ducts have the same general structure and goblet cells may be found in the epithelial layer; the muscle coat is usually thicker and more prominent. The ducts of the right and left lobes join to form the
right and left lobar ducts, respectively, and the structure of these is similar to that of the hepatic and cystic ducts.

![Liver of Pig diagram](image)

**Fig. 192.—Liver of Pig.**

- a. Interlobular connective tissue containing a portal system consisting of
  - b. Interlobular branch of hepatic artery.
  - c. Interlobular branch of portal vein.
  - d. Interlobular branch of bile duct.
- e. chains of hepatic cells; f. central vein; g. chain of cells highly magnified.

The circulation of the liver is more peculiar and interesting than that of any other organ in the body. Two systems bring blood, yet it leaves through one. In other organs, the vessel that supplies
the functionating tissue is an artery, but here it is a vein, the portal vein. According to Pearce the portal vein furnishes about 60 per cent. of the blood and the hepatic artery about 30 per cent.

The portal vein is made up of the superior and inferior mesenterics, coronary (stomach) and splenic veins. This blood represents the venous return from the gastrointestinal tract. It is richly laden with the altered carbohydrates and digested proteins but contains little fat. It enters at the portal or transverse fissure of the liver, and forms two main branches, right and left, one for each main lobe. These rapidly form interlobular branches that give rise to the intralobular capillaries, found in the lobules, where they converge at the center and empty into the central, or intralobular vein.

The hepatic artery enters the transverse fissure, and forms lobar and interlobular branches. The latter rapidly form capillaries that lie in the interlobular connective tissue and nourish it, and the vessels found here. These are the interlobular capillaries, some of which enter the outer third of the lobule and empty into the portal vein capillaries. The remainder of the hepatic artery capillaries empty into the interlobular branch of the portal vein, or form small venules that ultimately empty into these.

The blood that has entered the central vein, from the portal vein and the hepatic artery, passes into the sublobular veins, which are tributaries by a union of the centrals, and then into the interlobular tributaries of the hepatic veins. The interlobulars are formed by a union of the sublobulars, and these, in turn, unite to form the hepatic veins that empty the blood into the postcava, or inferior vena cava.
The circulation of the liver might be outlined as follows:

**Portal vein.**

**Hepatic artery.**

**Lobar branches.**

**Lobar branches.**

**Interlobular veins.**

**Interlobular arteries.**

**Interlobular capillaries.**

As the portal vein blood comes into intimate relation with the hepatic cells, the latter remove the products required for nutrition, also the excess of glucose, which is converted into liver sugar, or glycogen, and, in addition, take out the constituents of the bile; it is now considered the seat of urea formation. The hepatic artery is very small in comparison to the size of the liver. As the portal vein is so large and as its blood comes in more-direct contact with the cells of the liver than that of the hepatic artery, the portal vein is in reality the nutrient vessel of the liver parenchyma. But the hepatic artery is essential to the life of the liver substance. When tied off for any reason whatever, the individual or animal (dog) will die in a
few days. The reason seems to be that by this ligation the liver is deprived of most of its oxygen and as it is the chief oxidizing organ of the body it requires a great deal of this element; it would seem that the chief function of the artery is to bring sufficient oxygen to the organ.

![Fig. 194. Terminal Branches of the Veins of the Liver.](image)

_H, Tributary of hepatic vein; P, branch of the portal vein; S, sublobular vein; C, central vein; i, interlobular branch of the portal vein. (After Mall.)_

The lymphatics are superficial and deep. The superficial drain into either the celiac and hepatic lymph nodes on the one hand, or through the diaphragm into the ventral mediastinal nodes. The deep pass out either through the portal fissure to hepatic and celiac nodes, or along the hepatic vein to pass through the diaphragm to nodes around the postcava. The blood-vessels are surrounded by lymph spaces that communicate with similar spaces at the periphery.
of the lobule and in the interlobular connective tissue. Within the lobule lymph spaces are not numerous as the endothelial cells of the sinusoids are attached to the epithelial cells of the hepatic tubules. In the interlobular area the lymph spaces and channels are numerous and the lymph is abundant.

The sympathetic nerves form the chief source of enervation of the liver. They lie in the interlobular connective tissue as plexuses, and from these some fibers pass to the bile ducts, and blood-vessels and others penetrate the lobules to pass beneath the cells. Here they are said to end upon the epithelial cells as knobs or fibrils.

The functions of the liver are numerous. First, it makes the bile; second, it stores up the excess sugar as glycogen; third, it makes the urea; fourth, it makes fibrinogen; fifth, it oxidizes those toxines formed by putrefaction in the intestine (potassium indoxyl sulfate, etc.) and these are later eliminated by the kidneys; sixth, it is said to prevent intravascular clotting; seventh, during intrauterine life it is an important seat of both red and white blood cell formation; eighth, in the adult it seems to contribute to the formation of leukocytes as these are far more numerous in the hepatic vein than in the portal vein and hepatic artery.

The excretory apparatus consists of the gall-bladder, hepatic, cystic and common ducts. They all possess three coats, mucous, muscular and fibrous.

The hepatic duct is about 2.5 to 3 cm. in length and 3 to 4 mm. in diameter; the cystic duct is about 3 to 3.75 cm. in length and 3 to 4 mm. in diameter; the ductus choledochus is about 8.5 to 10 cm. in length and to 6 to 7 mm. in diameter. These are alike in structure. The mucous coat consists of a single layer of tall columnar and goblet cells that rest upon a basement membrane and tunica propria. In the latter are seen a number of tubuloalveolar glands that open out upon the epithelial surface. Diverticula of the mucosa are also numerous especially in the hepatic duct and even within the liver substance. The muscles fibers are quite distinct. They are arranged as circular, longitudinal and oblique layers. The circular fibers of the common duct form a sphincter at its entrance into the duodenum. This is supported by a rather thick layer of white fibrous tissue constituting the fibrous coat.
**Fig. 195.**—Cross-section of the Hepatic Duct.

*a, a*, Tubules of glands; *b*, areolar tissue; *m, m*, smooth muscle tissue of muscle coat; *L*, lumen of the duct. (*After v. Ebner.*)

**Fig. 196.**—From a Section of the Gall-bladder of an Adult, *A*. × 100.  
*B*, The portion *x* of *A*. × 560. (*Lewis and Stöhr.*)
The **mucosa of the gall-bladder** consists of tall columnar and goblet cells, *basement membrane* and fibro-elastic *tunica propria*. The epithelial cells resemble those of the small intestine and secrete mucin. The tunica propria contains a few mucous glands, some diffuse lymphoid tissue and even solitary nodules and some muscle fibers derived from the muscle coat. In the empty and partially distended condition the mucosa is seen formed into rugous folds, which at the neck are permanent.

The **muscle coat** is composed of smooth muscle tissue and a considerable quantity of white fibrous tissue, the latter predominating near the mucous coat. Elastic tissue is also present. The muscle fibers interlace somewhat although most of them are circularly arranged. The **fibrous coat** consists of white fibrous tissue that is attached to and connected with the fibrous tissue of the liver. It is partially invested with the peritoneum.

The **lymphatics** are connected to those of the liver by the subserous plexus, into which the vessels from the muscular coat empty.

The **nerves** are **sympathetic** and **cerebrospinal**, the former passing to the blood-vessels and muscles, and the latter ending in the mucosa, near large arteries. Sympathetic ganglia, also, are found in the walls of the gall-bladder and nerve fibers and free sensory organs are found in the epithelial layer.

**SALIVARY GLANDS**

The **salivary glands** are the **parotid**, **pancreas** (the abdominal salivary gland), **sublingual** and **submaxillary glands**. In addition, there are a large number of small unnamed glands in the lips, mouth, tongue, pharynx, base of the epiglottis, palate and esophagus.

According to secretion, they are divided into **mucous**, **serous** and mixed.

The **mucous** glands are distinguished by their large *secretory units* that stain lightly. These are the *acini, alveoli* or *tubules*, and they give rise to a thick viscid secretion. Such glands are the small glands of the mouth, pharynx and esophagus. The **sublingual** is almost a pure mucous gland.

**Serous** glands are those in which the acini stain darkly, owing to the presence of secretory granules in the cytoplasm, which retain
the stain. The acini are usually smaller than those of mucous glands. These glands secrete a thin albuminous fluid. Such are the parotid and pancreas.

The mixed glands are those that stain both lightly and darkly, and secrete a mixed fluid, as the submaxillary and sublingual.

![Image](image.png)

**Fig. 197.—Interstitial Tissue of the Human Sublingual Gland.**

As all of these glands have the same general structure, this will be first considered, and the special points then noted.

Each is surrounded by a capsule of white fibrous tissue that limits it from the surrounding organs or tissues. The capsule sends in prolongations that divide the gland into lobes and lobules. The lobules, or structural units, consist of the functionating units that are composed of a single layer of glandular epithelial cells (parenchyma) supported by a basement membrane. External to the basement membrane, is the interstitial, or intertubular connective tissue, which is composed of reticulum, and in which the blood-vessels, nerves and
lymphatics are found. It corresponds to the tunica propria of a mucous membrane.

The **secretory units** lead into minute intermediate, or intercalated tubules that unite to form intralobular ducts, which pass into the interlobular connective tissue. Here they unite to form the interlobular ducts; these, by union, form the lobars, and then the single excretory duct. The intermediate tubules are lined by simple squamous or low columnar cells, supported by basement membrane and interstitial tissue; the interlobular branches contain simple columnars, the intralobulars and interlobars are lined by pseudostratified columnars, and the excretory duct usually by stratified columnars. In the latter duct the muscle coat is distinct.

The blood-vessels follow the divisions of the ducts, and form plexuses of capillaries around the secretory units, and in close proximity to the epithelium.

The nerves pass down in the same manner, and, after penetrating the basement membrane, end around the cells.

The **parotid gland** is a compound alveolar gland and is divided into lobes and lobules as has been described. It represents the largest oral salivary gland. In each lobule are seen the secreting units, or acini, which are serous in character, the intercalated and intralobular ducts. Each acinus consists of a number of small darkly staining cells of a pyramidal shape arranged in a single layer upon the thin basement membrane. In the center of the group of cells is a lumen, the size of which depends upon the stage of activity of the gland. The acini are comparatively small. The **basement membrane** contains flattened basket cells at the bases of the epithelial cells, and the processes of these basket cells pass between the functioning epithelium. These are supposed to be young secreting cells that replace the older ones as they give out. The **cytoplasm** of the secreting cells is nearly clear and finely granular in the early resting stage; during the latter part the granules increase in number and a small amount of clear cytoplasm and the nucleus occupy the basal portion of the cell. The cell becomes so swollen as to occlude the lumen and as these zymogen granules are discharged during the active stage the cells become smaller and the granules nearly all disappear; the clear cytoplasm increases in amount and spreads through the cell.
Prozymogen, or mitochondrial filaments have been demonstrated in the basal portion of the cells. In the cytoplasm and between the cells there is a set of secretory capillaries, or canaliculi. The acini pass the secretion to the intercalated tubules that are lined with squamous cells and these join the intralobular ducts that are lined with low columnar elements. These in turn empty into the interlobular ducts that lie in the interlobular connective tissue. These are larger in caliber and are lined with columnar cells and possess three coats.

Considerable adipose tissue is found in the interlobular tissue of the parotid gland.

The parotid duct is the excretory duct.

The pancreas is the other serous gland and is compound alveolar in structure. It is also called the abdominal salivary gland. Its general structure is analagous to that of the parotid. The lobules contain the secreting units, or acini that are larger than those of the parotid however. These acini are usually distinct, sharply outlined and stain darkly. Here and there between them are seen the islands of Langerhans that will be described later. The cells lining an acinus are of the pyramidal type and the amount of lumen showing will depend upon the stage of secretory activity. These cells rest upon the basement membrane but interposed are the peculiar stellate basket cells that are immature secreting cells, so it is said. During rest these cells show a clear cytoplasm, only a few granules being present near the lumen end. As the secretion is being formed these zymogen granules increase in amount, the cell becomes swollen and only a narrow rim of cytoplasm, containing the nucleus, is seen at the basal portion of the cell. The lumen is practically occluded. With the discharge of the secretion the clear cytoplasm increases and spreads through the cell, which is much smaller in size. The nucleus plays an important part in secretion. A paranucleus is seen in active cells. This is derived from extruded nuclear material and is said to be changed into secretion granules but this is denied by some. In the basal portions of the cells mitochondrial filaments are readily demonstrated. These are said, by some, to give rise to the zymogen granules, but others believe that they are concerned only with the metabolic activities of the cell. Within many of the acini are seen
lightly staining flattened elements that are called the *centro-acinar cells*. These are characteristic of the pancreas and represent the squamous cells of the intercalated tubules invaginated into the acinus. They are separated from the secreting cells by intercellular secretory capillaries.

![Diagram of Human Pancreas Showing Pancreatic Islands](image)

**Fig. 198.**—**Section of Human Pancreas Showing Pancreatic Islands.**

*a*, interlobular connective tissue; *b*, capillary; *c*, interlobular duct; *d*, intralobular duct; *e*, cells of acini; *f*, area of Langerhans.

In addition to the acini numerous groups of lightly staining cells are scattered in the lobules; these are the *pancreatic islands*, or *areas of Langerhans*. These are oval, or circular in outline and each is surrounded by a delicate capsule that sends in trabeculae that seem to arrange the cells into irregular groups, or cords. The number of cells in an island varies from several to many so that these islands may be microscopic or macroscopic (3 mm.) in size. The cytoplasm of these cells stains lightly and contains some fine eosinophilic granules that are supposed to be of two kinds and therefore form two different kinds of secretion. The blood-vessels are of the sinusoidal
type and are in close relation to the cells, forming glomerule-like masses in injected sections. These possess no outlet for the secretion (enzyme, or hormone) that they form and this is supposed to be passed directly to the blood capillaries.

Recently Banting and others succeeded in making an extract of the islands alone and this is called insulin. Injections of this substance have been used with great success, in patients suffering from diabetes mellitus; in such patients if the injections are taken regularly sugar metabolism is controlled. Whether an ultimate cure can be affected is still doubtful. To do that nature would have to establish enough new islands to replace those destroyed by the fibrotic changes; in addition, the original fibrotic condition would have to be checked.

These islands are most numerous in the splenic end of the pancreas and vary considerably in number. Dole states that they may be increased in size and number by means of secretion and that in long hunger they are also increased; this probably merely represents a normal individual variation. Thompson and others claim that there is a connection or lumen between the islands and acini in reptiles and fishes. This connection does not apparently exist in man as
ligation of the pancreatic duct does not affect the islands nor does it interfere with carbohydrate metabolism. If the islands are diseased (in some cases at least) or if the pancreas of an animal be removed diabetes mellitus follows. The areas then, postmortem, show degenerative changes.

According to Bensley some of these islands may be found in the interlobular tissues connected with the ducts; some in the lobules connected with the ducts; other in the lobules connected with the ducts and acini; others not connected with the ducts or the acini.

Although the acini and the islands seem to have the same origin in the embryo after their adult stage they are unalterable. They may be stained intravitam by means of neutral red and janus green.

The excretory duct, the duct of Wirsung, is lined by simple columnar cells.

The submaxillary gland is a tubuloalveolar gland in structure and a mixed gland in secretion. The mucous tubules may be collected in individual lobules and lobes or they may be mixed with the serous acini. In man it is said that the serous acini are five times as numerous as the mucous tubules. The serous acini resemble in structure those of the preceding glands and the acini are intermediate in size between those of the parotid and pancreas. The mucous tubules are the larger. The cells are of the column variety, are quite
large and stain lightly. In the fresh condition the cytoplasm is clear and refractile. In properly fixed tissue the cytoplasm contains a coarse reticulum that is basophilic in reaction and is located mainly in the lumen portion of the cell. The cytoreticulum contains some coarse granules that respond to special mucin stains. During the resting stage these granules increase in number and the cells become larger and have a swollen appearance. When the secretion is to be discharged water from the lymph between the cells passes into the cells, the granules swell and are dissolved and the secretion is discharged. The cell is then smaller. These granules do not show in ordinary preparations as they are so soluble that they must be fixed in certain reagents only. In the full cell the nucleus and a little finely granular cytoplasm are forced against the base of the cell. When the secretion is discharged the nucleus moves away from the base and the cytoplasm spreads towards the distal extremity of the cell. In these tubules of most of the mucous and mixed glands (exceptions are those of the soft palate and base of the tongue)
other cells are found between the mucous cells and the basement membrane. These are darkly staining cells and are arranged in the form of crescents and constitute the crescents of Gianuzzi, or demilunes of Heidenhain. These groups are chiefly located at the blind extremity of the mucous tubules and although at times they may reach to the lumen they are usually separated therefrom by the mucous cells. The cytoplasm is quite granular and the nucleus quite chromatic and basally placed. Intracellular and intercellular capillaries are numerous; the secretion is discharged from the former into the latter and through these gains access to the lumen of the tubule. In this they resemble true serous cells and in addition Krause has shown that these cells will discharge sodium indigo sulphate granules just as do the serous cells. Stöhr and others believe these cells to be the resting stages of the mucous cells. The intralobular ducts are unusually large and distinct in some animals and often represent a distinguishing characteristic of this gland.

The excretory duct is the submaxillary duct, or duct of Wharton. Each sublingual gland really represents a collection of glands and not an individual organ in the floor of the oral cavity. Each mass weighs only 3 to 4 grams and so represents the smallest of the
salivary glands. It is compound tubular in structure and nearest to the pure mucous glands as it does not contain many serous acini; the serous portion is represented by the *crescents of Gianuiz*. Occasionally sections of serous acini are apparently seen but these are said to represent cross-sections of the tubules, near the blind end, in which the crescents abound.

**Fig. 203.—Section of Submaxillary Gland of a Fox.**

*a*. Connective tissue; *b*. serous acinus; *c*. intralobular ducts; *d*. lumen of a mucous acinus; *e*. mucous cells; *f*. demilune of Heidenhain; *g*. capillary.

There are usually several ducts, called the *sublingual ducts* or *ducts of Rivinus*. If but one is present it is called the *duct of Bartholin*.

The *blood-vessels of the pancreas* pass into the interlobular connective tissue and accompany the ducts, to which they give branches. At the surface of the lobules small arterioles enter and form a capillary plexus around the acini. Special arterioles pass to the islands
and form a glomerular mass of capillaries that resembles those of the kidney. The extent will depend upon the size of the island and these vessels are characteristic of the pancreas. The blood is collected in *venous channels* and this venous blood no doubt contains the hormones elaborated by the islands; these are carried to the liver by the portal vein. By this vessel the hormones are delivered to the liver cells and here assist or cause the liver cells to store the excess sugar and to dole it out in only the required amounts.

**Fig. 204.—A Portion of the Submaxillary Gland of a Rabbit.**

*a*, A cell filled with secretory granules. *b*, later stage of secretory activity with the granules swollen; cells are clear and show a reticulum; *c, c*, secretory canaliculi. (*After E. Müller.*)

The *lymphatics* are numerous in the interlobular connective tissue where perivascular plexuses are formed. These drain the lymph spaces of the lobules.

The *nerves* are of the *sympathetic system* and accompany the vessels in the interlobular tissue where small ganglia may be numerous. Branches supply the muscle of the vessels and ducts and others pass into the lobules and form a meshwork around the acini and pass between the epithelial cells. In the pancreas of the cat Pacinian bodies are very numerous.
The blood-vessels of the parotid, submaxillary and sublingual glands are very numerous and pass into the glands in the same manner. Within the lobules a rich capillary plexus is formed around the acini and the endothelium of the capillaries may be in contact with the basement membrane in many places. The venous blood is returned in a corresponding manner.

The lymphatics are not so numerous as in the pancreas but are somewhat similar.

The nerves for the oral salivary glands are from both the cerebral and sympathetic nerve systems. These nerves pass into the interlobular connective tissue with the blood-vessels. In the lobules these fibers form plexuses around the walls of the acini, penetrate the basement membrane and terminate in fibrils or enlargements upon the epithelial cells. These secretor fibers are supposed to be derived from the cerebral nerves through the sympathetic. The fibers to the blood-vessels are vasoconstrictor and vasodilator fibers; the former are supposed to come from the cerebral nerves through the sympathetics and the latter directly from the sympathetics.
CHAPTER XI

RESPIRATORY SYSTEM

This system comprises the nares, nasal fossae, upper part of the pharynx, the larynx, trachea, bronchi, lungs and pleuræ. Although there is no direct connection, the thyreoid and parathyreoids are included in this Chapter.

The nares are the two openings that lead into the nasal cavities. Here the skin of the nose changes to a mucous membrane and this area constitutes a mucocutaneous junction. Just within each of the nares is the vestibule, or first part of the nasal cavity; the lower part of this is the respiratory part and the upper the olfactory portion; the latter will be considered in another section.

The vestibule is lined by a mucous membrane that consists of epithelial cells, basement membrane and tunica propria. The epithelial cells are of the stratified squamous variety that show a change from the keratinized epithelium of the skin to the more delicate type as found in the internal parts of the body. They resemble somewhat those of the lip at the mucocutaneous junction but are not quite as well developed. Near the outlet there are some very large hairs, the vibrissae that possess no arrector muscles. These cells rest upon a thin basement membrane and this is supported by the tunica propria which is attached to the cartilages beneath. In this areolar tissue are found the roots of the hairs and connected sebaceous glands, some sweat glands, diffuse lymphoid tissue and at times a few small mucous and serous glands.

The mucous membrane of the vestibule continues as the mucosa of the nasal cavity of each side, and at the dorsal limit of the cavities becomes continuous with the mucosa of the nasopharynx.

The nasal mucosa likewise consists of three layers. It is usually thicker over the turbinals and septum. The epithelium is, however, of the stratified ciliated, or pseudociliated variety containing goblet cells in great numbers. The cilia measure from 5 to 7μ in length. Beneath these are the basement membrane (which responds to the
elastica stains) and tunica propria. The basement membrane is cribiform in structure and varies in thickness up to 20 μ. Through its openings processes from the underlying connective tissue cells extend into the epithelial layer. These openings have been called basal canals. The tunica propria varies in thickness in the different parts. Over the conchal bones it is thickest and in the accessory sinuses thinnest. It consists of fibro-elastic tissue containing the vessels and nerves and a considerable quantity of diffuse lymphoid tissue and even solitary nodules. Mucous and serous glands are also numerous. Some smooth muscle tissue is present and this chiefly surrounds the venous channels in circular or longitudinal bands. The blood-vessels are very numerous and in the thicker parts of the mucosa may constitute erectile tissue. This is especially true of the turbinals and septum. Here the venous channels are usually broad and extensive and they may be surrounded by bands of smooth muscle tissue (plexus cavernosi conchorum). These probably assist in warming the inspired air. The tunica propria is attached to the periosteum of the bony boundaries of the nasal cavities. The cilia create a current toward the choanae, or pharyngeal openings of each nasal fossa so that the secretions are carried to the nasopharynx.

The accessory cavities (paranasal sinuses) the frontal, ethmoidal, sphenoidal and maxillary sinuses, are lined with an extension of the mucosa from the nasal cavities proper. The mucosa is very thin, seldom over 0.02 mm. and is firmly attached to the periosteum of the bony boundaries. It is readily thickened by pathologic processes, especially at the openings of the sphenoidal and maxillary sinuses, as here the tunica propria is thicker. Glands are not numerous in these cavities. In the sphenoidal and maxillary sinuses the glands are most numerous at the outlets of these spaces. The cilia in all of these sinuses wave toward the outlet so that these sinuses empty into the nasal fossa.

The nasopharynx has a mucosa that is partially attached to the bony wall and partly attached to the fibrous and muscle coats that extend throughout the pharynx. The mucosa consists of stratified ciliated cells that rest upon a basement membrane beneath which there is a tunica propria consisting of areolar tissue. Goblet cells are numerous in the epithelial layer. Some small glands and diffuse
lymphoid tissue are found in the tunica propria, as well as solitary nodules; the latter are especially numerous in the dorsal wall. When these hypertrophy in the child they constitute adenoïds. This lymphoid tissue constitutes the pharyngeal tonsil. The mucosa is firmly attached to the bony dorsal boundary but laterally and ventrally it is loosely attached to the muscles of the palate and tongue. At the sides of the nasopharynx the epithelial cells are continuous with those lining the auditory tube. The tunica propria of the pharyngeal extremity of this tube contains a considerable amount of lymphoid tissue that is referred to as the tubal tonsil.

LARYNX

The larynx is a hollow, cartilaginous organ connecting the pharynx with the trachea. It consists of epiglottis, vocal cords and larynx proper.

The epiglottis is a projecting flap that protects the glottis during deglutition. It is covered by stratified squamous cells upon both sides, and these are continuous at the edges, and rest upon basement membrane and papillated tunica propria. The latter is composed of fibro-elastic tissue, and contains diffuse lymphoid tissue, and, also, some glands, near its attachment. In the epithelial portion of the ventral surface, taste-buds are found. Beneath the tunica propria is the submucosa, which consists of loose white fibrous connective tissue. In it is found a palate of elastic cartilage that gives the stiffness, and also the elasticity, to this organ.

The vocal cords comprise the true and the false. The former are the functionating structures, while the latter (plicae ventriculares) are merely heavy folds of mucous membrane that seem to resemble the former. Mucous glands are said to be present in the plicæ. The true cords alone are of importance.

The true vocal cords, plicæ vocales, are covered by stratified squamous cells that are supported by basement membrane and tunica propria. The central portion consists of a band of elastic tissue that extends from the angle of the thyreoid cartilage to the vocal process of the arytenoid cartilage. The epithelial layer is usually thin and exposes the yellow color of the elastic tissue. A small nodule of elastic cartilage (Luschka’s) is found in the ventroinferior part of each fold. They contain no glands.
Between the two sets of cords there is a space, or recess, on each side, called the ventricle of the larynx. This is lined with stratified ciliated cells and diffuse lymphoid tissue is found in the tunica propria. The saccule is an offshoot of the ventricle and has 60 to 70 small mucous glands within its tunica propria which form a secretion that is squeezed out upon the vocal cords to lubricate them.

The remainder of the larynx consists of mucous, submucous and fibrous coats.

The mucous coat, including that of the ventricles, is lined by stratified ciliated epithelial cells. The tunica propria contains a great deal of diffuse lymphoid tissue. That portion of the submucosa adjacent to the tunica propria possesses a number of small mucous glands. In its peripheral portion, the cartilage masses are found.

The form of the larynx is given by the cartilages, which are chiefly hyalin. Those of Wrisberg and Santorini, middle of the thyreoid and the apices of the arytenoids are elastic cartilage.

External to the cartilage is the fibrous coat, which is composed of white fibrous tissue, supports the other coats, and connects the larynx to the surrounding organs or tissues.

The arteries are derived from several sources. The larger vessels pass to the submucous coat from which the smaller vessels are sent to the muscle and mucous coats. In the mucosa the capillaries form quite a plexus beneath the epithelium and around the glands. The blood is collected by venous channels that ultimately join the various thyreoid veins.

The lymphatics are numerous. They start in the mucous coat and the upper set passes through the thyreohyoid membrane, its efferents conduct the lymph to the nodes near the bifurcation of the common carotid artery. The efferents of the lower set pass through the cricothyreoid membrane and conduct the lymph usually to the inferior laryngeal node.

The nerves are from the vagal and sympathetic nerves. The cricothyreoid and part of the arytenoid muscles and the mucosa are supplied by the superior laryngeal nerve, while the remaining muscles are supplied by the inferior laryngeal nerves. These terminate in regular motor end-plates. The sympathetic nerves are for the muscles and glands. Sensor fibers pass to the mucosa where
they terminate between the epithelial cells in a network of fine fibrils. *Taste-buds* are found on the ventral surface of the epiglottis.

**TRACHEA**

The *trachea* connects the larynx with the lungs, its lower end bifurcating to form the *bronchi*. It has **three coats**, *mucous*, *submucous* and *fibrous*.

![Cross-section of segment of the trachea](image)

**Fig. 205.**—Cross-section of Segment of the Trachea.

*a*, Mucous coat; *b*, submucous coat; *c*, *d*, fibrous coat containing some voluntary striated muscle; *l*, *m*; *e*, stratified ciliated epithelium; *f*, basement membrane; *g*, goblet cells; *h*, mucous glands; *i*, blood-vessel; *k*, elastic tissue and perichondrium; *l*, longitudinal, and *m*, cross-sections of voluntary muscle fibers.

The **mucous coat** is a continuation of that of the larynx. It is composed chiefly of *stratified ciliated* and *goblet* cells that rest upon the *basement membrane* and *tunica propria*. The *basement membrane*
is usually quite prominent, and the *tunica propria* contains considerable diffuse lymphoid tissue. It consists of fibro-elastic tissue, in which the fibers have chiefly a longitudinal direction. That portion of the mucosa opposite to the attachment to the esophagus is lined, at times, by *stratified squamous* cells, and is usually irregular.

The *submucosa* is made up of white fibrous tissue, and supports the large blood-vessels and a large number of mucous glands, the *tracheal glands*. These lie in that portion near the tunica propria and the largest are in the *dorsal* part of the trachea. Special study shows that the glands are mostly mixed, mucoserous, and that they possess a tubuloalveolar structure. This mixed character is brought out very well with the mucicarmin stain. In the peripheral part are found the *cartilage rings*.

These *so-called* rings are C-shaped masses of *hyalin cartilage*, with the open portion at the attachment of the organ to the esophagus. These masses are thickest in front, and taper as the ends are reached. Although the cartilages are supposed to consist of one piece, they are commonly made up of a number of plates. The ends of the C's are connected by traversely and longitudinally arranged smooth muscle fibers, which are attached to the inner and outer perichondriums, and then bridge the spaces between the ends of the cartilage. This strip of muscle extends the length of the trachea, but no complete muscularis is present. The rings are sixteen to eighteen in number, and are separated from one another by white fibrous tissue.

The *inner transverse fibers* are the more numerous; the *outer fibers* are arranged in a few longitudinal bundles.

The *fibrous* coat lies outside of the cartilage rings, and consists of white fibrous and yellow elastic tissues.

The *blood-vessels* and *lymphatics* have their larger branches in the submucosa, from which smaller vessels extend to the other coats, and form capillaries.
The nerves are chiefly sympathetic.

The bronchi have the same general structure as the trachea. Usually the C-shaped ring of cartilage is replaced by a number of plates.

**LUNGS**

The lungs resemble compound tubuloalveolar glands, the bronchi corresponding to the excretory ducts.

![](image)

**Fig. 207.—Section of Guinea-pig’s Lung.**

*a*, Pleura; *b*, alveolar septum; *c*, alveus, or air sac; *d*, alveolus; *e*, intralobular blood-vessel; *f*, interlobular blood-vessel; *g*, interlobular bronchial tube; *h*, cartilage; *i*, branch of pulmonary artery; *k*, gland.

Each lung is invested by a fibrous sheath, covered almost entirely by serous membrane, the visceral layer of the pleura, which is reflected over the inside of the pleural cavity, as the parietal layer of the pleura. Between these two layers is the so-called pleural cavity, but as the lungs fill it in the living condition, it does not exist as a
cavity. In it is found a small amount of lymph that lubricates the membranes.

The pleurae have the same structure as other serous membranes. Each consists of mesothelial cells and subendothelial connective tissue that pass from the lung over to the body wall. Stomata are not present and the subendothelial tissue is firmly attached to the subserous tissue that corresponds to the capsule of other organs. Over the thoracic wall the pleura is but loosely attached. The elastic fibers are numerous. The pleura extends into the fissures of the lung, covering the opposed surfaces and separating them completely.

The blood-vessels are numerous, forming extensive capillary plexuses. Lymphatic plexuses are also extensive.

The nerves are from the vagal and sympathetic nerves. The latter are vasomotor and the former are sensor. These sensor fibers may terminate in delicate fibrils, in small bulbous expansions or there may be lamellar corpuscles present.

The subserous tissue constitutes practically the capsule of the lung as it is continuous with the interlobular tissue of the organ. It consists of a thin layer of white fibrous and a considerable quantity of yellow elastic tissues. In guinea-pigs a network of smooth muscle tissue is found in this layer, while in the lion and leopard this layer is a strong elastic membrane.

Upon the medial surface of each lung there is an area of considerable extent where the vessels and ducts enter or leave the organ. This is limited by the reflection of the pleura and is the hilus, or root.

The lungs, like other glands, are merely systems of tubules that branch and rebranch, and are lined by different varieties of cells. Each is an alveolotubular gland, and although no liquid secretion or excretion is formed, it plays an important part in the excretion of gases and organic matter from the blood and in the oxygenation of the blood. The structure, however, seems to be more of a compound alveolar nature.

The bronchi divide like the ducts of any gland, and, ultimately, the small divisions called bronchioles are reached. Each bronchiole forms a system separate and closed from its neighbors. The bronchiole (0.5 mm. in diameter) divides into the respiratory bronchioles (0.3 to 0.4 mm. in diameter); these, in turn, give rise to alveolar
ducts (0.2 mm.), which end as large spaces, the alvei, alveolar sacs or air sacs (0.3 by 5 mm.); along the walls of these divisions, are found small depressions the alveoli, or saccules (0.1 mm. to 0.4 mm. in the adult), and these are the final divisions.

A lobule or structural unit, consists of the divisions of a bronchiole, and varies from 0.3 cm. to 3 cm. in diameter. It is surrounded by white fibrous tissue containing larger vessels and ducts, which are called interlobular, are over 0.5 mm. in diameter, and contain cartilage. The alvei, or air sacs, are separated from one another by yellow elastic tissue, in which a dense capillary plexus is found. In some animals the lobules are more distinctly outlined by the abundant interlobular connective tissue. The ultimate lobule is one alveus, or infundibulum, with its six to eight alveoli. These are grouped together to form secondary lobules and several of these form a large division. All are bound together and separated from one another by connective tissue that supports the vessels and nerves. These lobules are roughly pyramidal in shape with the bases toward the surface of the lung and the apices toward the root.
As the bronchus divides and redivides, the tubules contain less and less cartilage. The first important change is the formation of a complete investment of cartilage, composed of a number of plates. As this occurs, the muscle tissue begins to increase, so that soon a distinct layer is seen internal to the cartilage. The lining cells are stratified ciliated, but the whole mucosa becomes irregular and corrugated, due to the formation of longitudinal folds; as the divisions become smaller, the cartilage diminishes. The glands disappear when a diameter of 1 mm. is reached. The cartilage is retained until a diameter of 0.5 mm. is attained.

Such a tubule is a bronchiole and it constitutes the apex of a secondary lobule. It is lined by simple ciliated epithelial and goblet cells, supported by a basement membrane and an elastic tunica propria. External to this, the circular muscle fibers are quite prominent, and as a result, folds of the mucosa are formed. The external

Fig. 209.—Reticulum of the Alveoli of the Lung. (After Mall.)
fibrous tissue contains elastic fibers, as well as vessels and nerves. This blends with the interlobular tissue.

The respiratory bronchioles arise by a division of the above tubules. They are short and are lined partially by simple ciliated and partially by nonciliated cells. The former are of the simple variety, and few in number. The nonciliated cells at first are columnar, but quickly give way to low cuboidal and flattened cells.

![Diagram of respiratory bronchiole](image)

**Fig. 210.—Scheme of the Termination of a Bronchial Tube.**

B, Bronchiole; V, vestibule; At, atrium; S, air-sac; C, C, alveoli; A, lobular arteriole; LV, lobular venule. (After W. S. Miller.)

The last named are called respiratory epithelium. Along the walls of the tubules, little depressions, the alveoli, are seen, and here the respiratory epithelium is marked. Muscle fibers are found beyond the tunica propria, and elastic tissue becomes more abundant.

The alveolar ducts or infundibula contain many alveoli lined by respiratory epithelium, which consists of thin, nonnucleated plates of various sizes, arranged individually or in groups. The smaller cells are derived from the cuboidal cells and are flattened by inspiration, and the larger are formed by a fusion of the smaller ones.
The walls of these ducts consist of tunica propria, muscle tissue and considerable elastic tissue circularly arranged. The smooth muscle is in scattered bundles but at the end of the duct forms a ring.

The alveolar duct leads into the alveus, air sac, or alveolar sac. On the walls of this part are the small depressions, the alveoli or saccules. These are separated from one another by minute partitions, or septa, that consist of elastic tissue covered by simple squamous cells, the respiratory epithelium. The alveoli of a system are said to communicate with one another by means of small channels, or pores, but Miller states that these are not present in the cat. At the base of the alveus, the elastic tissue is formed into a thick ring. In the meshwork of the elastica of an alveolus is found a dense plexus of blood-capillaries. The amount of elastica allows a great increase in size of the air sacs (2 or 3 times).

The alveoli vary in size in the different animals; in adult man, under moderate distension they measure about 0.25 mm. but vary up to 0.1 to 0.4 mm. In the cat and dog they are visible upon the surface of the lung. They are larger at the surface of the lung than deeper in. In the infant they measure usually under 0.12 mm. and increase from that on to old age. They are larger in the male than in the female. Each lung is said to contain from 300 million to 400 million alveoli in the adult condition.

From W. S. Miller's careful studies of the structure of the lungs, the terminal bronchioles terminate as follows: Each respiratory bronchiole divides into one or more alveolar ducts, which widen at their outer ends. Each duct opens into several atria, which, in turn
communicate with the air sacs, or alvei, on the walls of which are the alveoli.

The circulatory system is peculiar. As in the liver, two sets of vessels enter, the pulmonary and bronchial, but, unlike those of the liver, they do not unite to form a single system, but remain individual. There is some anastomosis between the two systems of vessels.

The pulmonary artery conveys the blood to be oxygenated and is the nutrient vessel of the functionating epithelial cells. It branches at the root, and the divisions follow those of the bronchus very closely, one for each division. Between the lobules, its branches are the interlobular divisions, and these penetrate the lobules and one branch accompanies each division of the terminal bronchiole. These form the densest-capillary plexus of the body, within the elastica of the alveoli. Here the endothelial cells of the capillary, and the squamous epithelial cell of the alveolus, separate the blood from the air. Such an exceedingly thin membrane allows the interchange of oxygen and effete gases, and also the absorption of nutrient matter by the epithelial cells, and the outward passage of the waste matter.

Fig. 212.—Section of an Injected Lung of a Dog. (Photograph Obj. 16 mm., oc. 7.5 X.)
At the periphery of each lobe the blood is collected by the \textit{venous} radicals of the \textit{pulmonary vein}, and these unite to form the \textit{interlobular branches}, that ultimately form the \textit{pulmonary veins}. These \textit{interlobular veins} run an independent course and are not so close to the smaller bronchial tubes as the arterial branches are.

The \textit{bronchial artery} branches somewhat as the pulmonary artery, but its divisions \textit{do not penetrate to the same degree}. The branches of the bronchial artery lie in the walls of the bronchial tubes and nourish them, \textit{but not the respiratory epithelium}. The larger branches lie in the fibrous coats while the smaller lie in the submucous and mucous coats. Between these two sets of vessels, the pulmonary and bronchial arteries, there is some anastomosis, so that the pulmonary veins carry some of the bronchial artery blood from the lungs. The bulk of the bronchial blood, however, is collected by the radicals of the bronchial veins that finally empty into the \textit{venae azygos, right and left} (or \textit{left superior intercostal}).

From this it is readily seen that the bronchial arteries supply only the larger bronchial tubes. All of the smaller ones (those within the lobules), the alveolar ducts, alveoli, intralobular tissue and the pleura are supplied or nourished by the pulmonary artery.

The \textit{lymphatics} accompany the veins and comprise a \textit{superficial} and a \textit{deep set}. The \textit{former} lies under the pleura and its afferents draw the surrounding regions. These \textit{deeper lymphatics} start in the lobules in the intercellular spaces; the vessels lie in the interlobular tissue and accompany the veins. The bronchial tubes of large size may have a plexus of lymph vessels in the mucous coat and another in the submucous coat peripheral to the cartilage. These communicate with those around the pulmonary artery and vein branches. In the interlobular connective tissue there may be considerable diffuse lymphoid tissue and solitary nodules; lymph nodes may be found at the bifurcation of the bronchial tubes. These usually contain numerous dark granules that represent inhaled dust particles. These are conveyed to the lymphoid structures by the leukocytes that have a phagocytic action. The efferents from the deep set, according to W. S. Miller, pass to the superficial set and from the latter vessels pass directly to independent nodes at the hilus.
The nerves are derived from the pulmonary plexuses that contain both sympathetic and vagal fibers. The motor fibers are for the muscle tissue of the bronchial tubes and the blood-vessels and the sensor fibers are for the mucosa of the bronchial tubes and the epithelium of the alveoli.

The following are the epithelial cells that line the various portions of the respiratory tract:

<table>
<thead>
<tr>
<th>Nares</th>
<th>First part</th>
<th>Stratified squamous.</th>
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<tbody>
<tr>
<td></td>
<td>Second part</td>
<td>Stratified ciliated.</td>
</tr>
<tr>
<td>Pharynx</td>
<td></td>
<td>Stratified ciliated.</td>
</tr>
<tr>
<td></td>
<td>Epiglottis</td>
<td>Stratified squamous.</td>
</tr>
<tr>
<td>Larynx</td>
<td>Vocal Cords</td>
<td>Stratified squamous.</td>
</tr>
<tr>
<td></td>
<td>Remainder of Larynx</td>
<td>Stratified ciliated.</td>
</tr>
<tr>
<td>Trachea</td>
<td></td>
<td>Stratified ciliated.</td>
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<tr>
<td>Bronchi</td>
<td></td>
<td>Stratified ciliated.</td>
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<tr>
<td>Bronchial Tubes</td>
<td></td>
<td>Stratified ciliated.</td>
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<tr>
<td>Bronchioles</td>
<td></td>
<td>Simple ciliated.</td>
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<tr>
<td>Alveolar Ducts</td>
<td></td>
<td>Simple squamous (respiratory).</td>
</tr>
<tr>
<td>Alveoli</td>
<td></td>
<td>Simple squamous (respiratory).</td>
</tr>
</tbody>
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**THYREOID BODY**

The thyreoid body is a ductless, compound tubular gland, and consists of two large lateral lobes united by a narrow band, the middle lobe, or isthmus.

The organ is surrounded by a capsule of dense white fibrous tissue that sends in septa, which divide the gland into lobes and lobules. These divisions are irregular, and the lobules are composed of a number of short tubules, or vesicles, sometimes called follicles, that vary considerably in diameter up to 100 to 200 μ. Each tubule is oval or round in shape and is lined by cuboidal epithelial cells that rest upon a delicate, reticular basement membrane; outside of this is the intralobular, or intertubular, connective tissue that supports the blood-vessels. The cells are said to be of two kinds: (1) Chief cells; (2) colloid cells. This differentiation is brought out with the Erlich-Biondi stain. The first, lightly staining, are said to become
the second and these stain more darkly and contain droplets of colloid substance. It is said that these colloid cells become the colloid substance. The cytoplasm contains granules that are acidophilic in reaction. Fat droplets and granules that give the colloid reaction are also found. Intercellular capillaries are said to exist between the cells. In the tubules is seen a peculiar, homogeneous substance, the *colloid substance*, that is supposedly the result of the activity of the cells. If a fresh organ be cut a glairy substance oozes out.

![Fig. 213.—Section of Human Thyroid Gland.](image)

*a*, Epithelium; *b*, basement membrane; *c*, colloid substance; *d*, interlobular connective tissue; *e*, interlobular vein.

It has a yellowish color, and as blood-cells are frequently seen in it, the color may be due to the hemoglobin from these. It contains iodin in the form of *tiodothyrin*. Sometimes, the *colloidal material* is shrunken, and then its edges are crenated; in such tubules, the epithelial cells are drawn away from the basement membrane. Gulland and Goodall found granules of iron in the interlobular tissue cells and in the epithelial cells of the tubules. These granules were most abundant in those tubules in which the colloid substance was small in amount. The colloid material and cells vary in
appearance in different individuals; this difference may depend upon diet and nutritional conditions.

It is not unusually found that the colloid substance in the same tubule is of different reaction, most of it responding to plasmatic stains, while a smaller amount, centrally located and surrounded by the preceding, responds to the nuclear stain.

_Blood-vessels_ are numerous, and dense plexuses are formed around the tubules. It is thought that the colloid material may represent an internal secretion that is absorbed by the blood-vessels, or perhaps the lymphatics.

_The lymphatics_ are numerous, and lie between the tubules. _They often contain some of the colloid substance._

_The nerves_ are derived from the sympathetic system. They form fine plexuses in the walls of the tubules; from this terminal fibrils end upon and between the epithelial cells. Other branches pass to the muscle tissue of the vessels.

The thyrеoid gland seems to control oxidation to a great extent. Its removal is usually fatal. In addition it seems to play an antitoxic role. In man and mammals the thyrеoid shows enlargement at menstrual periods.

_Accessory thyrеoids_ have been found near the lateral lobes and along the line of the thyroglossal duct.

**PARATHYREOIDS**

The _parathyreoids_ are usually _four_ in number, two of which lie in close relation with each lateral lobe of the _thyrеoid_. They are small, and the epithelial cells are usually of the _glandular type_, and are arranged in _groups_, or _chains_, _forming a network_, or even _tubules_. They exhibit no constant and regular structures in man and that of the dog and cat seems to be more basophilic than that of man.

Each gland is surrounded by a capsule of white fibrous tissue that is thin but tough. Within this there is a delicate reticulum that supports the epithelium, vessels and nerves. These cells respond very readily to the protoplasmic stains and are usually quite deeply stained, in marked contrast to the cells of the thyrеoid body. Rulison states that there are two kinds of cells: The _principal cells_ are
the smaller and most numerous. These are oval in shape, the cytoplasm is clear and the nucleus rather large vesicular in appearance. The acidophilic cells are larger cells in which the cytoplasm contains a number of acidophilic granules. The nucleus is smaller and contains much chromatin. Between the cells is white fibrous connective tissue that supports quite a capillary plexus. Occasionally, colloid material is seen in the tubules. When the thyreoids are removed and the parathyreoids remain, they are said by some to hypertrophy and carry on the function of the removed organs. According to some investigators, the parathyreoids do not assume the function of the thyreoids. Removal of the parathyreoids is fatal within a short time.

FIG. 214.—SECTION OF HUMAN PARATHYREOID GLAND.
Some of the spaces show colloid substance. (Photograph Obj. 32 mm., oc. 5 X.)
CHAPTER XII

THE URINARY SYSTEM

The urinary organs comprise the kidneys, ureters, bladder and urethra. On account of its proximity to the kidney, the adrenal will also be considered.

The kidney is a compound tubular gland, and, next to the liver, the largest in the body. The kidneys represent the urea excreting organs while the ureters, bladder and urethra are the conducting tubes, reservoir and outlet tube by means of which the urine is carried, stored and emptied. The kidneys lie in the dorsal portion of the abdominal cavity dorsal to the peritoneum. Each is surrounded by a considerable quantity of adipose tissue called the perirenal fat. The quantity depends upon the nutritive condition of the body and in some animals constitutes an enormous mass in which the kidney appears as a very small part. Some of this fat persists even though the animal dies of starvation. Along the medial margin of the organ is a deep notch, the hilus, at which the renal artery and nerves enter and the renal vein, ureter and lymphatics leave.

The kidney is surrounded by a thin capsule of white fibrous tissue that normally strips readily from the organ. This is of great importance, when the organ is studied pathologically. It consists of white fibrous tissue containing some smooth muscle and elastic fibers. It continues into the organ in the form of small trabeculae which form the gross framework of the organ; within this there is a delicate network of reticulum that supports the parenchyma, vessels and nerves. At the hilus the capsular tissue blends with that of the pelvis of the ureter and forms a mass of areolar tissue that surrounds the pelvis and blood-vessels and fills the renal sinus. Adipose tissue is deposited in this tissue. Although the trabeculae tend to divide the kidney into lobes and lobules only parts of the lobes are distinct in the adult condition. These are represented by the apices
of the medullary pyramids, the bases of which are somewhat separated from one another by the columns of Bertin. The cortical portion shows no lobulation, but in the fetal condition the surface of

the kidney is nodulated and these nodules indicate the lobules; by birth these lobules are all fused and give the surface a smooth, even contour in most animals. In reptiles, birds and some mammals
these lobulations are retained throughout life. In the guinea-pig, cat and rabbit no lobulation whatever is noticeable. A renculus is represented by a single medullary ray surrounded by the adjacent convoluted tubules of the labyrinth. The interlobular vessels constitute its boundary.

Beneath the capsule is the kidney substance that comprises the interstitial tissue, or supportive substance already mentioned, and the parenchyma, the functioning part that consists of epithelium arranged in the form of tubules. These uriniferous tubules are comparatively long and have a very irregular course. These consist of a single layer of epithelial cells, basement membrane and tunica propria. The homogeneous substance of the basement membrane is very resistant to acids. When pieces of the kidney are subjected to hydrochloric acid the interstitial tissue is dissolved but the basement membrane remains intact and holds the tubule together in its entirety. In this way beautiful mounts of these tubules may be obtained. In special preparations Mall has shown that the basement membrane contains delicate fibrils that are continuous with the reticulum of the interstitial tissue. These fibers are circularly and longitudinally arranged. These are imbedded in the homogeneous substance which alone shows in the ordinary preparations. The tunica propria of the convoluted tubules is not prominent.

When the organ is sectioned, upon microscopic examination it is seen to consist of an outer margin, the cortex, and an inner broader portion, the medulla. Just within the hilus is seen a space, the sinus. In the ordinary condition this is not a space as it contains the pelvis of the ureter, the branches of the renal artery, the tributaries of the renal vein, nerves and lymphatic trunks imbedded in adipose tissue. If these structures be removed then the space is demonstrable.

The cortex constitutes the outer third of the organ, and is further subdivided into medullary rays and labyrinth. This division is represented by the alternating dark and light bands, which are at right angles to the capsule, and gives a striated appearance to the cortex.

The medullary rays, or pyramids of Ferrein, consist, microscopically, of the straight portions of the tubules that extend from the medulla into the cortex, surrounded by the intertubular, or inter-
stitial reticulum. They never extend to the capsule, but diminish in width as the outer portion of the cortex is approached.

The labyrinth lies between the medullary rays, and is composed of the Malpighian, or renal, corpuscles, the starting points of the tubules, and the convoluted portions of the uriniferous tubules. These are supported by the interstitial connective tissue that contains the blood-vessels.

![Fig. 216.—Section of the Cortex of the Human Kidney.](image)

The renal corpuscles are found only in the cortex, and here are limited to the labyrinth. There are probably over a million of these renal corpuscles in each human kidney. In the cat there are said to be 16,000 in each kidney. Each one consists of a tuft of arterial capillaries, the glomerulus, or renal tuft, surrounded immediately by a delicate double membrane of simple squamous cells, resting upon a basement membrane. The inner layer lies upon the tuft, and the outer forms the wall of the tubule. This membrane is Bowman's capsule, and, with the tuft, comprises the renal corpuscle. The tuft
itself is not a simple structure. The arteriole, upon entering, divides into a number of branches, each of which forms a set of capillaries. This apparent lobulation is quite distinct. As these capillaries unite to form an efferent arteriole, this arrangement is called a retia mirabilia. The afferent arteriole is larger than the efferent.

The medulla is sharply outlined from the cortex, microscopically, by the absence of renal corpuscles and the regularity of the tubules. At the junction are to be found the great vessels, and this portion is called the boundary zone. The medulla consists of the medullary, or Malpighian pyramids, separated from one another by the columns of Bertin.

The medullary pyramids are ten to sixteen in number. Their bases continue with the cortex, and their apices are directed toward the hilus and project into the sinus. Each consists of a large number of straight tubules that become fewer in number as the apex is reached, where but fifteen to twenty are present. These are the papillary ducts, or ducts of Bellini. The tubules are supported by reticulum, in which the capillaries are found.

The pyramids are separated from one another by a narrow band of tissue that is, near the apices, chiefly white fibrous; toward the bases, the cortical parenchyma begins to enter into its formation. This is the column of Bertin, and within it are the large vessels that pass from the sinus to the boundary zone.

The pyramids represent the embryonal condition when the whole organ consisted of lobes. At birth, usually, the bases of the lobes have fused to form the cortex, but the inner ends never reach that condition. The columns of Bertin then represent the interlobar connective tissue and spaces. In some animals the lobulation never disappears.

The uriniferous tubule has a very peculiar and convoluted course. It starts in the cortex, and passes into the medulla, to return to the cortex for its final passage through the medulla. It originates at the renal corpuscle, which is merely the invaginated end of the tubule, containing a tuft of capillaries. From this, the presence of a double capsule can be readily understood.

The inner, or glomerular, layer of this capsule covers the tuft of capillaries following all of its irregularities; the only gap is where the
arterioles make connection with the glomerular tuft. The outer layer is continuous with the inner at the point of this reflection over the arterioles. The external (lumen) surface of the glomerular layer and the internal (lumen) surface of the outer layer are lined with a single layer of squamous epithelial cells that are almost in contact with each other, the narrow space represents the lumen of the first part of the uriniferous tubule. The outlet of this space is opposite to the point of connection of the blood-vessels and represents the neck of the uriniferous tubule. The epithelial cells contain an oval nucleus and the cytoplasm is clear. The layer of cytoplasm, however, is so thin that the nucleus bulges. These cells rest upon a thin delicate basement membrane that is homogeneous and is supported by a thin layer of white fibrous tissue that represents the tunica propria of the ordinary mucous membrane. This layer is said to be thicker in those corpuscles near the medullary region of the cortex. The epithelial cells of the internal layer of the capsule are in direct contact with the endothelium of the capillaries simulating a sinusoidal

![Section of a Renal Corpuscle of the Preceding Section under Higher Magnification.](image-url)
condition. This facilitates the rapid discharge of water into the capsule during the formation of the urine.

The neck is one of the narrowest and most constricted portions of the tubule. It is short and rapidly goes over into the first convoluted portion. It is lined by simple squamous, or low cuboidal epithelial cells. These rest upon the basement membrane and tunica propria.

The proximal convoluted tubule is the next division and is called the distal convoluted tubule in embryology. This part is very irregular and tortuous in its course. It lies in the labyrinth and is the longest and widest portion of the actively functionating portions of the tubule. The two convoluted tubules form the greatest part of the cortex. The cells are of the columnar type but they are irregular in height so that not only is the tubule tortuous but the lumen itself is irregular and tortuous. While the basal and lumen boundaries of the cells are distinct the lateral boundaries are not readily seen. They may be outlined with silver nitrate solutions. Under this condition the outlines are seen to be very irregular, resembling the sutures of the skull as the cells articulate with one another. The cytoplasm varies in appearance. In the lumen end of the cell it is usually clear or faintly striated and presents a cuticular border. This does not always show as this portion of the cell is easily injured. The basal portion of the cell contains the lightly staining nucleus

![Figure 218](image-url)

**Fig. 218.—Portion of a Longitudinal Section of a Convoluted Tubule.** Prepared by the Golgi method. The irregular lines represent the outline of the cells. (After Landauer.)
in which the chromatin is rather evenly scattered. The cytoplasm shows striations or cytoreticulum. The granules are arranged in the form of filaments (probably mitochondria) connected with the formation of urinary excretions. Under the influence of diuretics the granules in the cells of the convoluted tubules become fewer, larger and scattered. Diet also affects them and they are more numerous after a pure meat diet. These granules are probably derived from the disintegrating filaments that probably represent mitochondria. The state of secretory activity of the cells is indicated by a dome-like swelling of the lumen area of the cells; here a centrosome may be observed and in some animals the convoluted tubule cells may be ciliated. These probably indicate the ciliated

![Interstitial Tissue of the Cat's Kidney](image)

**Fig. 219.—Interstitial Tissue of the Cat's Kidney.**

*M, M, Spaces occupied by renal corpuscles; mr, spaces occupied by the tubules of the medullary rays; the other parts represent the labyrinth. (After Disse.)**
cells of the nephridia of invertebrates. In hibernating animals these cells are tall and nearly occlude the lumen, representing the resting or inactive stage.

The descending limb of Henle's loop is the continuation of the preceding part. It is one of the narrowest parts of the uriniferous tubule and extends from the cortex into the medulla. It is lined by simple squamous epithelial cells in which the cytoplasmic layer is thin and the nuclei bulge. The cytoplasm is finely granular and the nucleus stains quite deeply and bulges. As the nuclei alternate, their projection into the lumen makes the cavity of this part of the tubule irregular. The cells rest upon the basement membrane and beyond this is the tunica propria.

The loop of Henle and the ascending limb are the continuations of the descending limb. The position of the loop depends upon the position of the renal corpuscles; if these are near the capsule of the kidney the loops are near the cortico-medullary boundary zone; if the corpuscles are near the medulla the loops are deeper in the medulla. The loop may be of the same size and structure as the descending limb or may correspond in these conditions with the ascending limb. The ascending limb extends from the medulla into the cortex, is double the diameter of the descending portion and is lined therefore with cuboidal cells that are quite regular in height and have distinct outlines. The cytoplasm is usually finely granular and basal striations may be present. The nucleus stains well.

The distal convoluted tubule is called the proximal convoluted tubule in embryology. This is smaller in diameter and shorter than the first convoluted tubule but like it lies in the labyrinthine portion of the cortex. The lumen is irregular here also because the epithelial cells are of unequal height. Outside of being shorter these cells resemble those of the proximal part in structure and function.

The arched connecting tubules and the remainder of the uriniferous tubules represent merely conducting portions. This tubule is short, lies in the cortex and is the connecting link between the last convoluted and the first collecting tubules. The cells are of the regular cuboidal type with distinct outlines and darkly staining nuclei. The cytoplasm is usually clear and stains lightly. The lumen is regular.
The straight collecting tubules have a straight course and begin in the cortex, pass into the medulla, where many join together increasing in size and terminate in the papillary ducts. In the cortex they form the medullary rays and in the medulla they are parallel to one another. The epithelial cells vary in form in the different portions. In the cortex where the diameter is least the cells are of the cuboidal type; as the diameter increases the cells become gradually columnar of a low and then of the tall type. The cytoplasm is clear, the nucleus stains well and the cell outline is distinct.

The papillary ducts, or ducts of Bellini represent the terminals of the uriniferous tubules. There are fifteen to eighteen of these ducts in each medullary pyramid apex and these represent the junctions of thousands of the straight collecting tubules. They are large in diameter and the epithelial cells lining them are of the very tall columnar type. The cytoplasm is clear and the nucleus stains deeply. In some animals these ducts are lined with stratified columnar cells.

The various portions of the uriniferous tubule are distributed as follows:

Cortex.—In the labyrinth are found the renal corpuscles, neck, first and second convoluted tubules. In the medullary rays, the upper ends of the descending and ascending limbs of Henle’s loop and straight collecting tubules, and the arched connecting tubule.

Medulla.—The lower ends of the descending and ascending limbs and the loop of Henle and the straight collecting tubules and papillary ducts.

The diameter of the different parts of the tubule varies. The renal corpuscle is large, measuring 120 to 200 microns. The neck averages about 15 microns, and the proximal convoluted tubule is quite irregular, but the average is about 50 to 60 microns. The descending limb is quite narrow, 10 to 13 microns, and the ascending limb about 25 microns. In the second convoluted tubule, the diameter again increases, averaging 40 to 45 microns. From the beginning of the straight tubule to the end, the diameter progressively increases 18 to 50 microns; so that the papillary ducts may have a diameter of 200 to 300 microns.

The blood-vessels have a characteristic distribution. The renal artery passes through the hilus and enters the sinus, where it divides
into four or five branches, of which the greater number supply the ventral three-fourths of the kidney. The branches that go to the ventral pyramids carry three-fourths of this blood. The rest of the kidney is supplied by the dorsal branches. The branch that supplies each pole, derived from the ventral division, divides into ventral, middle and dorsal branches, which are in no way united. The trunks pass up through the columns of Bertin, where small branches are given off to the vessels and tissue as the interlobar branches. These branches mass to the boundary zone, where they arch between the cortex and medulla, forming the arterial arches, or arcade. From the cortical side of the arch, the cortical, or interlobular, arteries are sent toward the capsule; from these, small arterioles afferent, pass to the renal corpuscles, enter and form several smaller branches, each of which breaks into a capillary tuft. From this, it will be seen that the renal tuft consists of several bunches of capillaries. Each capillary group is separate, and the vessels unite to form arterioles that leave the tuft as a single vessel, the efferent arteriole. The blood is still arterial. The efferent arterioles soon form dense plexuses of capillaries around the tubules of the labyrinth and medullary rays. Those capillaries near the boundary zone pass into the medulla and surround the tubules there. The capillaries become venous in character, and unite with others to form the interlobular veins. The cortical artery continues to the capsule, where it forms a star-shaped mass of venules, the venae stellatae. These are, in reality, the starting-points of the interlobular veins, which run parallel to the arteries of the same name, and empty into a
Fig. 221.—Diagram of the Course of the Renal Blood-vessels.
(Lewis and Stöhr.)
venous arcade that is formed at the boundary zone by the union of the large vessels. Such is the blood supply of the cortex.

The medulla receives its blood from the concave surface of the arterial arch. The arterioles given off have a straight course, and are the arteriolae rectae. They very soon break up into capillaries that surround the tubules of the medulla. Huber and others state that some of the arteriolae rectae are derived from the efferent glomerular arterioles nearest the medulla. These are the arteriae rectae spuriae and possess no circular muscle fibers. They proceed in the same manner as the true arteriae rectae. These continue as venous radicals that unite to form straight veins, venae rectae, which empty into the venous arch on its concave surface.

The venous arches unite at the columns of Bertin, and pass down these, parallel to the arteries, as the interlobar veins. In the sinus, they unite to form the renal vein.

In addition to the branches from the renal artery the capsule also receives many branches from neighboring arteries and these anastomose with the end branches of the interlobular arteries. The vessels of the kidney, therefore, communicate with those of the perirenal fat, through the vessels of the capsule. This is of importance surgically. Direct anastomoses between arterial and venous vessels occur in this organ.

At the junction of the ventral three-fourths and the dorsal one-fourth of the kidney (extending in a longitudinal direction) is a zone in which there are comparatively few blood vessels. To this region the ventral and dorsal vessels extend and as they do not anastomose freely this region is one of low vascularity and is called the exsanguinated zone of Hyrtl.

About one cm. ventral to the exsanguinated zone, or at the junction of the ventral three-fifths and the dorsal two-fifths of the kidney there is another longitudinal region which is the most vascular zone of the kidney. This represents the area of fusion of the columns of Bertin with the large blood vessels. It does not extend into either pole of the kidney and is called the white line of Broedel.

The lymphatics of the kidney comprise a capsular set, cortical and medullary plexuses. The capsular vessels receive lymph from the capsule and perirenal fat and the efferents convey the lymph partly
to the deep set and partly to the lymph nodes of the lumbar region. The cortical vessels form a plexus in the interstitial tissue, receive some of the lymph from the capsular region and pass the lymph to the medullary plexus. The latter receives the lymph from the cortex and from the plexus of vessels in the interstitial tissue of the medulla and the efferents convey the lymph to the hilus and from there to the neighboring lymph nodes. These lymph channels accompany the vessels and are irregular in caliber.

The nerves are derived from both systems. They follow the vessels and in the sinus form a plexus around the pelvis of the ureter, containing ganglia. The nerves follow the vessels and envelop them in networks to the smallest divisions. Some of these nerves supply the muscles of the vessels and others pass to the tubules where their terminal fibers pass through the basement membrane and end between the cells in small knob-like terminals.

The kidney is the organ that *excretes the urine*. The liver is the organ that makes the urea which is then carried to the kidney to be excreted. The urine contains urea, uric acid, urates and inorganic salts such as chlorides, sulphates, and phosphates of sodium, potassium and calcium all dissolved or suspended in the water. The color, reaction and specific gravity will depend upon the amount of the solids and the proportion of water. As the blood courses through the capillaries of the cortical portion of the kidneys the columnar cells of the convoluted tubules remove the salts by a "selective power" and transfer them to the lumen of the tubule. Through the capsule of Bowman and the walls of the descending limb of Henle's loop in cortex and medulla, the water diffuses or osmoses and passing down the tubules dissolves and carries along the solids. If the water is in sufficient quantity these are all dissolved. If the water is not sufficient the more insoluble salts, like uric acid, will be only partly dissolved and the remainder will be present in the form of a sediment. Sometimes these salts form urinary concretions in the kidney or the bladder. Such concretions are readily seen in the cells of the convoluted tubules of reptiles, birds and some mammals. In addition epithelial cells are present in the urine and even casts of the tubules are found. The cells of the different parts of the tubule are readily recognized.
THE EFFERENT APPARATUS

The efferent apparatus consists of the pelvis, ureter, bladder and urethra.

The pelvis is the upper, expanded portion of the ureter, and lies in the sinus. It is very irregular, and is divided into two or three main portions, the infundibula, or calices majores, which are arranged in little cup-like structures around the apices of medullary pyramids. The latter are the calices minores, and they are not equal in number to the pyramids as one calix surrounds the apices of two or three pyramids. The three coats, mucous, muscular and fibrous, extend throughout the ureter and bladder.

The mucous membrane consists of transitional cells, basement membrane and tunica propria. In the calyces minores the epithelium is of the simple columnar variety and is continuous with the same kind that covers the apices of the Malpighian pyramids and lines the papillary ducts. The epithelial cells of the remainder of the pelvis are of the transitional variety. The superficial cells are somewhat flattened and almost squamous. Just beneath these the cells are somewhat larger and pear-shaped while the deepest (basal cells) are polyhedral. These deeper cells divide by karyokinesis and these daughter cells replace the superficial cells as they desquamate. The superficial cells divide by the direct method.

The tunica propria consists of fibroelastic areolar tissue in which there may be some diffuse lymphoid tissue. On the epithelial side it is papillated and very vascular. The capillaries may extend even into the deeper parts of the epithelial layer. Racemose glands are said to occur in the mucosa but Shäfer denies their presence.

The muscular coat consists of smooth muscle tissue that is not arranged in distinct layers. Bundles of muscle fibers extend into the fibrous coat.

The fibrous coat is a thin supportive layer of white fibrous connective tissue. Its fibers connect with those of the areolar tissue of the sinus and at the lines of reflection of the calyces minores upon the apices of the Malpighian pyramids this fibrous tissue blends with the interstitial tissue of the kidney.

At the caudal extremity of the sinus the pelvis becomes drawn into a small tube that is the ureter.
THE URINARY SYSTEM

URETER

The ureter is the small tube connecting the kidney and the bladder, which organ it enters at an acute angle. Its coats are quite distinct and are mucous, muscular and fibrous.

The mucosa resembles that of the pelvis with which it is continuous. The epithelial cells are of the transitional variety and are arranged in four layers; the two basal layers are rounded or ovoid in form, the third layer somewhat pear-shaped and the superficial cells are large and cuboid in form, in the resting condition of the duct. Intercellular bridges, or processes connect the various cells together. The superficial cells may show two nuclei, a cuticular border is usually present and the cells usually divide by the direct

Fig. 222.

A. Cross-section of Human Ureter—\(a\), Lumen; \(b\), epithelium; \(c\), basement membrane; \(d\), longitudinal fold of mucosa; \(e\), tunica propria; \(f\), inner longitudinal muscle; \(g\), outer circular muscle; \(h\), vessels; \(i\), fibrous coat. B, Cross-section of Segment of Human Bladder—\(a\), Mucous coat; \(b\), muscular coat; \(c\), fibrous coat; \(d\), transitional epithelium; \(e\), basement membrane; \(f\), tunica propria; \(g\), blood-vessels; \(h\), white fibrous tissue; \(i\), inner longitudinal muscle; \(k\), middle circular muscle; \(l\), white fibrous tissue; \(m\), outer longitudinal muscle; \(n\), venule; \(o\), arteriole; \(p\), adipose tissue.
method. When the tube is distended with urine then the cells become flattened temporarily. The tunica propria often sends delicate fibers into the deeper layers of the epithelium and capillaries may even be present here. The basement membrane is thin and is pierced by the fibers mentioned above. The tunica propria consists of areolar tissue that is looser near the muscle coat. In it are found some diffuse lymphoid tissue and even solitary nodules; in lower animals small racemose glands of the mucous type are also present. This mucosa is thrown into longitudinal folds in the empty condition of the tube and the lumen then is small and stellate in shape.

The muscle coat consists of smooth muscle tissue arranged in definite layers. In the bulk of the ureter there are two layers, inner longitudinal and outer circular. The longitudinal layer is best developed in the first part of the tube and in the middle portion the circular fibers are most marked; in the lower part an outer longitudinal layer is added and this is well developed. Although this layer seems to be derived from the musculature of the bladder it belongs distinctly to the ureter and is called the ureter-sheath, by Waldeyer. This layer is distinctly separated from the middle circular layer and from the fibrous coat. The muscle coat has a considerable quantity of areolar tissue between the muscle bundles.

The fibrous coat is a thin, distinct layer of white fibrous tissue that surrounds the tube. Even in that part of the ureter that passes through the bladder wall this coat maintains its identity and at the terminal part of the ureter blends with the fibrous portion of the mucosa.

At the ureteral orifice in the bladder the mucosa becomes continuous with that of the bladder. At this region the mucosa of the ureter, at the upper part of the orifice, projects in the form of a small fold called the valve of the ureter.
The blood-vessels of the ureter are numerous. The arterial vessels pass into the fibrous coat and from these capillaries pass to the superficial parts of the mucosa and glands and to the muscle coat. This blood is collected by the venous channels that have a corresponding course and then empty in the neighboring veins.

The lymph from the interstitial spaces is carried to plexuses of vessels that lie in the mucous, muscular and fibrous coats; these plexuses communicate with one another and the lymph is ultimately carried to the plexus in the fibrous coat; from here it is carried by efferent channels to the neighboring lymph nodes.

The nerves are from the sympathetic system and they form a ganglionated plexus in the fibrous coat. The sensor fibers form a plexus in the tunica propria and from this some fibers terminate in the deeper epithelial layers while others terminate in the areolar tissue in tufts of fine fibrils. The motor fibers pass to the muscle tissue of the tube and to the muscle of the vessels.

**BLADDER**

The bladder is a muscular sac that acts as a reservoir for the urine. It consists of fundus or body, and a small constricted portion, the neck, which continues as the urethra.

The mucous coat resembles that of the ureter in structure. The transitional cells vary according to the state of the bladder. When this organ is empty and contracted the cells are of the transitional variety. When the bladder is distended the surface cells flatten in order to assist in covering the extended surface. The superficial cells reproduce by amitosis and the deeper ones by mitosis. In urinary examination it is impossible to tell the cells of the pelvis, ureter and bladder from one another. The tunica propria consists of areolar tissue and contains some lymphoid tissue of the diffuse variety and even solitary nodules. Mucous glands are said by some to be present while others deny their presence. These so-called glands are probably evaginations of the epithelium that may be solid or hollow. As a basement membrane seems to be absent, delicate fibrils of the tunica propria and even capillaries are sometimes seen in the deeper layers of the epithelium.
The mucosa is of a reddish-pink color (due to the vascularity) soft and loosely attached to the muscle coat except at the trigone; this triangular area has for its apex the urethral orifice and for its basal angles the ureteral orifices. A line connecting the two orifices of the ureters is the base and this area is the trigonum vesiceæ. In the empty and partially distended condition the mucosa is thrown into folds, except at the trigone, that are the rugae of the bladder. These gradually smooth out under distension and when the organ is fully distended the mucosa is even. In all of the hollow organs that undergo considerable distension this is the case.

The muscle coat is composed of smooth muscle tissue but the layer formation is not so distinct as in the ureter. Three layers are described, inner longitudinal, middle circular and outer longitudinal. The inner longitudinal layer is described by some as belonging to the submucosa of the bladder as it is separated from the middle circular layer by a narrow band of areolar tissue, the so-called submucosa. These muscle fibers are really irregular scattered and do not form a distinct longitudinal layer. At the fundus of the bladder there is an additional layer of smaller and finer fibers called the submucous muscle layer. They probably represent a partially developed muscularis mucosae and form the internal sphincter muscle of the bladder.

The middle circular fibers are not arranged in a distinct transverse manner but form a network especially in the upper part of the organ. In the lower part they are more distinctly circularly arranged and at the base of the bladder they disappear. Their place is taken by the submucous layer previously mentioned. The circular layer is thicker than the outer longitudinal layer.

The outer longitudinal fibers form a distinct layer on the ventral and dorsal surfaces of the organ; at the sides these fibers are more oblique in direction and interlace somewhat.

The fibrous coat is quite thin and poorly developed over the greater part of the bladder. Its fibers extend in between the muscle bundles and join the abundant white fibrous tissue of the muscle coat. About one-half of the bladder has a serous covering that represents a reflection of the peritoneum over the organ.
The muscular coat is so irregular in its thickness that in the distended organs parts of the wall are very thin. If these areas become so weak as to permit the mucosa and fibrosa to bulge the bladder becomes sacculated and the projections are each known as an *appendix vesicae*.

The bladder receives its *blood-supply* from the superior and inferior vesical arteries and, in the female the uterine artery sends branches. These vessels form a network in the fibrous coat and from this branches extend to the muscle coat to form an extensive capillary plexus; other branches pass to the mucous coat (submucous of some) and form a plexus here, the branches of which supply the mucous coat. The blood is then collected into *venous channels* that form plexuses that are located in the three coats, with the exception of the trigone area. From these plexuses veins arise that carry the blood to the internal iliac veins, but do not accompany the arteries.

The *lymphatic vessels* are found in the muscle and fibrous coats and the trigone of the mucosa. The lymph of the intercellular spaces is carried to these plexuses, the muscle plexus emptying into the plexus in the fibrous coat. The efferents from the fibrous coat carry the lymph to the neighboring nodes.

The *nerves* are both *cerebrospinal* and *sympathetic*. The *former* are *motor* from the third and fourth sacral spinal nerves chiefly and *sensor* from the twelfth thoracic and first and second lumbers; the sympathetic nerves are from the hypogastric plexus. Both sets of fibers go to the pelvic plexus and from this other fibers pass to the bladder and form the vesical plexus. From this each half of the bladder is supplied independently. In the fibrous coat there are *ganglia* that are more numerous near the base of the bladder; fibers from these ganglia form a fine plexus in the muscle coat and the terminal fibers of this plexus supply the muscle fibers. There is another fine plexus in the mucous coat, fibers from which supply the neighboring muscle fibers and the epithelium of the deeper layers.

**THE FEMALE URETHRA**

The *female urethra* consists of *two coats*, mucous and muscular. This tube is shorter and of a wider caliber than in the male.
The **mucosa** consists of epithelium that is of two varieties; at the beginning of the tube the *transitional cells* of the bladder continue into it and are somewhat flattened. As the external urinary meatus is approached the epithelium changes to the *stratified squamous* variety that is continuous with that of the vestibule. Some describe a stratified columnar variety in the middle part of the tube. These cells rest upon the *tunica propria* that is usually papillated and also thrown into longitudinal folds. In the areolar tissue are found a few racemose mucous glands, the *glands of Littre*. Some tubular glands may be present near the bladder and these will contain structures that resemble the amyloid bodies of the male prostate gland. Near the external orifice are seen the ducts of the *periurethral glands*. The outer part of the tunica propria is loose and contains many large calibered venous channels that constitute *erectile tissue* sometimes called the *corpus spongiosum urethrae*.

The **muscle coat** consists of smooth muscle tissue arranged into incomplete *outer circular* and *inner longitudinal layers* separated from each other by an intermuscular layer of white fibrous tissue. The longitudinal fibers are best marked at the distal end of the urethra and in the dorsal wall; the circular fibers are best marked at the proximal extremity where they tend to form an indistinct *sphincter muscle*. Some voluntary striated fibers are found in this muscle coat.

**THE MALE URETHRA**

The **male urethra** in more complex and differs in function from that of the female in not only carrying the urine but also the genital secretions. It is 18 to 20 cm. in length and is divided into three parts, *prostatic*, *membranous* and *penile portions*. The *prostatic part* lies within the prostate gland and measures about 3 cm. in length and in the resting condition the mucosa is thrown into longitudinal folds. It is the least distensible part of the tube. Along the dorsal wall is a permanent ridge called the *urethral crest* and on each side there is a longitudinal groove called the *prostatic sinus* in which are seen the numerous openings of the ducts of the prostatic glands. In the urethral crest there are *three openings*
side by side; the middle one is the largest and represents the orifice of the prostatic utricle.

This is a blind pouch, the remnants of the fused distal extremities of the fetal ducts of Müller, representing the vagina of the female. This sac is from 6 to 12 mm. deep and is lined with simple columnar, or according to some simple ciliated cells. These rest upon a basement membrane outside of which is the tunica propria that contains considerable true erectile tissue and some smooth muscle fibers that are continuous with that of the urethral crest. In the side walls are the ejaculatory ducts and near the urethral orifice are some small glands that empty into the cavity of the sinus. It is said that when the crest is engorged with blood it prevents the passage of the semen backward into the bladder (Walker). On each side of the orifice of the utricle is seen the opening of each ejaculatory duct.

The membranous part of the urethra is about 18 mm. in length and lies between the layers of the triangular ligament. It connects the prostatic and spongy portions. It is the narrowest part and has the thinnest walls and is therefore most liable to rupture through the improper passage of urethral instruments. It is surrounded by smooth muscle and erectile tissues and upon each side is a gland of Cowper. On section the lumen is stellate.

The penile, or spongy portion is about 15 cm. in length and lies in the corpus spongiosum of the penis and is, therefore, surrounded by erectile tissue. Its caliber varies in its different parts and at its distal extremity, just within the external urinary meatus it is markedly dilated; this constitutes the fossa navicularis. In section the lumen is J-shaped.

The mucosa consists of epithelium, basement membrane and tunica propria. The epithelium of the three parts varies and although the following is a general description, variations are met with. In the prostatic part the cells are of the transitional type continued from the bladder. These cover the urethral crest and continue into the prostatic sinuses and ducts of the prostatic glands for a short distance. In the membranous part the epithelium changes to the stratified columnar type. In the penile part most of the cells are said to be of the simple columnar variety, but the fossa navicularis is lined with stratified squamous cells that are continuous with those
upon the surface of the glans penis. In many specimens examined, however, stratified columnar cells were found in the penile urethra of male (child and adult) and in animals. *Goblets cells* are also present. These cells rest upon a delicate basement membrane that is supported by the areolar tunica propria in which the elastic fibers are very numerous. This layer contains near the outer part, many anastomosing veins that connect with the cavernous spaces in the corpus spongiosum. In the tunica propria there are many small glands of the mucous type, these are the *urethral glands*, or *glands of Littré*. In addition there are many outpouchings of the mucosa forming the lacunæ the largest of which is in the fossa navicularis and is called the *lacuna magna*.

The **muscle tissue** is of the smooth variety. In the prostatic part the *outer circular fibers* are predominant and near the bladder end tend to form a sphincter. These fibers connect with the musculature of the prostate. The *inner longitudinal layer* is thin and continues into the membranous and penile portions. In the membranous part the muscle coat is thin and is reinforced by voluntary striated fibers that represent the *compressor urethrae muscle*. This tapers toward the prostatic and penile portion. In the penile part the muscle is all smooth and is found chiefly in the dorsal and lateral walls. It is mainly longitudinally directed and disappears before the glans is reached.

The **blood-vessels** are numerous. The *arteries* give off branches some of which form capillaries in the usual way; other branches are tortuous and gradually pass over into large dilated endothelial walled channels that are called *sinuses* and constitute the true erectile tissue. These are extensive cavernous spaces that lead into *venules* that conduct the blood from the organ. The ordinary capillaries supply the mucosa and the muscle tissue.

The **lymphatic vessels** of the urethra are chiefly in the mucosa; these receive the lymph from the interstitial spaces and the efferents carry the lymph to the abdominal nodes.

The **nerves** are derived from those of the clitoris or penis. They are both *cerebrospinal* and *sympathetic*. The cerebrospinal are *motor* and *sensor*, the *motor* going to the voluntary muscle and the *sensor* to the epithelium of the mucosa as free endings and to the
tunica propria where the fibers terminate in the genital corpuscles and Pacinian bodies. The sympathetic fibers from the hypogastric plexus pass to the smooth muscle tissue of the vessels and the muscle coat of the urethra.

The various portions of the urinary system are lined by the following cells:

**Kidney.**

**Uriniferous Tubule:**
- Renal Corpuscle................. Simple squamous.
- Neck............................. Simple squamous.
- First Convoluted Tubule........ Cuboidal to columnar.
- Descending Limb................ Simple squamous.
- Loop of Henle.................... Simple squamous or low cuboidal.
- Ascending Limb................. Low cuboidal.
- Second Convoluted Tubule........ Cuboidal to columnar.
- Arched Connecting Tubule........ Cuboidal.
- Straight Collecting Tubule........ Columnar.
- Papillary Ducts................ Tall columnar.

**Pelvis...................** Transitional.

**Ureter.....................** Transitional.

**Bladder..................** Transitional.

**Urethra. Female........**
- Transitional.
- Stratified squamous.

**Male**

- First Part (Prostatic)............ Transitional.
- Second Part (Membranous)......... Stratified columnar.
- Third Part (Spongy)............... Simple columnar.
- Fossa Navicularis................ Stratified squamous.

**ADRENAL**

The adrenal, or suprarenal body is a ductless gland. It lies at the cephalic pole of the kidney, and is yellowish in color. Upon section, it shows a yellow external layer, and a dark centrum. Upon the ventral surface of each gland is an indentation called the hilus which permits the exit of several veins.

The organ is surrounded by a capsule of white fibrous connective tissue that contains a considerable quantity of smooth muscle tissue. From the internal surface of the capsule trabeculae extend into the
organs and anastomosing form the coarse framework of the structure. These trabeculae contain some smooth muscle tissue. Within the network formed by the trabeculae there is a delicate meshwork of reticulum that constitutes the finer framework and this supports the functionating epithelium, blood-vessels, nerves and lymph channels. This reticulum is connected to and derived from the trabecular framework. The arrangement of the trabeculae differs in the various parts of the organ. Just beneath the capsule the trabeculae anastomose at short intervals forming spaces that are approximately from 0.0125 to 0.02 mm. in diameter so that the epithelial cells are arranged here in ball-like masses constituting the zona glomerulosa. In some areas these glomeruli are wanting perhaps because the trabeculae failed to form these spaces. Just within this zone the trabeculae are straight and parallel to one another causing the cells to arrange themselves in columns, two cells wide. This is the zona fasciculata and is the widest zone of the cortex. At the end of this zone the trabeculae again anastomose freely but irregularly so that the meshes here are more variable in extent and more irregular than in the glomerular zone. The cells in this inner zona reticularis are therefore arranged into anastomosing chains and form the narrowest and least distinct zone of the cortex. In the central part of the organ, the medulla, the trabecular arrangement is the most irregular of all. Here they course and anastomose in such a manner that in some places chains, in others glomeruli and groups are formed. In the stroma of the medulla considerable elastic tissue is said to occur.

The peripheral portion of the organ is the cortex and the arrangement of the parenchyma into its three zones is due to the direction taken by the trabeculae. The divisions are the zona glomerulosa, zona fasciculata and zona reticularis.

The zona glomerulosa consists of groups of cells and these cells measure from 0.0125 to 0.02 mm. in diameter. These groups may be spheroidal, or somewhat curved in form and this zone is two or three glomerules wide. In some places, however, the glomerules are absent and the zona fasciculata comes to the capsule. The groups are fairly widely separated from one another the intervening spaces being filled in with the trabeculae, reticulum and the capillaries.
The cells are mainly polyhedral, 12 to 20 microns in diameter, but in some animals they are columnar in shape and a central lumen may be apparent. The outlines of the cells are usually not distinct; the cytoplasm contains a large number of fine acidophilic granules and quite a few droplets of fat that assist in giving the yellowish color to the cortex. The spherical nuclei are rich in chromatin.

The zona fasciculata consists of comparatively long columns of cells that form the widest zone of the cortex. The cells of the innermost glomeruli may be continuous with the column cells. These columns, two cells wide, consist of polyhedral, or columnar cells, whose cell outline is distinct. In some cells the spherical nuclei are vesicular and in others they contain considerable chromatin. This condition seems to be in relation with the structure of the cytoplasm. In some columns the cytoplasm of the cells is finely granular (acidophilic) and the droplets of fat are extremely small. In such cells the nucleus (there may be two) are usually darkly staining. In other columns all of the cells show the cytoplasm to
contain but few granules while the fat droplets are numerous and large. The nuclei are usually pale and vesicular. The cell outline not quite so distinct as in the other cells. The fat in these cells seems to differ from the fat elsewhere in the body in chemical properties.

The zona reticularis consists of anastomosing chains of cells and although of the general form and size of the preceding differ in structure. The nucleus contains considerable chromatin while the cytoplasm contains very little fat. On the other hand the cytoplasm contains a large number of coarse granules of pigment. These granules are yellowish brown and are said to be present only in the adolescent and adult condition and also said to vary in different individuals. These are chromaffin granules.

In the fetus and at birth the large size of the adrenals is due to the excessive development of the inner part of the cortex. The cells contain no fat and this part is very vascular. This fetal cortex begins, shortly after birth, to show fatty degeneration of its cells so that by the end of the first year, usually, it is gone. The peripheral cells, however, are fat containing and form a very thin layer. From this the cortex, as seen later, is developed.

The medulla consists of epithelial cells that resemble those of the zona reticularis closely. They are different in size and the smaller ones are arranged in anastomosing columns while the larger ones are arranged in groups. The smaller cells contain more fat and the nuclei do not stain so deeply. The large cells are polyhedral, their cytoplasm is finely granular (acidophilic) and the nuclei stain more readily. They are said to contain secretory canaliculi. In these cells there are also granules like those found in the cells of the reticularis. These chromaffin granules are supposed to be connected with the formation of the adrenalin and they stain deeply with chromium salts. These granules are also found in the hypophysis. In the reticulum of the medulla in addition to the blood-vessels isolated sympathetic nerve cells and small ganglia are found.

The arteries are from several sources and their branches form a plexus of vessel in the capsule of the organ. Some of the branches of this plexus supply the capsule; others, the cortical arteries, soon form a dense plexus of capillaries of the sinusoidal type around the
cells of the various zones. The endothelium of the capillaries is in direct contact with the epithelium of the organ as in the liver. In the reticularis the sinusoids are larger and their anastomoses more frequent and from this plexus *venules* arise that pass directly to the central veins of the medulla. Other branches from the capsular plexus are the *medullary arteries*. These pass, without branching, through the cortex straight to the medulla where they form a meshwork of sinusoids around the cell-groups. In some places, it is said, the endothelium is absent and the medullary cells are bathed directly in blood. The presence of the sinusoids, especially those of the open type, facilitates the transfer of the internal secretion, *adrenalin*, from the cells directly to the blood. It is also stated that diverticula of the sinusoids penetrate the cell chains and groups. From the medullary plexus of sinusoids the blood is collected by a few *venules* that ultimately unite to form the two, to four *medullary veins*. These leave the organ at the hilus. The veins of the capsule do not join the central veins.

*Lymph vessels* are numerous. One plexus lies in the medulla and another in the capsule. These two are connected by vessels that pass through the cortex. The lymph from the lymph spaces in the medulla enters the plexus and from this the lymph of the cortex and that of the medulla is carried by efferent channels through the hilus.
to near lymph nodes. The lymph of part of the cortex and the capsule is carried by efferents from the capsular plexus to neighboring nodes.

The *nerves* are *sympathetic* and are derived from the solar and renal plexuses, but some possibly come from the phrenic and vagal nerves also. These nerves form a plexus in the capsule and from this fibers are sent to the cortex and others to the medulla. The latter form a plexus in the medulla. The cortical fibers are for the blood-vessel around which they form plexuses. In the medulla numerous *ganglion cells* and *ganglia* are seen. The fibers of this plexus supply the vessels here as well as the epithelium. The fibers to the latter terminate upon and between the cells in little knobs of fine fibrils.

The chromaffin cells form the adrenalin that controls the muscle tone of the heart and vessels, thereby controlling blood pressure. The cortex seems to secrete a substance of antitoxic nature that overcomes the effect of deleterious substances formed by destructive metabolism.
CHAPTER XIII

THE MALE GENITAL SYSTEM

The male generative organs form a very complex system. They comprise the testes, epididymi, vasa deferentia, seminal vesicles, ejaculatory ducts, prostate, glands of Cowper and the penis.

In the human being and in most mammals the testes lie outside of the body in a sac-like structure called the scrotum. This consists of a number of layers. Externally it is covered by the skin that consists of stratified squamous cells resting upon a basement membrane and papillated derma. The skin is darker in color than in common, in the Caucasian, due to the presence of pigment in the Malpighian layer. It contains numerous sweat and sebaceous glands, the latter being connected with the crisp curly hairs that are present. The skin is thrown into rugous folds and in the midline there is a ridge-like elevation that is continuous with a like ridge upon the under surface of the penis and the skin of the perineum. This is the raphé and indicates the line of union of the fetal genital folds. Beneath the skin is the dartos fascia. This consists of fibroelastic tissue containing a considerable quantity of smooth muscle tissue. The elastic tissue is abundant as is also the muscle tissue. This dartos forms the septum that divides the scrotum into two separate compartments. The muscle tissue is peculiar in that it does not respond to electrical stimuli as ordinary smooth muscle does. Cold, or extreme warmth, causes it to contract causing the scrotum to become shorter and thicker; moderate warmth causes the muscle tissue to relax and the scrotum becomes elongated and thinner and that portion between the level of the testes and the attachment to the body is drawn out into a neck-like part. The left testicle is usually a little more dependent than the right. Internal to the dartos fascia are three other layers of fascia composed of white fibrous tissue and containing some voluntary striated muscle, the
Cremaster muscle. These are derived from the abdominal wall during the formation of the scrotum and the descent of the testes. Each compartment is lined by a **serous membrane**, the **parietal layer of the tunica vaginalis testis**, that is derived from the peritoneum. This consists of a single layer of endothelial cells resting upon the fibroelastic subendothelial connective tissue. It is continuous with the serous membrane, **visceral layer**, that invests each testis. Between these two layers is a serous space in which the testis moves.

The **testis** is another **compound tubular** gland. It is surrounded by an unusually thick **capsule** called the **tunica albuginea**, which is composed of bundles of white fibrous tissue that interlace so as to form a very tough and prominent covering. It holds the substance of the testis under pressure for if the capsule be nicked the paranchyma bulge out through the incision. From its inner surface, prolongations, or **trabeculae**, pass into the center of the organ to divide it irregularly into compartments. These trabeculae all converge at the dorsal portion of the organ, where the capsule is very thick,
forming, at this point, a thickened mass called the corpus Highmori or mediastinum testis. Here a number of tubules, to be described later, are found.

The compartments correspond to the lobules of other glands and the septa to the interlobular connective tissue that forms a complete wall around each lobule. In the lobules is the interstitial connective tissue that consists of a delicate network of loose areolar tissue.

The meshes are large because the contained seminiferous tubules are unusually large. The elastic tissue is abundant and many fibers encircle the tubules forming a part of their tunica propria. This interstitial tissue supports the tubule, blood-vessels, nerves and some cells called the interstitial cells of Leydig. These are scattered or arranged in small groups and in some animals they are very numerous forming large masses, or are arranged in anastomosing chains. They
are large, polyhedral elements the coarsely granular cytoplasm of which contains crystalloids and fat globules and a double centrosome. Elongated, prismatic crystals have also been found but their origin and nature are as yet unknown. The crystalloids are said to be mitochondria. The fat reacts readily to osmic acid. The nucleus stains well, is eccentrically placed and contains a nucleolus. These cells are said to be derived from the flattened interstitial connective-tissue cells by a direct modification of these. These cells are fairly numerous in the sexually active male but their number is also subject to individual variation. In those testes that are not actively functional these cells are more numerous and usually contain more fat.

The interstitial cells are most numerous in the fetus, diminish in early childhood and increase again at puberty and are fairly numerous during the sexual life of the individual. These cells manufacture an internal secretion that seems to control sexual impulses and secondary sexual characteristics. In transplantation experiments by Steinach, the transplanted ovaries or testes showed degenerative changes in the ovarian follicles or seminiferous tubules but the interstitial cells were increased in number. Secondary sexual characteristics were developed. In animals that have regular "seasons" these cells are most prominent at the periods of sexual activity. In hybrids that are incapable of reproducing the testes contain great numbers of interstitial cells and the sex cells are poorly developed and show degeneration signs. Such animals, although incapable of reproduction, experience "heat."

The mediastinum testis occupies about one-third of the dorsal border of the organ. It consists of the septa that come from the capsule, after forming the compartments; the bundles of fibers form a coarse meshwork in which is supported the blood-vessels, lymph channels, nerves and the anastomosing ducts that form the excretory ducts. It corresponds to the hilus as it is here that the vessels and ducts enter or leave.

The tunica vaginalis testis is a serous membrane that at one time, was continuous with the peritoneum. It covers almost the entire organ, and is attached to the tunica albuginea, and constitutes the visceral layer of the tunica vaginalis. It is reflected over the inner
surface of the scrotum as the *parietal layer*. Some writers consider this membrane part of the tunica albuginea, and describe it as such, but as it is *genetically different*, it should be considered a separate covering.

The **parenchyma** of the testicle is made up of **tubules**, which, like those of the kidney, are very convoluted, and consist of **secretory**

![Human Testicle Diagram](image)

**Fig. 228.—Human Testicle.**

A, Peripheral portion of the testicle showing the capsule and tubules—*a*, Tunica albuginea; *b*, blood-vessel; *c*, membrana propria of tubule; *d*, interstitial cells; *e*, spermiogenetic cells; *f*, lumen of longitudinal tubule. B, Single seminiferous tubule highly magnified—*a*, Tunica propria; *b*, basement membrane; *c*, spermiogonia; *d*, cells of Sertoli; *e*, mother and daughter cells; *f*, spermids; *g*, spermia. C, Spermia highly magnified. D, Tubule of the epididymis.

and **conductive** portions. These tubules are the **seminiferous tubules**, and are collected into groups which correspond to lobules that number from 100 to 150.

The seminiferous tubules are said to end blindly underneath the capsule at the base of the compartment although Bremer states that they may anastomose or branch.
In rabbits the two tubules of a lobule are continuous like a U, or one limb may be in one lobule and the other in a neighboring lobule; again the anastomoses may be more complex. These anastomoses, according to Curtis, are most numerous in the rabbit, less so in the dog and uncommon in the mouse. There are said to be three to four convoluted tubules in each compartment, or about 600 in the testicle of man. According to Lauth there are 800 to 900 seminiferous tubules in each testis.

When straightened each measures about 50 to 80 cm. in length; the length of them all together is given as 650 to 800 meters. At the apex of a compartment these convoluted tubules reduce markedly in size to form the same number of straight tubules that are conductive in function. These are the \textit{vasa recta}, which pass into the mediastinum, where they anastomose to form a network called the \textit{rete testis}. In the upper portion of the mediastinum, these tubules join to form a few, ten to fifteen, vessels that pass toward the edge of the corpus Highmori as the \textit{vasa efferentia}. As these leave the testicle, they become convoluted and dilated into cone-shaped structures called the \textit{coni vasculosa} (also called \textit{vasa efferentia}) or \textit{globus major}, of the epididymis. The \textit{coni vasculosa} unite to form a single tubule that runs a very convoluted course, forming a narrow continuation of the above, called the \textit{body} of the epididymis. At the lower pole of the testicle, the mass formed by the continuation of the body is somewhat larger, and is named the \textit{globus minor}. The tubule that continues from this point into the abdomen is called the \textit{vas deferens}.

The \textit{seminiferous tubules} are from 140 to 200 microns in diameter, and form the bulk of the testicle. The square surface of each tubule is said to be 1784 sq. mm. Each consists of a small amount of tunica propria, and a \textit{basement membrane}, upon which are found two to three layers of cells. The \textit{basement membrane} is thin and delicate and rests upon the relatively thick tunica propria. This measures about 7 to 10 microns in thickness and consists of lamellae; the inner ones are closely arranged and the outer ones are looser forming a meshwork in which most of the fibers have a circular direction. The elastic tissue of the intertubular region contributes numerous fibers to this network. The cells of the tunica propria are
flattened elements. The basal layer of the epithelial cells in the tubules consists of two varieties, the spermiogonia, which are the more numerous, and the sustentacular cells, or columns of Sertoli. These cells vary according to the secretory activity of the organ.

Before puberty the basal cells are regular while the other cells are polyhedral and practically fill the tubule, occluding the lumen. Some spermiogonia are noted. After puberty the various tubules are not all in the same stages of spermiogenesis. In those tubules in which spermia are fully developed three layers of cells are seen; (a) basal cells; (b) large, clear spermiocytes derived from the basal cells and these spermiocytes increase by their own mitosis; (c) spermids, smaller cells that become spermia. The spermids are derived from the spermiocytes by mitosis.

The basal cells comprise the spermiogonia and the cells of Sertoli. The spermiogia are fairly large cells but usually not so large as the spermiocytes. They form a single layer along the basement membrane with the Sertoli cells at frequent intervals. The cytoplasm is finely granular and stains lightly. The nucleus is large, stains deeply and mitotic figures are numerous. These cells by mitosis give rise to two cells one of which remains as a basal cell and the other one becomes a spermiocyte of the second layer.

The sustentacular cells, or cells of Sertoli are seen at fairly regular intervals along the basement membrane and their appearance varies with the stage of secretory activity of the tubule. In the resting stage each is a rather tall pyramidal cell with the base resting upon the basement membrane. The cytoplasm contains pigment, crystalloids, lipoid granules and fat droplets. The origin and function of the crystalloids is as yet unknown. The nucleus is located in the basal portion of the cells, contains little chromatin but presents several chromatic nuclei. As these cells apparently nourish the spermids during their transformation into spermia they have been called trophocytes. They reproduce by the direct method. In the stage of secretory activity these cells increase in size and extend through the thickness of the epithelial layer of the tubule. At that time from four to eight spermids become attached to one cell and as their transformation continues these spermids become inbedded in the
cytoplasm of the sustentacular cell. This mass of cells is then called a spermiblast.

The spermatozoön, or spermium, consists of three main parts, head, middle-piece, and tail, and measures 52 to 62 microns in length (Krause).

The head is somewhat pear-shaped when viewed from the side and is 4 to 5 microns long and 2 to 3 microns wide and 1 to 2 microns thick. It consists of the condensed chromatin of the spermid constituting 11 or 12 chromosomes. It is surrounded by a delicate layer of protoplasm, the envelop, or galea capitis. In some mammals a little body is seen at the front part of the head just beneath the enveloping protoplasm; this is the acrosome (perforatorium) and it represents the attraction sphere of a centrosome. This end of the spermium represents, apparently, a cutting edge, and in some lower forms it possesses a spiral or barbed projection that assists in the entrance of the spermium into the ovum.

The middle-piece, or connecting piece, is composed of several portions, the end-knob, axial fiber, spiral fiber and envelop. The end-knob connects the head with the middle-piece and is also called the neck. Here is seen the divided centrosome, one part of which becomes a flattened mass at the junction of head and middle-piece; the other elongates into the axial fiber with its front end enlarged to a disc-like mass that ultimately separates from the axial fiber to surround it as a darkly staining ring. Surrounding the axial fiber is a delicate spiral filament that is probably derived from the mitochondria. This filament is not distinct in the spermia of man. The envelop is a thin layer of protoplasm that surrounds the middle-piece and is continued over the head and tail portions of the spermium.

The tail consists of axial fiber and envelop. The axial fiber is the continuation of the axial fiber of the middle-piece, but is not so prominent. It represents an elongated centrosome. It forms the motor portion of the organism and its origin from a centrosome is not difficult to understand when we consider that in ameboid, flagellated and ciliated cells the centrosome presides over the property of motion. It is about 5 microns longer than the envelop. The envelop represents a thin protoplasmic covering of the axial fiber and
is continuous with that of the middle-piece. The tail is about 41 to 52 microns long and about 1 micron in diameter.

Abnormal forms of spermia are found such as double-tailed, split-tailed, four-tailed, double-headed, giant and dwarf. These defective spermia are thought to be due to a general weakening of the body from illness, alcohol, drugs and coffee.

Spermiogenesis is that peculiar change by which spermia are formed from cells several generations removed from the spermiogonia, or original cells. The male somatic cell is said to contain twenty-three chromosomes.

The spermiogonia represent the primordial cells. They reproduce rapidly, one of each of the daughter cells remains at the basement membrane to continue the cells and the other one is crowded with the cells from other spermiogonia to form the other layers of the
tubule. These latter cells are the spermiocytes. A period or rest and growth intervenes and the spermiocytes increase in size until they are quite a bit larger than the spermiogonia. Then maturation occurs. These primary spermiocytes prepare for mitotic division but instead of twenty-three chromosomes (diploid number) forming only twelve are formed. This is said to be due to the fusion by pairs of the original twenty-three and the twelve constitute the haploid number. One of the twelve is a single chromosome, it having no mate in the fusion. In some animals the double form is apparent after the fusion. In the formation of the equatorial plate, or monaster, eleven of these chromosomes split longitudinally and the unmated chromosome remains whole. This is the X Chromosome. When the cytoplasm divides eleven of these daughter chromosomes pass into one daughter cell and the other eleven and the undivided (X) chromosome pass into the other daughter cell. These secondary spermiocytes are about one-half the size of the primary spermiocyte and do not rest and grow to any extent but soon divide. As each daughter cell divides all of the chromosomes split longitudinally (including the X chromosome) so that the nuclear spindle of one-half of these daughter cells contains twenty-two daughter chromosomes and the other half of the daughter cells contain twenty-four daughter chromosomes. When the cytoplasmic division is complete the four granddaughter cells, or spermids, are of two classes; two possess eleven chromosomes and two possess twelve chromosomes. Each spermid becomes a spermium, or spermatozoon and if one containing eleven chromosomes fertilizes an ovum the offspring will be a male. If one containing twelve chromosomes fertilizes an ovum the offspring will be a female. The extra chromosome is the sex determinant.

In the formation of spermia, the spermids are of the most importance. According to some authors, the nucleus forms the whole organism, while others hold the head and middle-piece are of nuclear
THE MALE GENITAL SYSTEM

origin, and the tail protoplasmic. These cells become crowded or drawn to the columns of Sertoli, to which they apparently attach themselves. At the same time, the shape of the cell becomes modified by elongation. The chromatin of the nucleus becomes denser and migrates toward the attached, or peripheral end, while the protoplasm draws toward the central end. At the attached, or peripheral end, the nucleus has a small prominence developed that indicates the future head. The protoplasm becomes clear and draws centrally, forming a slender vesicle, in the middle of which a delicate line appears. This line joins the head, and, growing backward, breaks through the cytoplasmic membrane to form the tail of the spermium.

The centrosomes, usually two in number, become different in shape; the attraction sphere of the smaller passes to the head of the spermium to become the acrosome. The smaller centrosome then becomes disc-shaped and attaches itself to head at its junction with the middle-piece; the larger is cone-shaped, and differentiates into two portions, the larger of which passes toward the nucleus (head), and develops a flattened extremity just behind the preceding centrosome; the remainder elongates into the axial fiber of the middle-piece and tail. The envelop is held to be cytoplasmic in origin.

Fig. 231.—Diagram of the Process of Spermiogenesis in a Longitudinal Section of a Seminiferous Tubule.

*sp*, spermia; *S*, cell of Sertoli; *spg*, spermiogonia; *spg'*, same in mitosis; *spc*, spermiocytes; *spc'*, same in mitosis; *spt*, spermids; *spt''*, spermids changing to spermia. (Sobotta.)
As the spermia continue to develop, the column of Sertoli increases in length, and when development is complete, the organisms lie in the lumen of the tubule. The column of Sertoli, with the attached spermids, is called a spermioblast. Loisel believes that these columns secrete a substance that attracts the spermids (positive chemotaxis).

The semen consists principally of spermia suspended in a fluid derived from the various portions of the genital tract. It is a viscid, whitish, opalescent fluid of an alkaline reaction and characteristic odor. According to Lode each cubic millimeter of semen contains 60,800 spermia; an entire ejaculate of about 3370 cu. mm. contains about 200,000,000 spermia. During life it is stated that about 340 billions are formed or about 850 million for each ovum. The spermia are practically amotile until mixed with the secretion of the prostate, when they become actively motile. Beside the prostatic fluid other secretion is added by the seminal vesicles, glands of Cowper and urethral glands (Littré). In addition to the spermia, crystals and amyloid bodies from the prostate, fat globules and epithelial cells are seen in the semen.

![Diagram of the Cell Divisions in Spermatogenesis](image)
Motility may be exhibited by the spermia twenty-four hours after death. They have been kept alive for two weeks, under proper conditions, and this may readily occur in the female genital tract. Water, acids and metallic salts cause cessation of action, while alkaline and normal salt solutions aid it. Batelli, in 1902, found by experiments that the spermia travel better against than with the current although Lott (1872) and Hensen (1876) stated that they swim with the current. The movement depends upon the strength of the current. The spermia move at the rate of about 60 microns per second.

Motile spermia have been found in the testicle three days after execution. They have been found in the vagina twelve to seventeen days after copulation (Bassi) while Duhrsen and Zweifel have found living spermia in diseased oviducts four and one-half weeks after coition. In one to two hours after coition the spermia are in the oviduct.

The excretory system starts with the tubuli recti. These lie in the apices of the compartments and each is the direct continuation of the convoluted seminiferous tubules but is much smaller in diameter. Each is lined with simple squamous epithelial cells that rest upon a basement membrane that is supported by a delicate tunica propria that is continuous with the interstitial tissue of the lobule. Each is about 25 to 50 microns in diameter and passes out of the lobule to form the next part of the excretory system. They are the same in number as the seminiferous tubules.

The rete testis is made up of the anastomosing tubuli recti and lies in the mediastinum testis. These tubules have a larger and more irregular diameter than the foregoing tubules and are lined with simple squamous, or cuboidal cells that rest upon a basement membrane and tunica propria.

Along the dorsal and upper part of the mediastinum the tubules of the reti testi unite to form ten to fifteen tubules that constitute the vasa efferentia, or ductuli efferentes. They are about 0.5 mm. in diameter. The lining cells are peculiar in that in some areas it is simple ciliated and in others nonciliated. The ciliated cells are low and the cytoplasm contains fine granules that are acidophilic in reaction. The nucleus is basally placed. The nonciliated cells are
columnar or polyhedral cells that are usually collected into groups. The cytoplasm is clear and the nucleus stains well. They seem to represent secreting cells of some sort. Beneath the basement membrane is a tunica propria containing a considerable quantity of circularly arranged smooth muscle tissue.

The epididymis consists of a mass of convoluted tubules that lies outside of the testicle. It is divided into three portions, the globus major, or head, the body, and the globus minor or tail. The globus major consists of ten to fifteen large, cone-shaped tubules that are very convoluted. These tubules are the continuations of the vasa efferentia. The cilia are the largest in the body. The body and tail consist of a single long tubule that is very convoluted; if straightened it would measure 19 to 20 feet in length.

The epididymis is surrounded by a dense sheath, or capsule of white fibrous tissue that divides it into compartments. In the globus major, the tubules in a compartment represent the convolutions of one of the coni vasculosa.

The tubules are lined by stratified ciliated cells that rest upon a basement membrane, outside of which is a distinct tunica propria. The ciliated cells of the coni vasculosi and upper part of the body of the epididymis are said to be true ciliated cells while the remainder are said not to be. In these latter cells the protoplasmic processes of the cilia, within the cytoplasm of the cell, all converge to one point and do not have the basal particles. In the true cilia cells the intracellular portion of each cilium is separate and distinct and where it ends in the cytoplasm it has two little bodies, called basal particles, attached to it. These particles are probably of centrosomic origin. External to this are two layers of smooth muscle tissue, one circularly, and the other (thin) longitudinally arranged.

The arteries pass into the mediastinum and divide into branches some of which pass into the interstitial tissue of the lobules and form plexuses of capillaries around the tubules and others pass in the septa to the inner surface of the capsule which they supply. The arteries are thin-walled. The blood is collected by the venules that have a corresponding course and carry the blood from the compartments to the mediastinum and the spermatic cord. Here the veins branch and anastomose freely forming the pampiniform plexus of veins from
which one vein, the *spermatic*, carries the blood into the abdominal cavity. The epididymis receives branches from the spermatic artery as it passes into the mediastinum. The capillaries ramify the organ and the venous channels return the blood to the pampiniform plexus.

The *lymphatic vessels* form plexuses under the tunica vaginalis, under the tunica albuginea and in the interstitial tissue of the lobules. The efferents from the first two plexuses follow the vessels in the septa to the mediastinum and join the efferent from the lobules. The lymph spaces in the lobules pass the lymph to large sinus-like channels in the interstitial tissue and the efferents carry the lymph to the mediastinum. Here all of the efferents follow the veins to the spermatic cord and along this to the iliac nodes of the abdominal cavity.

The *nerves* are of the *sympathetic* type and follow the blood-vessels which they supply. Other branches are said to enter the lobules and end in relation with the epithelial cells. The branches that supply the epididymis may have ganglia connected with them.

**THE VAS DEFERENS**

The *vas deferens* connects the testicle with the urethra. It passes into the body through the inguinal canal, and is accompanied, to the internal ring, by the spermatic artery and vein, the deferential artery, pampiniform plexus of veins, cremaster muscle and fibrous connective tissue. These form the *spermatic cord*. At the internal ring the vas continues by itself to the under surface of the bladder and near its termination is considerably dilated; this part is called the *ampulla*.

The *vas*, or *ductus deferens*, consists of *three coats*, *mucous*, *muscle* and *fibrous*.

The *mucous coat* consists of epithelial cells, basement membrane and tunica propria. The epithelial cells of the first part are of the *stratified ciliated* variety a continuation of those lining the epididymis. The remaining portion is lined with stratified columnar cells. The *basement membrane* is thin and rests upon the areolar *tunica propria*. The mucosa is thrown into longitudinal folds which are larger and more numerous in the ampulla.
The muscle coat consists of three layers of smooth muscle fibers, inner longitudinal, middle circular and outer longitudinal. This is usually a thick coat and at times the circular muscle fibers are not well disposed but run obliquely and interlace with the bundles of the other layers.

The fibrous coat consists of a thin layer of white fibrous tissue that covers the muscle coat and sends in fibers between the muscle bundles.

The vas is about 45 cm. in length but the first 15 cm. are convoluted or coiled into a small mass at the end of the epididymis. The remainder runs practically a straight course. The diameter is 2 to 3 mm. and the lumen in general is small. The diameter of the ampulla is 6 to 8 mm. and the lumen is proportionately large.

THE SEMINAL VESICLES

The seminal vesicles lie beneath the bladder, and empty into the vas through the seminal ducts. They consist of three coats, mucous, muscular and fibrous.

The epithelial cells are of the simple columnar variety though pseudostratified cells, or two layers of elements may be seen. The cytoplasm of these cells usually contains a considerable quantity of yellowish pigment granules that are characteristic for this organ. These are probably secretory granules and with the desquamated cells constitute a part of the secretion of the organ. These cells rest upon a thin basement membrane that lies upon the fibroelastic tunica propria. The mucosa is thrown into a great many folds or rugæ that run in all directions connecting with one another so that sections of the organ sometimes have a honeycomb appearance. Small areas of the mucosa may give the appearance of enclosed glands.

The muscle coat consists of smooth muscle fibers arranged as inner circular and outer longitudinal layers. The entire coat is said to be thinner than the corresponding coat of the vas but sections of the human seminal vesicle do not bear this statement out.

The fibrous coat is a thin layer of white fibrous tissue and besides supporting the muscle coat it bridges over the gaps between the
coils of the seminal vesicle. These organs act as reservoirs for spermia, at times, besides secreting a fluid that helps to make up the semen.

The **ejaculatory duct** is really the continuation of the vas but apparently is formed by the junction of the vas and the duct from the seminal vesicle. It has a thinner wall than the seminal vesicle and is about 18 mm. in length. It passes through the substance of the prostate gland and opens into the urethra in the urethral crest. It consists of **three coats**.

The **mucous coat** consists of *simple columnar cells* that rest upon a *basement membrane* and *tunica propria*. The latter is thrown into folds so that the mucosa has an irregular appearance. The **muscle coat** consists of smooth muscle tissue, chiefly longitudinally arranged and is thin. In the prostate this muscle blends with that of the prostatic trabeculae. At the urethral extremity the lining cells are of the transitional variety.
The **prostate** is a pyramidal organ that is situated so that the middle of its base is opposite the urethral orifice of the bladder; as a result the urethra traverses the prostate from base to apex. It is pierced on each side by the ejaculatory ducts as they pass through the organ to the urethral crest. Some call it a branched tubular and others a compound tubuloalveolar gland. It really consists of thirty to fifty little branched tubular glands, sometimes referred to as lobules. The organ is surrounded by a thin layer of white fibrous connective tissue beneath which is the **true capsule** that consists of **smooth muscle tissue**. This forms a very thick layer and from its deep surface tapering trabeculae of smooth muscle pass toward the

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**Fig. 234.—Section of the Prostate Gland.**

*a*, interstitial tissue and muscular trabecula; *b*, capsule; *c*, glands; *d*, amyloid bodies; *e*, secretion; *f*, blood-vessel; *g*, duct.
urethra and divide the prostate into compartments in which are the glands. These trabeculae contain also some white fibrous tissue which continues into the tubules and forms a reticulum for the support of the gland tubules and the vessels and nerves. The smooth muscle tissue is not found around the tubules. The central ends of the trabeculae blend with the muscle tissue of the urethra. The trabeculae form about thirty to fifty lobules that represent the number of glands. The smooth muscle tissue of the intertubular stroma may be in the form of isolated fibers or small bundles. Connective-tissue cells are numerous.

The glands are distributed chiefly lateral and dorsal to the urethra in the form of a short deep crescent, on cross-section. The open ventral portion is filled in with smooth muscle tissue. Each gland is a branched tubular or tubuloalveolar structure and consists of the secreting tubules and a short duct.

The secreting tubules are lined with a single layer of columnar elements, although some state that in places several layers may be present. The finely granular cytoplasm contains some yellowish granules. The deeply staining nucleus is basally placed. These cells rest upon a basement membrane and outside of this is the areolar
tunica propria which is composed of white fibrous tissue. The tubules usually have a large diameter and the lumen is large. The mucosa is thrown into folds that may be extensive and high, in places extending all of the way across the lumen and dividing the tubule into two areas. The size of the tubules and the number of folds vary in different animals. In the lumina of many of the tubules peculiar masses, circular in outline are seen. These are the amyloid bodies, or prostatic concretions; they vary in size from a few microns to a millimeter in diameter. These are fewer and smaller in the young and increase in number and size as age advances. The ducts are twelve to fifteen in number on each side. These are comparatively short and each opens individually in the urethra in a groove at each side of the urethral crest called a prostatic sinus. These have been described in the male urethra. The proximal ends of the ducts are lined with simple columnar cells but the distal extremities are lined with transitional cells continued in from the prostatic portion of the urethra.

The secretion of the prostate gland is a viscid, opalescent fluid that is acid in reaction. In man the spermia, before they reach the urethra, are amotile or only feebly so but when mixed with the prostatic fluid they become actively motile. In some animals as the white rat and guinea-pig the prostatic fluid is passed into the vagina of the female after the semen has been passed and then it coagulates and forms a plug that prevents the escape of the semen. Atrophy of the prostate occurs after the removal of the testes and in old individuals the organ is subject to hypertrophy.

The arteries enter the organ through the capsule and branches follow the trabeculae and enter the lobules and form extensive capillary plexuses around the tubules and in the trabeculae for the supply of the abundant muscle tissue. The blood is collected by venous channels that run toward the periphery and form a network in the capsule.

The lymphatics originate in the septa and follow the venous channels.

The nerves are mainly sympathetic. They enter the capsule and here numerous small ganglia may be seen. Some of the nerve supply the muscle tissue and other sympathetic fibers apparently end
between the epithelial cells. The myelinated fibers terminate in corpuscles that resemble those of Krause.

The glands of Cowper, or bulbourethral glands are racemose glands that empty into the penile portion of the urethra. They are surrounded by a capsule of white fibrous tissue that divides the gland into lobes and lobules. The interlobular septa contain both smooth and voluntary striated muscle fibers. The alveoli that make up a lobule are lined by low columnar mucous cells. Some of these cells, however, contain fine granules that are acidophilic in reaction and do not respond to the mucin stains. These rest upon a cellular basement membrane and tunica propria. The smaller ducts are lined by cuboidal cells, while the larger possess stratified columnar cells. The muscle coat of the main duct consists of longitudinally arranged smooth muscle.

The main duct of each gland passes through the superficial layer of the triangular ligament and empties into the bulbous portion of the urethra.

THE PENIS

The penis is an organ surrounded by a loosely attached skin. The latter contains no adipose tissue. The thin skin extends over the end of the organ as the prepuce, which is covered, upon both surfaces, by stratified squamous cells. The inner surface possesses the characteristics of a mucous membrane.

The organ consists of three main portions, the glans and the body and root.

The glans is covered by stratified squamous cells, and is separated from the body by a narrow constricted area, the cervix. At this point, the squamous cells of prepuce and glans are continuous.

The body consists of two corpora cavernosa and the single corpus spongiosum.

The corpora cavernosa lie side by side, forming the dorsal portion of the penis, and are bound together by a thick sheath of white fibrous tissue called the tunica albuginea. From the inner surface of this, trabeculae pass inward and form a series of communicating spaces, or caverns. These are venous blood spaces. The trabeculae contain tortuous arteries, the helicine arteries, which, when engorged,
become straightened as the organ increases in size. The spaces become filled with blood, and, with the vascular trabeculae, constitute true erectile tissue. This engorgement produces the erection. False erectile tissue depends for its action upon smooth muscle tissue.

The corpus spongiosum has a thin tunic, and consists of two portions, urethral and peripheral. The urethral part is quite dense and rich in veins, while the peripheral part resembles, somewhat, the cavernous portion.

The glans is a continuation of the corpus spongiosum, and consists of a delicate network of connective tissue enclosing a number of small spaces. It is covered by a delicate skin, which is continuous with the prepuce, or foreskin. In the cervix are located a number of glands that secrete the smegma. These are the glandulae odoriferae.

The root is that portion by means of which the organ is attached to the pubic arch. It consists of two tapering structures each of which is the beginning of a corpus cavernosum. Each starts from its respective side of the pubic arch and meets its fellow in the midline to form the body of the penis; each gets larger as it forms the body.

**FIG. 236.—CROSS-SECTION OF THE PENIS OF AN ADULT.**

a, a, Corpora cavernosa; b, corpus spongiosum with the urethra; c, tunica albuginea. (Photograph Obj. 72 mm.)
Between these tapering structures lies a rather large vascular mass that is the beginning of the corpus spongiosum; because this mass is bulb-like and because the urethra enters it as this mass becomes the corpus spongiosum proper, this bulb is called the bulbus urethrae. It is very vascular being composed of erectile tissue covered by a heavy sheath of white fibrous tissue. The tapering parts of corpora cavernosa have the same general structure as that portion in the body of the penis, but on a smaller scale.

The blood-vessels and spaces are numerous. The arterial branches follow the septa, in which they run such a convoluted course as to receive the name of helicine arteries. They form capillary plexuses in the trabeculæ, some of which empty into the spaces, while others pass over into the veins. The branches within the tunica form capillaries that empty into the spaces. Anastomoses between arterial and venous capillaries are numerous.

The emissary veins receive blood from the tunica and superficial vessels, and partly from the deeper tissues and vessels; they pass through the tunica to empty into the dorsal vein of the penis that lies in a groove between the corpora cavernosa. These veins are pressed upon when the superficial vessels are filled with blood, in that way preventing egress, but not ingress, of the blood.

The lymphatics of the penis are abundant. Plexuses exist in the subcutaneous tissue of the body and glans, in the prepuce and in the mucosa of the urethra. The efferents conduct the lymph to the superficial inguinal nodes. The deeper lymph vessels of the skin and of the trabeculæ form a plexus and the efferents conduct the lymph along the blood-vessels to the iliac nodes.

The nerves are both cerebrospinal and sympathetic. The cerebrospinal are both motor and sensor; the motor supply the ischiocavernosus muscles and the sensor terminate in various ways. The free endings are among the epithelial cells of the glans and urethral mucosa. In the papillae of the skin are tactile corpuscles (Meissner’s); deeper in the derma are corpuscles of Krause and in the skin of the glands are the genital corpuscles; in the connective tissue of the corpora cavernosa Pacinian bodies are seen. The sympathetic fibers supply the musculature of the vessels and also the smooth muscle in the trabeculæ. Vasodilatator nerves to the vessels are
derived from the third and fourth sacral nerves (through the sympa-thetics) and these are the *nervi erigentes*.

The **paradidymis**, or **organ of Giraldes**, is found in the epididymis. It consists of a number of tubules, in which the lining cells are low columnar or even ciliated. The tubules are closed, and are separated from one another by vascular connective tissue.

The cells that line the various portions of the male genital tract are as follows:

Testicle.

<table>
<thead>
<tr>
<th><strong>Seminiferous Tubule</strong></th>
<th>Spermigonia</th>
<th>Basal layer.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sustentacular</td>
<td>Second layer.</td>
</tr>
<tr>
<td></td>
<td>Spermiocytes, or mother cells.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Daughter cells, or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spermids, third layer.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Tubuli Recti</strong></th>
<th>Cuboidal or squamous.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rete Testis</strong></td>
<td>Cuboidal or squamous.</td>
</tr>
<tr>
<td><strong>Vasa Efferentia</strong></td>
<td>Cuboidal or ciliated.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Epididymis</strong></th>
<th>Stratified ciliated.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vas Deferens</strong></td>
<td>Stratified columnar.</td>
</tr>
<tr>
<td><strong>Seminal Vesicles</strong></td>
<td>Stratified ciliated (some).</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Ejaculatory Duct</strong></th>
<th>Simple or pseudostratified columnar.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simple columnar.</td>
</tr>
</tbody>
</table>
CHAPTER XIV

THE FEMALE GENITAL SYSTEM

This system consists of the ovaries, oviducts, uterus, vagina, glands of Bartholin and genitalia.

The ovary, the distinctive female organ, is attached to the dorsal surface of the broad ligament and lies in the fossa ovarica at the side of the pelvic cavity. It is 3.75 cm. long, 18 mm. wide and 8 mm. thick. It is surrounded by a capsule of white fibrous connective tissue called the tunica albuginea. This is not so prominent as that of the testicle. The free surface of the capsule is covered by low columnar cells called the germinal epithelium.

The organ consists of cortex and medulla.

The cortex is the outer part, and surrounds the medulla, except at one point, at which the vessels enter and leave; this is the hilum, and here the medulla comes to the surface. The cortex is the glandular portion, where the cellular elements of the secretion, the ova,
are formed. It consists of a delicate reticulum, the stroma, in which the Graafian follicles, corpora lutea in various stages, and occasionally groups of large, polygonal epithelial cells, called the interstitial cells are found. The free surface of the stroma is covered by the modified mesothelial cells, the germinal epithelium, from which the ova are derived. These cells are low columnar elements and not peritoneal endothelial cells.

The medulla consists of a loose network formed by large, coarse bundles of white fibrous tissue, in which strands of smooth muscle tissue are found. These latter are limited to the medulla. In the meshes of the stroma are seen the interstitial cells, which are more numerous than in the cortex. The interstitial cells resemble those of the testis. Some believe them to be the remains of some of the cells of the fetal genital organs, others that they are scattered germinal epithelial cells that are considered capable of developing into ova; still others consider them derivatives of the connective-tissue cells and not embryonal remains. In this part of the ovary are found the large blood-vessel trunks which are very numerous.

The Graafian follicles are characteristic structures. They vary in size; the smallest are just beneath the tunica albuginea, the medium-sized near the medulla, and the largest extend from the medulla to the capsule, and cause a projection upon the surface of the organ.

Externally the mature follicle is covered by a layer of condensed stroma called the theca folliculi; the outer portion of this is called

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**Fig. 238.—A Section of a Human Ovary.**

a, Corpus luteum; b, Graafian follicles; c, corpus albicans. (After Nagel.)
the **tunica fibrosa**, and the **inner** the **tunica vasculosa**. The **theca** is lined by a number of layers of granular cells termed the **zona granulosa**, within which is a space, the **antrum**, filled by a liquid, the **liquor folliculi**. At one point, the granule layer projects into the antrum, and this mass contains the ovum. This projection is called the **discus proligerus**, or **cumulus ovigerus**. Just within the granule cells of the discus is seen a layer of long columnar cells, the **corona radiata**. A well-defined corona radiata indicates that the maturity of the ovum is almost completed (Bischoff, Waldeyer). These cells rest upon a thick homogeneous membrane called the **zona pellucida**, which is separated from the ovum by a small space, called

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**Fig. 239.**—Cross-section of Ovary of a Cat.

The Graafian follicles are so numerous that but little of the medulla is seen.  
- **a.** Germinal epithelium; **b.** tunica albuginea; **c.** immature Graafian follicle; **d.** ovum; **e.** cortical stroma; **f.** interstitial cells; **g.** theca folliculi; **h.** zona granulosa; **i.** antrum containing liquor folliculi; **k.** discus proligerus; **l.** corona radiata; **m.** zona pellucida; **n.** vitellus; **o.** germinal vesicle; **p.** follicle without ovum; **r.** hilum; **s.** medulla showing the tubules of the parovarium; **t.** arteriole; **u.** venule.
the perivitelline space. This space is disputed by some writers. The corona is supposed to give rise to the zona pellucida. The ovum that lies just within the space consists of a cell-wall, the vitelline membrane, and cell-body, the vitellus. In the vitellus is seen the

nucleus, or germinal vesicle, which contains the prominent nucleolus, or germinal spot.

The ovum is the most characteristic and largest cell in the female. Its diameter varies from 0.22 to 0.32 mm. The zona pellucida that surrounds it is quite thick, measuring from 10 to 11 microns (Ebner). It is probably the result of the activity of the cells of the follicle. It is said to contain small radial canals called micro-
pyles, through which the spermium gains entrance to the ovum in fertilization (denied by Keibel and others). The cytoplasm consists of a delicate reticulum and of yolk granules, the nutritive yolk, or deutoplasm, and the formative yolk, and is transparent in all stages. The oöplasm consists of two layers, an outer marginal zone that is finely granular and contains the germinal vesicle, the central portion contains the bulk of the deutoplasm. The latter consists of fine and coarse granules 1 to 3 microns in diameter; they are fatty in nature. The cytoplasm often contains chromidia that represent the yolk nucleus; these accessory nuclei may be independent or attached to the nucleus and may be also basophilic or acidophilic in reaction. These are said to be remnants of mitotic spindles. Mitochondria are also present. The nucleus averages about 30 to 50 microns, is eccentrically placed and sharply outlined by a membrane that pos-
serves a double contour. The chromatin is rather scant in the matured ovum, but the nucleolus is quite large (7 to 10 microns) and prominent. In the immature ovum the chromatin usually forms a dense mass. The nucleolus may be acidophilic, basophilic or neutrophilic. *The centrosome may be seen in ova that have not undergone maturation. If this process has been completed the centrosome disappears.* Hertwig states that they are found in ova of rabbits up to six or seven weeks of age, and in young guinea-pigs. Multinuclear ova are formed by fusion of separate ova or by direct division of the nucleus alone.

The Graafian follicles, of which there are about 36,000 in each ovary, are developed during intrauterine life, and all are usually present at birth. At birth or shortly after all oögonia have become mother cells (oöcytes of the first order). Not all of these develop, by any means. Hensen estimates that about 200 follicles in each ovary mature. The other follicles enlarge to a certain stage and then undergo atrophy and are absorbed. The smallest consist of the ovum, surrounded closely by a few layers of small granule cells and a delicate theca. They lie just beneath the tunica albuginea,

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**Fig. 242.—Diagram of the Cell Divisions in Oogenesis. (Compare with Fig. 209.) (Lewis and Stöhr.)**
and show no antrum. The medium-sized follicles lie near the medulla, and present an antrum. The granule cells are more numerous, the ovum larger and the corona radiata and zona pellucida appear. The fully developed follicles extend from the medulla through the cortex beyond the original surface level, projecting varying distances.

The follicular cells are derived from the germinal epithelium, and grow into the stroma in long columns during the developmental period, as the egg-tubes of Pflueger. In such a column will be found several large, and a great number of small cells. These columns become separated into a number of groups of cells consisting of one or more large, and many small cells. The large are the oögetic, and the small the granule cells. Gradually, the large cells fuse to form a single mass of protoplasm, and all the nuclei, except one, disintegrate. The single cell resulting is called the oöcyte. The egg-tubes are separated into these groups by the stroma that grows into the columns. This stroma further condenses around each group to form the primitive theca. Toward the age of puberty, these follicles begin to develop, though they may start sooner. The granule cells increase rapidly in number, and some of the more central ones disappear by disintegration or liquefaction. This gives rise to the space, or antrum, which becomes filled by a liquid, the liquor folliculi. The latter is probably derived from the blood.

Follicles containing several ova are formed as follows: (1) The egg-tube becomes separated, incompletely enclosing several germ cells in one mass; (2) fusion of two originally separated follicles.

Maturation is the process by which the polar bodies are formed and extruded. During intrauterine life oögonia multiply rapidly as do the spermatogonia in the male, but the latter process does not occur until the male is twelve to fifteen years of age. The resulting oögonia are small and undergo a period of rest and then growth and are then called primary oöcytes. These undergo the maturation process which is the same as in the spermiogonia. The germinal vesicle migrates toward the periphery, and undergoes mitotic change. Only twelve chromosomes, the haploid number, are formed due to fusion by pairs; these divide longitudinally forming twenty-four. When the nuclear spindle is formed parallel to one of the radii, the peripheral half, surrounded by a small amount of cytoplasm, is
thrust out of the cell. This is the first polar body. Without rest, the remaining chromosomes immediately undergo division again, and the extrusion process is repeated. This is the second polar body. The remaining chromosomes form a new nucleus called the germ-nucleus. By this change, the number of chromosomes is reduced from twenty-four, in the oögonium, to twelve, in the matured ovum. The first polar body often divides into two, and, as a result of maturation, four cells are formed. Of these four, the ovum is the only one capable of producing an offspring. The three polar bodies disintegrate and disappear. This is entirely different from

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**Fig. 243.—Diagram Illustrating the Reduction of the Chromosomes during the Maturation of the Ovum. (McMurrich.)**

Ovum; oc¹, oöcyte of the first generation; oc², oöcyte of the second generation; p, polar globule.
the change in the testicle. In that organ, the spermiocyte gives rise to four cells, each of which becomes a spermium, capable of fertilization.

Maturation of the ovum differs from karyokinesis in the following ways: (1) The nucleus moves to the periphery of the cell instead of remaining in the middle; (2) only one-half the somatic number of chromosomes is formed; (3) the resulting daughter cells contain only one-half the somatic number of chromosomes; (4) the resulting cells are unequal in size; (5) the successive divisions occur without rest; (6) the mature ovum contains no centrosome; (7) only one cell is of functional importance.

The differences between maturation of the ovum and maturation of the spermiocyte are as follows: The primary oocyte forms four granddaughter cells of which only one is nearly as large as the primary cells and the other three are very small immature cells. Although all contain the same number of chromosomes, twelve, only the matured ovum is of functional importance; the other three small cells, or polar bodies disintegrate and disappear. As the spermiocyte undergoes maturation (spermiogenesis) four granddaughter cells are formed but these are all small and of the same size. Two contain only eleven chromosomes and two contain twelve chromosomes. All of these cells, however, are of functional importance as any one is capable of fertilizing a matured ovum.

As the follicle increases in size, it approaches the tunical albuginea, and causes it to protrude. The stroma intervening between the ovum and the tunica gradually diminishes until merely the tunica albuginea remains. As the follicle increases and the pressure within becomes greater, the tunica becomes progressively thinner, until it is no longer able to withstand the pressure. A small area, the stigma, is the thinnest part and indicates the place of rupture. Then it ruptures, and the liquor folliculi and the ovum, surrounded by the granule cells, are cast out of the ovary. The vessels of the tunica vasculosa rupture, and the follicle fills with blood. When this occurs, the body is called the corpus hemorrhagicum. The cells of the theca penetrate the clot, and cause this to organize. In addition to these cells, there are certain other large cells that possess a yellowish pigment. These are the lutein cells, and their function
is unknown. These are derived from the theca. These increase in number and make a very large body. The corpus exhibits a pleated appearance due to the invagination of the white fibrous tissue of the theca folliculi and the blood-vessels.

If the ovum has not been fertilized, this body is called a corpus luteum spurium, which rapidly undergoes atrophy. In a few weeks, it leaves a white scar called the corpus albicans or corpus fibrosum, due to the increase of radially disposed white fibrous tissue and its resultant contraction. If fertilization has occurred, then the body persists until near the end of pregnancy, and is termed the corpus luteum verum.

The corpus luteum seems to be a gland of short duration. It seems to secrete a substance that causes the second succeeding menstrual flow, that is, of the next month. Experimental study upon animals, in which the follicles were destroyed, showed an almost invariable absence of the second succeeding period. The preceding flow was caused by the follicle preceding the experiment. This secretion also stimulates the uterus, and aids the implantation of the ovum in the uterine mucosa, providing fertilization has occurred.

Fig. 244.—Section of a Corpus Albicans in the Cortex of the Ovary of an Adult Female. (Photograph Obj. 16 mm., oc. 7.5 X.)
(Frankel). During pregnancy it seems to prevent the maturation of Graafian follicles, while during the later stages of pregnancy it is said to exert an influence upon the mammary gland.

Of all the ova formed, but few are ever fertilized. A great number atrophy; in the remainder, maturation occurs. Of these ova, there are those which are cast into the abdominal cavity and absorbed by the peritoneum; those which pass down the genital tract and are cast out, or disintegrate, and lastly, those that become fertilized.

**Ovulation** includes the delivery of the ovum from the follicle and its passage through the genital apparatus. In the lower animals, in which the young are developed from eggs outside of the body (oviparous), this process is evinced by the "laying of the egg." In the viviparous animals, or those in which the offspring is developed within the mother, this process is not accompanied by any outward signs or manifestations. In the temperate climate, it begins at about the twelfth to the fifteenth year, and continues until about the forty-fifth to the fiftieth year. At this time ovulation ceases, and fertilization cannot occur thereafter.

The ovarian and uterine arteries supply the ovary. These vessels pass into the hilus of the ovary between the layers of the mesovarium forming a number of branches that enter the medulla. These branches are comparatively large and have a spiral course resembling the helicine arteries of the male. Their walls are unusually thick, due to the presence of an excessive amount of smooth muscles a great deal of which is longitudinally arranged. Branches from these pass into the cortex where capillary plexuses are formed in and around the theca of the Graafian follicles and others form capillary plexuses in the stroma. The extent of the plexuses around the follicles depends upon the state of the follicle. When these are young and immature the plexus is not extensive; as the follicles mature the plexus becomes greater and increases until after the rupture of the follicle and during the active stage of the corpus luteum. As this retrogrades the capillary plexus becomes reduced so that in the corpus albicans it is less than in the surrounding stroma. The blood is collected by venules that have thin walls; these pass to the medulla where they form the pampiniform plexus
of veins analogous to that of the male. From this plexus the ovarian vein carries the blood from the organ.

Lymph spaces are numerous and they pass the lymph into large capillaries that accompany the blood-vessels. These capillaries form plexuses around the large follicles and the lymph is conducted by efferents to the hilus where these vessels join those from the body of the uterus. The lymph ultimately reaches the pelvic and lumbar nodes.

The nerves are derived from the ovarian plexus of the sympathetic system, enter the hilus and are distributed to the smooth muscle in the stroma, the smooth muscle of the vessels and some fine fibrils are said to end between the epithelial cells of the zona granulosa. Pacinian bodies are also described as being present. Winniwarter states that along the nerves and in the medulla there are small ganglia that contain, besides the ganglion cells, groups of pheochrom cells.

The parovarium, or epoöphoron, lies near the hilus of the ovary, and consists of a number of short vertical tubules united to a single horizontal tube. The vertical tubules are short, and are lined by low columnar cells. The horizontal tubule has a larger diameter than the preceding, and is lined by the same variety of cells. It often lies deep in the broad ligament.

The paroöphron lies in the broad ligament, between the ovary and uterus, and consists of a number of short, closed tubules lined by low columnar cells. The tubes resemble the vertical tubes of the epoöphoron.

THE OVIDUCT

Although the ovary possesses no excretory apparatus like other glands, the oviduct, or Fallopian tube, acts as such.

The oviduct consists of the outer fimbriated end, the middle, or ampulla, and the inner uterine end, or isthmus. It has three coats, mucous, muscular and fibrous.

The mucous coat consists of simple ciliated cells that lie upon a basement membrane and tunica propria. A muscularis mucosae is absent. The cilia wave in such a manner as to create a current toward the uterus. Here and there are seen patches of nonciliated
cells but none of the glandular nature are present. The basement membrane is thin and homogeneous. The fimbria are finger-like, or fringe-like projections one of which is especially large and is attached to the ovary. The others are free. Each fimbrium consists of a core of fibroelastic tunica propria covered, on the lumen side by

![Cross-section of the Human Oviduct](image)

Fig. 245.—Cross-section of the Human Oviduct.

a, Epithelium; b, tunica propria; c, villi; d, lumen; e, muscular coat, inner circular layer; f, blood-vessels in the fibrous coat; g, blood-vessels in villus; h, fibrous coat; k, epithelium of fimbria; l, tunica propria of fimbria.

...simple ciliated cells and upon the abdominal cavity side by the endothelial cell of the peritoneum, though at times the ciliated cells seem to surround the whole structure. The tunica propria is thrown into longitudinal folds that are high in the fimbriated end, but diminish in height as the uterus is approached. These folds are the villi, which possess a very narrow base, but the part lying in the lumen of the tube is greatly branched forming the secondary folds. The tunica propria consists of white fibrous and yellow elastic tissues, in which diffuse lymphoid tissue is found. The
mucosa is thickest at the fimbriated extremity and the lumen varies from 2 to 8 mm. in diameter in the different parts. The uterine extremity has the smallest lumen.

The **muscle coat** consists of smooth muscle tissue. This is arranged into *inner circular* and *outer longitudinal layers*. The *inner circular layer* is the broader and some of its fibers are oblique in direction and may penetrate the tunica propria of the mucosa. This layer is thickest at the uterine extremity of the oviduct. The *outer longitudinal layer* is in general poorly developed and in areas may be wanting. It is said to be best developed opposite to the attachment of the mesosalpinx. It is thickest at the fimbriated extremity of the oviduct. At the uterine extremity an *inner longitudinal layer* is added. This probably represents a muscularis mucosae. The whole muscle coat is thickest at the uterine end of the tube.

The **fibroserous coat** consists of a thin layer of white fibrous tissue that is the real fibrous coat. This is invested by a layer of the peritoneum which is derived from that of the broad ligament. Opposite to the free edge of the tube the two layers of the peritoneum unite and form a delicate band that connects the tube to the broad ligament; this band is the **mesosalpinx**. Through this the vessels, nerves and lymphatics gain access to or leave the organ.

The **arteries** are branches of the ovarian and uterine arteries. These pass to the tube between the layers of the mesosalpinx and at the fibrous coat send branches into the outer coats. These form capillaries in the muscle and mucous coats and the blood is collected by **venules** that form a plexus in the muscle coat and from here the blood is carried by larger venules that accompany the arteries.

The **plexus of lymph vessels** in the mucosa sends the lymph to the serous coat, as is also the case of the plexus in the muscle coat. From the serous coat efferents carry the lymph to pelvic and lumbar nodes.

The **nerves** are from the ovarian sympathetic plexus. The branches pass to the muscle tissue of the tube and the vessels and other fibers form a subepithelial plexus from which probably fine branches pass to the epithelial cells of the mucosa.
THE UTERUS

The uterus is a flattened, pear-shaped organ that consists of body and cervix. It is an important organ, as within it develops the offspring, in viviparous animals. It is about 7.5 cm. long, 5 cm. wide and 2.5 cm. thick in the virgin. In this condition it weighs from 1 to 1½ ounces. After the first pregnancy it never returns to this weight and size. All parts consist of mucous, muscular and fibrous coats.

The mucous coat of the body is about 2 mm. in thickness (Hitschmann and Adler) of a grayish color and smooth, and is composed of simple ciliated cells, basement membrane and tunica propria. Mandle (1908) states that the amount of ciliated epithelium varies. Within the tunica propria are found a rich capillary plexus and diffuse lymphoid tissue. The surface is not smooth, but is broken by the formation of glands. These are tube-like depressions, of the branched tubular variety, lined by the simple ciliated cells; these glands are slightly spiral, in course obliquely directed and usually their ends are bent upon themselves. They are the uterine glands and extend to the muscular coat, and may even penetrate the inner layer. They are often so long that, when they reach the muscular coat, they turn and extend parallel to it for some distance.

The tunica propria of the uterus is said to resemble embryonic connective tissue. Elastic fibers are said to be absent and the white fibers are present in small numbers. Cells are very numerous, some of which are lymphocytes and these constitute diffuse lymphoid tissue. The other cells are oval, or spindle-shaped and may have branches. In addition, especially during the formation of the menstrual mucosa, there are some large clear cells present called decidual cells. These are few in number in the resting mucosa but during the menstrual stage they increase greatly in number. These are also found in the placenta and are no doubt derived from the uterus during the formation of the placenta.

The mucosa of the cervix is a little different. The uterine end is lined by simple ciliated cells, and glands are present. The vaginal end is lined by stratified squamous cells, and gland-like depressions are present. The orifices often closed, causing them to become distended
with secretion. In this condition, they produce globular projections called the ovuli Nabothi. The cervical mucosa is thrown into folds called the plicae palmatæ. The vaginal portion of the cervix is covered by stratified squamous cells.

![Fig. 246.—Resting Uterine Mucosa.](image)

The muscle coat of the body of the uterus is arranged in distinct layers in some animals but in the human being these layers are not distinct. In the cervix, however, they are distinct. In the body the innermost layer represents a greatly hypertrophied muscularis mucosae and according to Shäfer this forms the greater part of the thickness of the wall of the uterus. In the fundus the bundles of fibers form concentric rings around the openings of the oviducts; in the cervix and lower part of the body they have a circular direction and a few
internal longitudinal fibers may be present. The middle portion consists of bundles of fibers that have a circular direction but interlace somewhat. The main blood-vessel trunks are in this layer and these with the areolar tissue present make this the thickest layer on section of the organ. The presence of the blood-vessels makes it resemble a submucosa and the layer is called the stratum vasculare. There may be some longitudinal fibers along its internal part. According to Shäfer this layer is best developed over the dorsal and lateral parts of the fundus. The outermost fibers are called the stratum supravasculare. The fiber bundles are chiefly longitudinally directed and form a thin layer just beneath the serous coat. Some of the bundles are continuous with those of the oviducts, the round ligaments and broad ligaments. The innermost fibers of this layer have a circular direction.

In the cervix the muscle fibers are arranged into distinct layers, inner and outer longitudinal and middle circular. The circular fibers form the sphincters at the internal os and external os.

The muscle fibers average 50 to 60 microns in length; but, during pregnancy, they lengthen to from 300 to 600 microns.

The fibrous, or serous, coat is quite thin. It is completely invested by peritoneum in the body.

Menstruation is the periodic change that occurs in the uterine mucosa, usually every twenty-eight days, during the child-bearing period (thirteenth to fiftieth year). The superficial part of the mucosa softens, disintegrates and is removed. It is divided into stages, the premenstrual, or hypertrophic, menstrual, or desquamative, postmenstrual, or reparative and intermenstrual, or resting stages.

1. The premenstrual stage requires usually six to seven days. The mucosa increases two to three times in thickness due to edema and enlargement of cellular elements. The gland lumina become

![Fig. 247.—Section of the Mucosa of the Human Uterus. (Photograph Obj. 16 mm., oc. 5 X.)](image)
wider and irregular due to the projection of epithelium and tunica propria. The secretion in the glands is mucous. The superficial connective tissue cells become larger, rounded and the cytoplasm becomes clearer; they represent preliminary decidual cells. In these changes the mucosa becomes divided into two layers, stratum compactum and stratum spongiosum. The vessels dilate and become
engorged and the mucosa is of a deep red color. Hemorrhages occur within the tunica propria, these areas become confluent forming a subepithelial hematoma.

2. The **menstrual** stage shows the epithelium denuded at intervals permitting the blood to flow mixed with edematous fluid and glandular secretion. As a result of this outflow there is a rapid shrinkage in the thickness of the mucosa. The glands are collapsed, the lumina straight and the cells smaller and lower. The decidual cells degenerate, disappear or diminish in size. The surface epithelium may be only slightly affected or the entire stratum compactum may be expelled. This stage occupies from three to five days during which time 26 to 52 cu. cm. of blood is lost according to Hoppe-Seyler.

3. In the **postmenstrual** stage the glands are narrow and straight, the former decidual cells are long and fusiform and only small hemorrhagic areas are to be seen. After a few days the glands become wavy, the lining cells enlarge somewhat and the mucosa becomes quiescent. This stage requires from four to six days.

4. During the **intermenstrual** stage the gland cells, at first small and closely set, enlarge and the cytoplasm becomes homogeneous and acidophilic. In the tunica propria leukocytes and even solitary nodules are seen. The gland cells produce secretory granules that are passed into the gland lumina. This stage occupies fourteen days. Should fertilization occur at the time of the premenstrual stage, the other three stages may not take place. Bryce and Teacher claim that menstruation occurs merely to maintain a mucosa at all times ready for the formation of a decidua.

The uterus of the female at birth is different in appearance than at the age of puberty and in the adult condition. The mucosa is comparatively thin and the epithelial runs a smooth and unbroken course as glands are not present. These form between the first and fifth years.

The **blood-vessels** are important. Two arteries, the uterine and ovarian, supply the organ. The main branches of these arteries pass to the middle circular layer of muscle, where they form an extensive plexus of large vessels as in the submucosae of other organs. From this plexus branches pass to the muscle coat and form plexuses of capillaries; other branches pass to the mucosa and form a dense
capillary meshwork just under the epithelium. The extent of this plexus will differ at the various stages of menstruation. The blood is collected by venules that accompany the arterial channels.

*Lymphatic spaces* and *capillaries* are numerous in the mucosa. The capillaries form an extensive meshwork and receive the lymph from the spaces. The lymph is carried by efferents to the plexus in the inner muscle layer and then to another in the muscular coat proper and from here, by means of valved vessels, the lymph is conducted to the subserous plexus, ultimately to be carried to the neighboring lymph nodes.

The *nerves* are from the *cerebrospinal* and *sympathetic systems* through the pelvic plexus. These supply the muscle tissue of the uterus and of the vessels from a plexus formed in the stratum vasculare; other fibers from this plexus are said to form a delicate subepithelial plexus from which terminal fibers pass between the epithelial cells of the mucosa.

**THE VAGINA**

The coats of the *vagina* are the same as those of the uterus. The *mucous* coat consists of *stratified squamous* cells, supported by *basement membrane* and *tunica propria*. The subepithelial portion of the tunica propria is papillated. The deeper portion contains many large elastic fibers and considerable diffuse lymphoid tissue. Occasionally, some simple tubular glands are met with, and the lining cells are of the simple ciliated variety.

The *muscular* coat varies in thickness, that nearer the outlet being the thicker. The layers are not sharply separated from one another, but the general direction is *inner circular* and *outer longitudinal*. The fibers are long and slender. The mucous and muscular coats are thrown into folds that are called *rugae*. The outlet of the vagina is surrounded by voluntary striated muscle tissue that is called the *sphincter vaginae* muscle.

The *fibrous* coat consists of dense fibrous tissue, and serves to connect the vagina with the surrounding tissues and organs. It contains the large blood-vessels, lymphatics and nerves.

The larger *vessels* lie in the deeper portion of the fibrous coat and send branches into the mucosa and muscularis. The capillaries of
the mucosa pass chiefly to the papillae. The veins form dense plexuses beneath the fibrous coat. Large vessels occur in the deeper part of the mucosa, causing it to resemble cavernous tissue.

The lymphatics follow the same course as the blood-vessels.

![Cross-section of Segment of Human Vagina](image)

**Fig. 249.—Cross-section of Segment of Human Vagina.**

*a*, Stratified squamous epithelium; *b*, tunica propria; *c*, inner circular muscle fibers; *d*, outer mixed muscle fibers.

The nerves are both myelinated and amyelinated. These form an extensive plexus containing a number of small ganglia in the fibrous coat; from this plexus motor fibers pass to the muscle tissue of the vessels and vaginal wall and sensor fibers pass to the epithelium of the mucosa.
THE GENITALIA

The vaginal orifice is guarded by a delicate annular, or crescentic membrane called the hymen. This consists of white fibrous tissue covered upon its external and internal surfaces by stratified squamous cells. Occasionally, it is very vascular.

Just outside of this fold, the primitive urinogenital sinus spreads to form the vestibule of the vagina. This is a triangular space, with the apex formed by the junction of the labia minora, the sides by these folds and the base by the vaginal orifice. It contains the opening of the urethra. This space is lined by stratified squamous cells. In the tunica propria, are found a great many elastic fibers and mucous and sebaceous glands, especially near the opening of the urethra. The lower portion of the tunica propria contains so many large venous channels that it is practically erectile tissue.

Opening into the vestibule upon each side is a gland, the analog of the gland of Cowper of the male. This is the gland of Bartholin, which is a compound racemose gland, and the acini are lined by large, clear, mucous cells. The ducts are lined by low columnar cells.

Covering the vaginal orifice, to a greater or less extent, are seen the labia minora, or nymphæ. These consist of a central mass of loose connective tissue, in which the blood-vessels are abundant, especially the veins. In the tissue between the veins, smooth muscle tissue exists, and this with the vascularity, forms the erectile tissue. The folds are covered upon both sides by stratified squamous cells that rest upon a papillated tunica propria. In these papillæ, capillary plexuses are seen. Sebaceous glands are numerous, but hairs and sweat-glands are absent.

The glans clitoris lies in the tissue formed by the junction of the labia minora. It is covered by stratified squamous cells. The central part consists of erectile tissue, and many large and small vascular papillæ are present. Genital corpuscles and sebaceous glands are found. The glans is covered by a fold of skin, the prepuce, in which the sebaceous glands are quite numerous.

The labia majora are merely folds, or pouches of skin. Their outer surfaces are covered by ordinary skin. In the subcutaneous tissue are seen numerous vessels, nerves, glands, bundles of smooth muscle and an abundance of adipose tissue. Along the median line,
they come in contact with each other, and the skin surface is somewhat modified. Here elastic and muscle tissue are abundant, but adipose tissue is wanting. The skin of the labia majora is somewhat darker than that in the immediate neighborhood, due to the presence of pigment in the epithelial layers. Over the pubis, the two labia meet and form a prominent mass, the mons veneris.

The various portions of the female genital tract are lined by the following cells:

- **OVIDUCT**.......................... Simple ciliated.
- **UTERUS**..........................
  - **BODY**.......................... Simple ciliated.
  - **CERVIX UTERINE END**........ Simple columnar
  - **VAGINAL END**.................. Simple ciliated.
- **VAGINA**.......................... Stratified squamous.
- **VESTIBULE**...................... Stratified squamous.
- **LABIA**........................... Stratified squamous.
CHAPTER XV

THE PLACENTA AND UMBILICAL CORD

A description of the formation of the *placenta* and *cord* must be given in order to understand their structure at term.

Should the ovum become fertilized, it is passed down the oviduct by the ciliated cells, as fertilization usually occurs in this portion of the genital system. It is surrounded by the *zona pellucida* and *corona*, or *zona radiata*. The mucous membrane of the uterus becomes thickened, as for menstruation, and the ovum becomes lodged, usually in the fundus. The implantation process requires about one day. If the implantation is in the main cavity of the uterus it is called *central*, as in carnivors, rabbits, etc.; if in a furrow or diverticulum it is called *excentric*, as in hedge-hog and mouse; if it is by destruction or erosion of the mucosa and therefore outside of the uterine cavity proper in the interstitial tissue it is called *interstitial*, as in man and guinea-pig.

The mucosa of the uterus is divided into regions: that immediately beneath the ovum is the *placental decidua*, or *decidua basalis*; the ovum becomes covered by a portion called the *decidua capsularis*, or *ovular decidua*, or *reflex decidua*; the remainder is the *uterine decidua*, or *decidua parietalis*.

The ovum divides and redivides, and passes down the oviduct toward the uterus. By the time the ovum reaches this organ it is 5 mm. in diameter and the *mesoderm* has appeared. These cells form an irregular mass, the *morula* (see Fig. 250, A). The outer cells of this mass arrange themselves beneath the zona pellucida as the *trophoderm*, or *outer cell mass*, while the remainder constitute the *inner cell mass*. The entire structure grows rapidly, and the inner cell mass becomes differentiated into three groups of cells, the *ectodermal* mass, *entodermal* mass and *mesodermal* mass (B, Fig. 250). Cavities appear in these masses through the vacuolization and disap-
Fig. 250.
A, Morula—a, Morular cells; b, zona pellucida.  B, Later stage—d, Trophoderm; e, ectodermal mass; f, entodermal mass; g, mesodermal mass.  C—d, Trophoderm; h, amniotic cavity; i, ectoderm; c, c' indicate respectively the direction of the cephalic and caudal extremities of the embryonic area.  The trophoderm is shaded, the ectoderm black, the entoderm dotted and the mesoderm lined.

Fig. 251.—n, The trophodermal villi penetrated by the chorionic mesoderm, representing the chorionic villi; o, embryonic shield; p, beginning body-stalk.
pearance of some of the cells. That within the ectodermal mass is the *amniotic cavity*, that within the entoderm the *enteric* and that within the mesoderm (extræmbrionic) the *celom* (C, Fig. 250). The cavities are filled with liquid and the entire structure is called the *triploblast* or *blastodermic vesicle*. During these internal changes the trophoderm has become thickened and the zona pellucida, having performed its function, has disappeared. The ovum has become implanted and is covered by the decidua capsularis.

In examining C, Fig. 250, it will be seen that at first the ectodermal roof of the amniotic cavity is in continuity with the trophodermal

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**Fig. 252.—** N, Chorionic villi; O, embryonic shield; P, body-stalk; N', amnion; S, allantois; T, yolk-sac with vessels; V, blastopore. Mesoderm unmarked.
cells. The floor of the amniotic cavity is called the *embryonic shield*, or *button* and in this area alone the embryo is developed. Fig. 251 shows that the mesoderm has separated the ectoderm from the trophoderm and also that the mesodermal tissue of the right wall of the amniotic cavity has been increased. This is of significance. Fig. 252 shows this latter tissue greatly increased forming what is called the *body-* or *belly-stalk*. This stalk has become pronounced through the splitting of the mesoderm of the roof, this cleft extending all the way to the body-stalk (Fig. 252). This membrane (ectoderm and mesoderm) roofing the amniotic cavity is the *amnion*, the formation of which is not the same in all vertebrates. If the embryonic shield be examined it will be found to consist of ectoderm and entoderm in the embryonic area proper, the body mesoderm having as yet not been developed.

If this area be viewed from the ectodermal (dorsal) side a linear groove extending over the greater part of the shield will be noted. This is the *neural* groove. This groove deepens, its dorsal lips...
meet and fuse and thus a tube of ectoderm, the *neural tube*, is buried beneath the ectoderm. From this tube the entire central nerve system is developed.

![Fig. 254.](image_url)

**Fig. 254.**

A—b', Buccopharyngeal membrane; d', neurenteric canal; z', part of the notochordal canal, shown in broken line, forming posterior wall of the gut-tract. B, Cross-section of A. At z, the notochordal canal is shown by a broken line. C—b, Buccopharyngeal membrane; d', neurenteric canal; z', completed notochord. D, Cross-section of C showing the notochord completed. The white or lined spaces indicate mesoderm.

At the cephalic extremity (left in Fig. 253, A and B), of the embryonic area a slight transverse groove (x) appears called the *head fold of the amnion*. This marks absolutely the head limit of
the embryo. At the caudal extremity (right in Fig. 253, A and B), a like groove (y) appears, the *tail fold of the amnion*. Two lateral linear grooves appear called the *lateral folds*, limiting the body laterally (Fig. 254, B and D). As those folds deepen and approach one another ventrally the body is completely outlined. The ectoderm and mesoderm form a layer called the *somatopleure* (Fig. 255), that gives rise to the amnion and body wall. The entoderm and mesoderm constitute a layer, the *splanchnopleure*, which gives rise to the gut-tract, yolk-sac, vitelline duct, cloaca and allantois.

As seen in the foregoing the ectoderm, entoderm and extraembryonic mesoderm have been formed from solid masses by the disappearance of certain of their cells, or *delamination* as it is called. The body or intraembryonic mesoderm is formed in another manner. At the caudal end of the neural groove a small depression appears due to the cord-like invagination of ectoderm between ectoderm and entoderm. This is the *notochordal invagination* and this constitutes a modified *gastrulation* (Figs. 252 and 253). The mass of ectoderm continues to grow cephalad to within a short distance of the head end of the neural tube, to which it lies ventral. This cord

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*Fig. 255.—Section of a Chick Embryo with Eight Segments.*

(Balfour.)

*a*, lateral fold of the amnion; *b*, somatopleuric mesoderm; *c*, muscle plate; *d*, mesoderm of somite; *e*, intraembryonic celom; *f*, extraembryonic celom; *g*, splanchnopleuric mesoderm; *h*, primitive kidney anlage; *i*, aorta; *k*, notochord; *l*, entoderm of gut-tract; *m*, vessel; *n*, entoderm of yolk-sac.
becomes a tube by the disappearance of its central cells and then its ventral wall and the entoderm (against which it lies) both disappear, thereby (Fig. 254, A and B, $Z'$) making the notochordal ectoderm the dorsal boundary of the enteric cavity, and leading former observers to believe that the notochord arose from the entoderm. Soon the notochordal ectoderm folds off from the entoderm forming a solid cord (Fig. 254, C and D, $Z''$) the *notochord proper*. When the notochordal cavity became continuous with the enteric cavity this later cavity communicated with the amniotic cavity through notochordal depression; this short canal is called the *neurenteric canal*, because the neural tube ultimately closes off the amniotic connection and then the canal leads from the neural canal into the enteric canal. 

As the notochordal invagination is formed other ectodermal cells are set aside here between ectoderm and entoderm. These begin to multiply rapidly forming an entirely different group of cells that spread in all directions between ectoderm and entoderm, constituting the *body mesoderm* that soon connects with the extra-embryonic mesoderm.

By this time, the ovum has become lodged in the uterine mucosa. This process is accomplished by the aid of the trophodermal cells, that have the power of *phagocytosis* (destruction of tissue) and erode the superficial tissues of the mucosa, forming a cavity into which the ovum sinks. The trophodermal layer has become increased in thickness. The epithelium of the uterus is lost in this region and also in the glands and the superficial vessels are exposed. The trophoderm, or *placentoblast* becomes altered as follows: Cells vacuolate and disappear at irregular intervals leaving a fringe of epithelial villi, the *trophodermal villi*. As a result, there are formed a series of intercommunicating spaces, the *trophodermal lacunae*. According to some the trophoderm first consists of two layers of cells. These increase in an irregular manner forming little finger-like projections, the *trophodermal villi*. When these become invaded by the mesoderm they constitute *chorionic villi*. The villi are composed of trophoderm and mesoderm. When the vessels of the mucosa are exposed, they rupture into the glandular spaces, and from these, the maternal blood gains access to the *trophodermal*
lacunae, or spaces. Thus does the embryo receive nourishment from the mother, before the umbilical vessels are present. The area of the ovum left uncovered when the ovum becomes lodged, is covered by mucosa that is reflected from the lining at the sides of the ovum.

This is, therefore, called decidua capsularis or ovular decidua. The trophodermal villi soon receive a core of mesoderm and are then called chorionic villi, the whole membrane being termed the Chorion. We must remember that the belly-stalk connects the embryo with the chorion. This belly-stalk is of importance, because it presents that part of the embryonic disc that does not lose connection
with the prochorion during the formation of the body-wall and gut-tract. Into the belly-stalk the allantoic evagination of the gut-tract extends for a short distance, while the allantoic vessels pass along the entire extent of the stalk to the forming chorion. With the passage of the allantoic vessels to *vascularize the chorion*, the belly-stalk becomes the so-called extraembryonic portion of the allantois. In some animals, the *oviparous*, the allantois develops as an independent sac there being no belly-stalk in those forms. It remains as a dilated sac, and serves as a receptacle for urine. In the *viviparous* animals, it remains connected with the belly-stalk, and is said to connect the embryo with the uterus, becoming the organ of nutrition and respiration. As a matter of fact, it is the belly-stalk that forms the link between fetus and chorion; the chorion becomes the fetal portion of the placenta, while the belly-stalk becomes the umbilical cord by the addition of the vessels. It would seem that the *allantois proper has nothing to do with the formation of the placenta and cord in the higher types*. In this mesoderm, four main vessels develop, *two arteries* and *two veins*. Later but one vein is found, due either to a fusion of the two veins, or probably to the *atrophy of the right vein*. The two veins enter the body and proceed toward the heart, while the other two vessels pass into the body, and connect with the aorta. The distal ends of all the vessels pass into the chorion, and divide to ramify all the villi. These villi are still covered by the trophoderm, consisting usually of two layers. Of these, the outer becomes converted into a thin layer of protoplasm, in which the original nuclei remain and the cell-boundaries are lost. This protoplasm constitutes the *syncytium*. The villi do not remain simple, but branch and rebranch; the vessels follow these branches, and penetrate to the very ends. Some of the villi enter the uterine glands, in which the epithelium becomes denuded by about the sixth week, and the surface cells by the fourth week, and are the *floating villi*; others become attached, and form the *fixed villi*. When the epithelium of the uterus is lost, the engorged superficial capillaries of the placental decidua become connected with the glands, and the blood enters these, and then the trophodermal spaces. These channels are the later *intervillous spaces*. From these cavities, the blood is returned to the venous
channels of the mucosa, but no direct connection is established between the fetus and the mother.

These villi are very abundant, and may be scattered all over the ovum or be limited to the equator of the mass. Up to this time, all are equal in size. Soon a difference is noted in size, those at the place of attachment of the ovum increase in number and size, forming the chorion frondosum (the later placenta), while the remainder disappear and constitute the chorion laeve. The latter do not become vascularized.
At about the fifth month, a villus has the following appearance. Of the trophodermal cells, the outer do not remain large, distinct elements, but become flattened, and represent a mere layer of nucleated protoplasm that covers the villi; this is the syncytium, and it is the covering of the embryonic connective tissue that constitutes the core of the villi and supports the vessels. In the inner layer, the cells remain distinctly outlined, and persist for a short time as the cell-layer of Langhans. From the fifth month on, this layer disappears so that ultimately only the syncytium remains. Here and there on the villi are seen groups of cells that represent collections of syncytial cells, the cell knots. These, like the other syncytium, contain nuclei that are small, but stain deeply. The cytoplasm responds well to the acid stains. The Langhans cells, however, contain large nuclei, but neither these nor the cytoplasm respond well to stains.

Fig. 258.—Cross-section of some Villi of the Placenta at the Fifth Month.

a, Syncytium; b, cell layer of Langhans; d, mesenchymal core of villus. (Photograph Obj. 4, mm., oc. 5 X.)
After the third month, the number of villi that becomes attached to the mucosa rapidly increases, so that after that time the fetal and maternal portion become more and more fixed to each other. This is the beginning of the formation of the placenta as it is seen at birth. The villi branch repeatedly, and the whole structure grows rapidly, causing the child to do the same. Any disturbance that will retard the growth of the placenta will also retard the growth of the fetus in greater proportion. The difference between the placenta at the fourth or fifth month and at birth is merely in size. This is due to the increase in number and branches of the villi. The villi are separated into groups by connective tissue septa that are derived from the uterine tunica propria. These are the placental septae and they contain the decidual cells.

At birth the placenta is a flesh-like, saucer-shaped mass, the attached surface of which is divided into lobes, or cotyledons. The fetal surface is covered by the amnion, a continuation of the sac in which the fetus lies, and shows the vessels as they enter and leave the organ; the opposite surface is divided into lobes, or cotyledons, covered by the decidua basilaris. The weight of the placenta is from 500 to 1200 grams, averaging about one-sixth that of the child. It consists of two portions, the fetal and maternal.

This organ consists of a fleshy mass lying between two membranes. Upon the fetal surface, we find the amnion and chorionic mesoderm. The amnion consists of a single layer of cuboidal epithelial cells that rest upon the mesodermal tissue. These epithelial cells possess prominent, deeply-staining nuclei, but the cytoplasm does not react well to the stain. The mesodermal tissue is somewhat fibrillar, and few cells are present. It is avascular.

The chorionic mesoderm is composed of mesodermal tissue in which the fibrils are more or less distinct. This mesoderm is covered by trophodermal (ectodermal) cells that later become the syncytium. From the side opposite to the amnion are seen projections. These may vary from small simple villi to those resembling a tree possessing an enormous number of twigs. Along this surface of the chorion, may be seen masses of a fibrillar substance that are called canalized fibrin. The bulk of the placenta consists of villi. These form a reddish spongy mass, divided into masses called cotyledons.
The main stems contain two or more vessels surrounded by meso-
dermal tissue. Peripherally, each villus is covered by a thin layer of
nucleated protoplasm, the syncytium. The small twigs consist of a
core of mucous connective tissue supporting several small capillaries.
The syncytium surrounds each twig. In places are seen collections
of nuclei representing the cell-knots. The cavities between the villi
are the inter villous spaces containing the maternal blood and, at
times, canalized fibrin.

From this, it is readily seen that the fetal and maternal blood
currents do not intermingle. They are separated from each other,
the endothelium of the fetal capillaries on the one hand, and the
syncytium of the villi on the other.

The maternal side of the placenta is covered by the decidua
basalis, or the stratum compactum of the mucosa. It is less than
a millimeter thick, and possesses a number of short oblique channels.
These are the remains of the uterine glands; they now represent blood
sinuses, which contain maternal blood.

The basalis extends into the fetal portion as the placental septa,
and divides it into the cotyledons. At the edge of the placenta, it
becomes attached to the chorion, and continues as the decidua
parietalis. At this junction there is a considerable space that
extends all around the edge of the placenta. This is the marginal
sinus, and is prominent because few or no villi have developed here.

The membranes consist of the amnion, chorion and the uterine
lining, or the stratum compactum. The latter is thin, and contains
neither glands nor epithelium. When the fetus increases in size and
causes a dilatation of the uterus, the amniotic sac, covered by the
chorion, is forced against the uterine lining, and causes an atrophy of
the glands and cells of the stratum compactum. As a result, a mere
fibrinous membrane, that has a loose connection with the amnion, is
produced, due entirely to pressure.

Fossati, by means of the Golgi method, found a peculiar network
of fibers surrounding the blood-vessels of the placenta and umbilical
cord; this network also seemed to come into relation with the epi-
thelium. He considered this network nerve tissue.

There are four varieties of placentae: (1) Villous, in which the villi
simply fit into the uterine glands, as in the pig and armadillo.
(2) Cotyledonary, in which the placenta consist of many scattered button- or ring-like masses, as in the cow, horse, camel and sheep. (3) Zonary, in which the placenta is a band-like mass surrounding the uterine tube transversely, as in the cat and dog. (4) Discoidal, in which the placenta is a discoidal mass, as in man and rodents.

The umbilical cord is the connecting link between the fetus and the placenta, and represents the early belly-stalk. It is peculiarly twisted and may even be knotted. It is surrounded by one or more layers of cuboidal epithelial cells, continuous on the one hand with epithelium of the amnion, and on the other with the ectodermal cells of the body, supported by a little subepithelial fibrous tissue. Within this covering is the peculiar tissue called Wharton’s jelly. This is embryonic connective tissue in which the cells are chiefly spindle-shaped; some round and stellate cells, however, are seen. The intercellular substance is semi-solid, and takes a peculiar homogeneous stain. During the early months of pregnancy, the intercellular substance contains a great deal of water, and the cellular elements are few. At the end of pregnancy the intercellular substance is somewhat fibrillar, though the semi-solid portion predominates. At this time the cells are mostly of the stellate type, but not numerous. At the body end, occasionally, traces of allantoic cavity and yolk sac are found.

The vessels contained are the single umbilical vein and two umbilical arteries. These are all thick-walled and well-developed, and the muscle fibers run both circularly and longitudinally. The wall of the arteries is thicker than that of the vein. The insertion of the cord into the placenta is usually eccentric, and at this point the vessels branch rapidly and spread out in all directions.

The circulation of the placenta is a closed one. The blood is carried from the iliac arteries to the umbilicus through the hypogastric arteries, which continue in the cord as the umbilical arteries. These branch to follow the villi and ultimately terminate in tufts of capillaries in the terminal villous twigs. The blood at this point receives the oxygen and nutritive matter from the maternal blood that circulates in the intervillous spaces in which the villi lie. There is no direct communication between the fetal and maternal blood, for they are separated from each other by the endothelium of the capil-
laries and the syncytium covering the villi. As the oxygen and nutritious substances pass into the fetal blood, the effete matter and gases pass out into the maternal blood. The principle is the same as in the lung, where the blood is oxygenated. Red cells never pass from one system to another, but leukocytes that have the power of ameboid motion may. The blood is collected by the radicals of the umbilical vein and carried into the body to the under surface of the liver, where a portion enters the portal vein through the continuation of the umbilical vein, is distributed to the liver and collected by the hepatic veins and emptied into the postcava; the remainder is

![Fig. 259. — Cross-section of Human Umbilical Cord. (Minot.)](image)

*Fig. 259. — Cross-section of Human Umbilical Cord. (Minot.)*

*A, A', Umbilical arteries; V, umbilical vein; Y, remains of allantois.*

carried to the postcava (inferior vena cava) by the ductus venosus. The blood passes to the right atrium, then through the foramen ovale to the left atrium, from which it passes, through the atrio-ventricular orifice, into the left ventricle. The blood then passes into the aorta chiefly to the upper extremities and head, is collected by the radicals of the precava (superior vena cava), and emptied into the right atrium. From this chamber it passes through the atrio-ventricular orifice into the right ventricle, from which it passes into the pulmonary artery toward the lungs. As these organs do not functionate at this time, most of the blood is sent to the aorta through the ductus arteriosus. The blood then passes toward the lower extremities, and, as it reaches the internal iliac arteries, most of it is sent to the placenta through the arterial trunks, which inside of the body are called the hypogastric arteries, and in the cord the umbilical arteries.
The skin covers the external surface of the body and is its most extensive organ. It varies in thickness in the different parts; upon the medial surfaces of the extremities it is thinnest and gradually increases in thickness over the thorax, abdomen, lateral surfaces of the extremities, back, buttock, palm and sole.

It consists of two portions, the epidermis, or cuticle, and the cutis vera, or corium. The epithelial portion is the protective part while the connective tissue derma is the vascular portion and also contains the accessory structures. The skin besides being protective is also very sensitive; in the derma are the tactile organs and various other sensor nerve organs for the perception of general sensations, pain and temperature changes. It is also an important excretory organ and maintains, or regulates body temperature. It has a number of different appendages. The hairs serve as a protection and are not evenly distributed, as will be seen later. The sebaceous glands secrete an oil that serves to keep the skin pliable and tends to keep the hairs soft and flexible. The sweat glands have a double function; they are excretory glands and are assistants to the kidneys. The perspiration also serves to regulate the body temperature. The nails are protective. These appendages lie wholly or nearly so, except the shafts of the hairs, within the vascular derma.

In general pigment is lacking in the skin of the Caucasian except around the nipples and genitalia and in those individuals who live in the tropical and subtropical regions. Pigment is deposited in those individuals as a protection against the actinic rays of the sun. The general pinkish color is due to the vascularity of the derma and the thicker the epidermis the lighter the color providing pigment is absent. The skin is continuous with the mucous membranes of the body at the various orifices of the various tracts, as the oral and nasal
apertures and the anal and urinogenital orifices. At these *mucocutaneous junctions* the skin is more delicate and more vascular and the transition from skin to mucous membrane is sharp and distinct.

![Diagram of skin layers](image)

**Fig. 260.—Skin of the Palm of a Child at Birth Showing Stratified Squamous Epithelium.**

The *epidermis* is the epithelial portion of which the appendages are modifications. It varies in thickness from 0.03 mm. to over 1 mm. in different parts of the body. This is in direct proportion to the amount of mechanical disturbance to which the part is subjected. It consists of *stratified squamous* cells, which, over the
general body surface, are divisible into two layers, stratum Malpighii and stratum corneum.

The stratum Malpighii, or rete mucosum, is composed of a number of layers of cells. The basal part consists of columnar elements, and is called the genetic layer. The cells stain deeply, and under certain conditions show pigment granules. The layer is uneven in its course, as it conforms to the waves of the corium. The upper cells of the stratum Malpighii are large polyhedral elements that do not touch one another, but are separated by intercellular spaces. These spaces form an extensive area for the diffusion of lymph and are bridged by delicate cytoplasmic processes that extend from one cell to another. This is sometimes called the stratum spinosum. These are prickle cells that are also seen in other stratified layers. As the upper part of this stratum is approached, the cells become flattened and have an even course. Very often the uppermost layers of cells contain granules constituting the stratum granulosum to be described later.

The stratum corneum ordinarily forms a thin layer. Its cells are very thin and scale-like and usually possess no nuclei. They are derived from the cells beneath, but differ from them in consisting of keratin, or pareleidin, that gives them their hard and horny characteristic. This substance is shiny and highly refractile, and does not respond readily to ordinary stains. These cells are constantly cast off, and the cells below increase to replace them. The
cells of the lower layers acquire a distinct exoplasmic zone, the
prickles become shorter and thicker and the nucleus shrunken and
dried.

Over the general cutaneous surface the cells of the stratum
corneum are scale-like and no longer resemble cells. When treated
with a solution of potassium hydroxid they swell and appear vesicular. Upon the sole
and palm the cells of the stratum corneum are larger and appear swollen. They repre-
sent the epitriceal cells of the fetus which seem to persist in those parts devoid of hairs.

In certain parts of the body, sole and palm, the stratum granulosum and another,
the stratum lucidum, are well developed.

The stratum granulosum lies external to the stratum Malpighii, and is composed of
two or three layers of flattened, spindle-shaped cells that contain a deeply staining
nucleus and coarsely granular cytoplasm. The granules are keratohyalin that later
form the horny matter of the stratum cor-
neum. This substance is peculiar to mam-
mals. These granules are quite large and
prominent, and respond well to hematoxylin
as it is strongly basophilic. They seem to be modified cytoplasm,
but some hold that they represent products of the nucleus but not
chromatin.

The stratum lucidum lies external or peripheral to the stratum
granulosum, and separates this from the stratum corneum. It
forms a narrow, glistening band of cells, two or three layers broad,
in which the keratohyalin granules have fused to form a homogeneous
substance, called eleidin. In the stratum corneum these granules
become pareleidin; this will blacken slowly in osmic acid due to the
oil from the glands, not fat in the cells. This substance reacts well to
eosin. The nuclei are not prominent nor are the cell-bodies dis-
tinct. This layer is absent where the skin is thin.
As the cells of the stratum corneum are constantly desquamating they must be replaced. This is brought about by active karyokinesis of the cells of the stratum Malpighii.

In injuries to the skin where the epidermis is lost the stratum Malpighii, at the margins of the area, gradually extends onto the injured area and from this extension the special layers are later derived. When the denuded area is great skin-grafting is employed. In this each, minute graft represents a little island from which the stratum Malpighii spreads in all directions and the denuded area ultimately becomes entirely covered if the work is successful.
The **derma**, **true skin**, or **cutis vera**, is composed of connective tissue arranged in two or more less distinctly separated layers. These are the **stratum papillare**, or **outer**, and the **stratum reticulare**, or **inner**.

The **stratum papillare** consists of delicate bundles of small white fibrils forming a close network with elastic fibers.

The upper portion of this stratum is thrown into small waves called the *papillae*, to which the stratum Malpighii conforms. Over the general skin surface, these papillæ do not extend through the stratum Malpighii, but in the **palmar** and **plantar** regions they are visible externally, and assist in forming the peculiar markings seen in these areas. These papillae are important, as they contain *either* capillary *plexuses* or *special sensor nerve organs*. These are the **vascular** and **tactile papillae**, respectively. The lower portion of the stratum papillare consists of a looser network, in which the vessels form plexuses parallel with the surface. It gradually passes into the stratum reticulare. These papillae are tallest and most numerous in the palmar and plantar regions, poorly developed in the skin of the face and here tend to disappear in old age. In the palmar and plantar regions there are usually two papillae under each ridge.

The **stratum reticulare** is not distinctly separable from the preceding. It is composed of larger bundles of coarser fibrils of white fibrous tissue, and contains some yellow elastic tissue, as will be seen below. Here are found the larger blood-vessels and the appendages and special sensor nerve beginnings. In the corium of the scrotum, penis and nipple, smooth muscle fibers are found. When these bundles contract, "goose-flesh" is produced. In the skin of the face and over joints elastic tissue is most abundant. It decreases everywhere with old age.

The elastica is often separated into layers, of which there are four, the **subepithelial**, **papillary**, **reticular** and **subcutaneous** elastic layers. In the scrotum they form a membranous layer.

The derma varies in thickness from 0.5 mm. to 5 or 6 mm.; the latter measurement represents that of the derma of the back and shoulders. Here this layer is quite dense and many of the bundles of white fibrous tissue pass vertically through it to the panniculus adiposus.

Beneath the stratum reticulare is the **subcutaneous tissue**, or **panniculus adiposus**. This varies in thickness and density in the various
parts of the body and the amount of fat is also variable. It connects the skin to the deep or muscle fascia and its mobility varies. It consists of bundles and septa of coarse white fibrous tissue forming meshes that contain the adipose tissue. The latter is usually in the form of lobules of different sizes. In some regions of the body the bundles course nearly parallel to the skin and here the meshes are larger and the skin is more mobile. Where the bundles are more vertical the skin is more firmly held. In addition to the cutaneous nerves and vessels this layer contains the roots of the larger hair follicles, and the larger sebaceous and sweat glands. Häggquist has described a thick bundle of smooth muscle tissue at the boundary zone between the stratum reticulare and subcutaneous tissue in those regions called cold spots and not elsewhere. By the reflex contraction of this muscle the adjacent blood-vessels are constricted when the skin here is subjected to a cold object.

Very little elastic tissue is present in this layer and pigment granules have been found in the corium. In the white races, this pigmentation is limited to the nipple and genital region. In the colored races the amount of pigmentation gives the varying degrees of depth of color. In the lighter individuals the pigment (melanin) is limited to the lower layers of the stratum Malpighii but as the color deepens not only is there more pigment but more layers, higher up, are involved and the connective tissue cells of the derma will contain increasing amounts of pigment.

In the colored races the pigmentation of the skin is not manifested for several days after birth, although the pigment is present for several weeks before birth. Whether the pigment is due to the vital activity of the cells, or whether it is brought here and deposited, is not definitely settled. The former seems to be the origin of that of the retinal cells and probably of that of the skin. Recently it has been found that the pigment is of nuclear origin. This pyrenoid substance arises in the nucleus, passes through the nuclear membrane into the cytoplasm and here differentiates into melanin. It seems to be the result of the action of tyrosin, or chromogen of the cytoplasm, upon the tyrosinase formed by the nucleus.

The presence of pigment in the skin seems to be for the purpose of protection against the actinic rays of the sun. In the torrid
regions where the actinic rays are more active Caucasians who are exposed to these rays very much soon become colored or tanned so that the exposed parts of the body no longer seem to belong to a Caucasian. This process occurs to exposed individuals even in the temperate regions, but to a lesser degree as the actinic rays here are not so powerful.

The skin is the protective organ, and varies in thickness in the different regions. It is thinner on the less exposed surfaces, as the inner surfaces of the thighs and arms, and thicker on the exposed regions, as back, sole and palm.

Upon the palmar and plantar surfaces the epithelium is thrown into ridges. These are arranged in definite patterns characteristic of each individual. Recorded impressions of these surfaces have been used as means of indentification for various purposes. Wilder considers the plantar patterns more characteristic than the palmar patterns. Recently the hospitals in one of the large cities began taking the plantar prints of babies born there in order to prevent any mistakes of identity.

These start to form in the eleventh week of intrauterine life and by the eighteenth week are visible upon the surface. These peculiar patterns remain permanent throughout life. Even though the epidermal surface may wear somewhat and scars may be present the general and special characteristics may still be made out as Galton has shown. These markings are present even in the skin of mummies and also in specimens preserved in jars. Under these extreme conditions they are still clear and distinct. Finger prints are now added to the Bertillon measurements in the criminal departments of all of the large cities and in the army and they have proved their value.

Locard in France has made a special study of the distribution and arrangement of the pores of the sweat glands and claims that these are more characteristic than the finger prints. They are certainly more difficult to make prints of and anything interfering with the making or taking of finger prints naturally would interfere with making prints of the pores. This subject is called poroscopy.

The blood-vessels of the skin vary in size and number, according to the location; in the gluteal, plantar and palmar regions, they are
greater, while in the most movable parts they are most branched. The larger trunks lie in the lower part of the corium and form a plexus parallel to the surface. This plexus supplies the fat and sweat glands. Other branches pass to the superficial part of the corium, anastomose and send terminal twigs to the vascular papillae (subpapillary plexus) and to the hair sheaths and sebaceous glands. The hair papillae receive independent branches. In the papillae the vessels continue as venous capillaries, that form a plexus just beneath the papillae (subpapillary plexus). This empties into another in the lower portion of the derma that communicates with a subdermal plexus; the latter lies between the derma and the panniculus adiposus, and its vessels possess valves.

The lymphatics of the skin consist of superficial, or papillary plexus, which receives the lymph from the spaces in the papillae, and a deeper, or subcutaneous plexus that consists of larger trunks, that anastomose with the above, and communicate with the special plexuses of the appendages.

The long nerve trunks are found in the reticulare, and from these branches form a subpapillary plexus. Myelinated fibers extend toward the surface, and form the special organs.

The sensor organs are very numerous in the skin. These comprise the free terminals, or those in which the naked axis cylinder pierce the epithelial layer, branch and send these divisions between epithelial cells. The higher forms of beginnings comprise tactile corpuscles of Meissner, most numerous in the palmar and plantar skin of the fingers and toes (there is usually one corpuscle to every four papillae; here a pad of tissue is found that corresponds to the "walking pads" of carnivores); bulbs of the conjunctiva and genitalia; Pacinian bodies especially in the palms and soles; and the organs of Ruffini, resembling the neuro-muscular organs. For a detailed description, see Nerve Tissue (p. 170). In addition, there is the usual nerve supply to the blood-vessels.

THE APPENDAGES

The appendages of the skin are the hairs, nails, sebaceous, sweat and mammary glands. These are all derived from the epidermis.
The **hairs** are protective organs limited to certain portions of the body. Hairs are absent in the sole, palm, glans penis, glans clitoris, prepuce, medial surfaces of the labia majora, lateral and palmar surfaces of the phalanges and the dorsum of all of the ungual phalanges. They are most numerous upon the scalp where they average...
from 200 to 300 per square centimeter. Here they are distributed in groups of three or five. The slope of the hair varies in different parts of the body. They seem to be arranged in lines that form whorls, making a general *hair pattern* over the body surface. Each consists of a **root**, that portion within the skin, and a **shaft**, that part seen above the surface.

![Fig. 265.—From a Section of Scalp. (Stöhr's Histology.)](image)

1. Hair-shaft; 2, hair-root; 3, sebaceous gland; 4, arrector pili muscle; 5, root sheaths; 6, follicular sheath; 7, hair-bulb; 8, papilla; 9, fat cells.

The **root** is somewhat flask-shaped, the lower end being enlarged to form the **hair-bulb**. This, on its under surface, is indented and invaginated by a little mass of connective tissue, the **hair papilla**, that contains a small tuft of capillaries, upon which the nourishment of the hair solely depends. The root is surrounded by a condensation of the derma, in which the connective tissue bundles are arranged into two layers.

In the **outer**, the fibers have a longitudinal course, while in the **inner**, they run circularly. The fibers of the **outer layer** interlace
somewhat and are coarser than those of the inner layer. Capillaries and nerves are numerous but elastic fibers are few in number. The

fibers of the inner layer also interlace to some extent and contain a rich capillary meshwork and many nerve fibers that form a plexus
just beneath the epithelial layer. Within this circular layer is a prominent homogeneous band, the glassy membrane. This represents a greatly hypertrophied basement membrane. It is partly derived from connective tissue and partly from the exoplasm of the epithelial cells. Few connective tissue cells are present. These layers constitute the follicular sheath. Internal to it are found the epithelial cells, which are continuous with the epidermis. These

![Diagram of hair follicle](image)

**Fig. 267.**—**From a Horizontal Section of the Human Scalp.**  
X 240. (Stöhr.)  
Cross-section of a hair and its sheaths in the lower half of the root.

are arranged into layers that are the root sheaths, of which there are two, outer and inner.

The outer root sheath is the direct continuation of the stratum Malpighii. These cells are the same as elsewhere, and continue to the bottom of the root, where they blend with those of the inner root sheath. Throughout the greater part of the follicle, this layer consists of several rows of cells. Toward the bulb, it gradually becomes reduced to a single layer.

The inner root sheath begins at the lower edge of the orifice of the sebaceous gland that opens into the hair follicle. Above the
duct it is replaced by the stratum corneum. This sheath consists of two portions, the outer of which is called the layer of Henle. This lies next to the outer root sheath, and is composed of a single layer of flattened cells. The cells are clear and the nuclei are usually invisible. This layer is comparable to the stratum lucidum of the skin and may be absent or seem a part of the inner root sheath. Within this layer is the sheath, or layer of Huxley, which consists of two or three layers of large irregular cells. The cells are flattened and keratinized and correspond to the cells of the stratum corneum of the epidermis. It must be borne in mind that the structure of the root varies at different levels and in order to see all of the mentioned layers the section must be some distance from the bulb. In the bulb the root sheaths are no longer distinguishable as distinct and separable layers but blend. Most of the cells represent the outer root sheaths which are the elements that really form the hair. Their great number cause the formation of the bulbous portion of the root. The cells here may often contain a large number of pigment granules.

The hair papilla is a club-shaped mass of delicate connective tissue from the derma in which the connective-tissue cells are very numerous. It contains a rich plexus of blood capillaries and also many nerve fibers that are no doubt trophic in function.

The hair occupies the central portion of the follicle, and is composed of three parts, cuticle, cortex and medulla.

The cuticle is composed of a single layer of irregular, nonnucleated scales. These are very thin and overlap. Within the follicle they lie closely applied to the layer of Huxley. These cells are thin and keratinized. The cortex consists of a great many layers of long, spindle-shaped elements. The nuclei are rod-shaped. These cells are keratinized and may contain pigment granules.

The medulla is absent in lanugo hairs and usually so in the hairs of the scalp. The medulla, when present, is composed of several rows of cuboidal cells that do not extend the length of the hair. They contain granules of keratohyalin, and frequently have a dark appearance; this is due to the presence of small air-bubbles.

The heaviest hairs are found on the scalp and pubis, in the axilla, and upon the face of males. Those of the scalp measure from 11 to
160 microns and those of the face up to 200 microns in diameter. Delicate hairs occur all over the body surface and measure about 5 microns in diameter; these are like the lanugo hairs of the fetus.

Light-colored hairs are finer than black hairs. The straight hairs are usually coarser and thicker than the crisp hairs and on cross-

**Fig. 268.—Longitudinal Section of Hair Follicles in the Scalp of a Fetus.**

- *a*, Papilla; *b*, Epithelial root sheaths; *c*, shaft; *d*, sweat-gland.

(Photograph Obj. 16 mm., oc. 10 X.)

section are usually circular in outline. The crisp hairs are oval upon section and are most flattened in the Japanese, Chinese and Indians.

Shortly before and after birth there is a general shedding of the hairs. In adults this loss and renewal is constant. Scalp hairs are said to live 1600 days. The process of shedding is as follows: The hyalin membrane and circular fibers of the outer root sheath thicken, and the matrix ceases to produce an inner root sheath.
The bulb becomes cornified and frayed. The increase of undifferentiated cells forces the old hair and inner root sheath outward. The hair follicle collapses and shortens. Later the matrix cells proliferate, lengthen the follicle and produce a new hair.

The color of the hair is due to pigment granules in the cortex. These cells may even contain pigment in solution. Diffuse pigment is abundant in dark and red hairs, but absent in white.

Opening into the hair follicles are the sebaceous glands. This is usually upon the side toward which the hair leans, and here is also seen the muscle of the hair follicle, the arrector pili muscle. This is smooth muscle, and is attached above to the derma, just beneath the stratum Malpighii, and below to the hair bulb. When it contracts it causes the hair to "stand on end." Arrector pili muscles are absent in hairs of the cheeks and lips and of the hairs of the eyelids (lashes) and of the nasal fossae (vibrissae).

The blood-supply of the hair is a special vessel that passes to the bulb and in the papilla, forms a tuft of capillaries and upon this the nourishment of the hair depends. The venous blood is returned to the general cutaneous plexus of the neighborhood.

Each hair receives nerve fibers for the papilla, follicle and arrector muscle. That for the follicle divides into branches that encircle the follicle and terminate between the epithelial cells of the root sheaths. That for the papilla forms a series of fine branches in the papillary connective tissue. The nerve fiber for the muscle is from the sympathetic system.

THE NAILS

The nails are peculiar appendages that serve for the protection of the ends of the fingers and toes, and consist of the root and the nail-body.

The root is the proximal end at which the organ grows. Here the epithelial cells are transformed into the hard substance that gives the nail its character. Along the sides, the nail is protected by an overhanging ledge of skin, which constitutes, at the root, the nail-fold, and at the sides, the nail-wall. The angle formed by the nail and wall is the nail-groove. The stratum corneum continues into the angle over the edge of the nail as the eponychium.
The nail-body consists of the nail proper and the nail-bed upon which the nail rests.

The nail represents a greatly hypertrophied stratum lucidum. The cells are flattened elements, in which the nuclei are indistinct, and the cytoplasm clear. At the proximal end is the root, and at this place alone the nail grows. It is marked by a white area, the lunula. Here the epithelial layer is so thick that the underlying capillaries are invisible according to some. According to others the color is due to the presence of keratohyalin granules in the cells. Still others believe that the light area is caused by the separation of the nail from the bed in this area. The cells also are said to contain keratohyalin granules. At the distal end, the nail projects as the free edge, which is produced by a forward growth due to the formation of new cells at the root area. The nail is derived from the cells of the stratum Malpighii of the root region. These new cells pass toward the surface, the cytoplasm becomes permeated with eleidin and the nucleus all but disappears. The result is the formation of a thick stratum lucidum that represents the nail. Nothing is added to the nail beyond the root area. From the root the nail is carried over the bed to the free edge at the rate of about 0.75 mm. per week.

The nail bed consists of the stratum Malpighii and the corium. The stratum Malpighii resembles that of the skin surface, and rests upon the papillated corium. That portion beneath the lunula is termed the matrix. The corium is composed of bundles of white
fibrous and yellow elastic tissues that have a general longitudinal direction. Between the bundles are vertical fibers that pass from the periosteum toward the nail. The papillae of the bed are not like those of the skin, but consist of long ridges that extend from the root to the end of the nail. They are small beneath the root, but increase in height as the free edge is approached, and end abruptly at that point. The nail bed is very vascular.

The nails represent protective structures. In some of the lower animals they take the form of claws where they represent weapons of offense and defense. In still other forms they become markedly hypertrophied and extended so that the animal walks upon them, constituting their hoofs. In some animals, as the elephant, the nails are extremely sensitive.

THE GLANDS

The glands comprise the sweat, sebaceous and mammary glands. The sudoriferous or sweat-glands are of the coiled tubular variety. Each consists of a secretory portion, 3 mm. long, three-fourths of which constitutes the coil that lies in the stratum reticulare, and an excretory duct that passes up through the derma and cuticle to open upon the surface.

The secretory portion consists of a single layer of cuboidal cells lining the tubule. These are separated from the basement membrane by a layer of smooth muscle fibers. This is wanting in the smallest sweat-glands and is best developed in those of the axilla, labia majora, root of the penis and circumanal region.

The cytoplasm is granular and may contain pigment granules and fat globules. There are said to be two varieties of cells present, one that is clear and the other that is dark and granular. During the period of rest the cells are taller and clear and intracellular and intercellular canaliculi are noted. The lumen of the tubule may be almost occluded. During the stage of secretory activity the secretion is poured into the lumen by way of the canaliculi, the cells are small and shrunken and the cytoplasm has a granular appearance. Delicate rods may be seen in the basal portions of the cells. The nucleus is usually quite distinct. The secretory tubule is coiled upon itself, and the various convolutions are separated from one
another by interstitial tissue that corresponds to the tunica propria.

The duct that leads from the secretory part to the surface has usually one-half the diameter of the secretory tubule, and is lined by two layers of cells that rest upon a basement membrane and tunica propria but muscle tissue is absent. In the epidermis its course is spiral, and no separate wall is present, the epithelial cells of the epidermis acting in this capacity. The diameter of this portion is greater than that of the corium. Its opening upon the surface is large and trumpet-shaped, visible to the naked eye and is called the sweat-pore.

These glands are generally distributed, except on the margins of the lips, glans penis and inner surface of the prepuce. They are most numerous in regions devoid of hairs as the palm, where they number about 370 per square centimeter; they are largest in the axilla. Upon the breast and abdomen there are about 155 per square centimeter while upon the limbs, neck and trunk there are about 60 to 80 per square centimeter.

The average diameter is 1 mm., but in the axillary region they may attain a size of 3 or 4 mm. comprising 30 to 40 mm. of coiled tube. In this region the secretory tubule may be branched. They acquire their large size at puberty, and have been termed sexual odoriferous glands. In the anal region the sweat-glands are mainly branched. Some of the large unbranched glands here are called circumanal glands.

The normal secretion is a thin watery fluid called perspiration. This represents an excretion and besides sodium chlorid contains a small amount of urea. These glands are, in a way, accessories to the kidneys and in certain diseases of the kidneys the sweat glands will excrete an increased quantity of urea. In addition to this function the sweat glands are important in maintaining an even body temperature. When the external temperature runs high the skin temperature tends to do the same but the sweat glands pour out their fluid and through the evaporation of this the temperature is held down. When the humidity and temperature are high, or during heavy exercise even in moderate weather the effort of these glands to maintain an even temperature of the body is seen in the
great amount of perspiration formed. As the quantity formed is too
great to be evaporated the excess runs off in streams.

The *ceruminous glands* of the eyelids, and of the external auditory
canals and the circumanalar glands are modified sweat glands. The
secretion, however, is of a fatty nature but the general structure is
the same. The glands of Moll of the eyelids and the circumanalar
glands are usually of the branched type.

The *sebaceous glands* are *racemose* structures. They vary in
size from 0.2 to 2.2 mm. They are usually found in connection
with the hair follicles; the largest hairs possess small glands, while
the smallest hairs are appendages of the attached sebaceous glands.
The largest glands are found on the nose where the ducts are visible
to the unaided eye. Each is surrounded by a capsule of white
fibrous tissue that forms the supportive structure.

![Fig. 270.—Section of Three Alveoli of a Sebaceous Gland Showing Their Solid Structure. (Photograph Obj. 16 mm., oc. 10 X.)](image)

The *alveoli* are from 4 or 5 to 20 in number and are lined by cells
that are a continuation of the cells of the stratum Malpighii, and
which rests upon a *basement membrane* and *tunica propria*. The
basal cells are small, while larger, rounded cells in various stages of
fatty change completely fill the alveolus. Those in the center, where
the lumen should be, are further advanced in changes than the basal
cells. The entire cytoplasm becomes converted into oil, which constitutes the secretion, and is called sebum; the nucleus likewise degenerates. The sebum is semi-fluid and consists of fat and disintegrated cells. The death of the cell is necessary to the formation of this secretion. The transformed cell is immediately replaced by another. The excretory duct is lined by several layers of cells that do not take part in the secretory activity, and are derived from the outer root sheath of the hair follicle.

Sebaceous glands are found in some regions devoid of hairs, as in the margins of the lips, glans penis, prepuce, glans clitoris and labia minora. None are found in the palms and soles.

THE MAMMARY GLAND

The mammary gland is a multiple alveolo-tubular organ. According to some writers, it is a modified sweat gland, while others hold it to be a modified sebaceous structure. It is composed of from fifteen to twenty individual compound glands. Each of these possesses its own excretory duct, that has its own opening in the nipple. The entire organ is covered by skin. This gland grows somewhat in both sexes until puberty. Then in the male all but the main ducts atrophy.

Each gland consists of lobes and lobules separated and supported by white fibrous and adipose tissues. All of the individual glands are further bound together in the same manner. The ducts converge and end in the nipple, which forms a small projecting mass. Each lobule consists of a number of acini, which are tubular or alveolar in structure. The number of these depends upon the state of activity. In the gland of pregnancy, the acini are very numerous, and are lined by simple columnar, or cuboidal cells, in which are accumulated the fat globules that form the important constituent of the milk. These cells rest upon a basement membrane, but in places are separated therefrom by peculiar elements called basket cells, which are compared to the smooth muscle tissue of the sweat glands. The ducts are lined by simple columnar cells that rest upon a basement membrane, outside of which circular bundles of white fibrous tissue are to be found. These ducts unite to form the main
secretory duct of the individual glands; each main duct dilates to form a small *ampulla*, or *sinus lactiferous*, before the nipple is reached.

The *nonlactating gland* consists chiefly of white fibrous and adipose tissues, in which are seen a number of ducts, but few acini. The bulk of the organ consists of the fibrous and adipose tissues. When pregnancy occurs, the ducts divide and redivide, and the terminal portions dilate to form the acini. This increase in the glandular part causes the increase in the size of the organ, and the tingling sensation that occurs at that time.

After lactation has ceased, most of the acini undergo retrogression, atrophy, and disappear. Some of the ducts undergo the same change. As a result, the gland becomes somewhat smaller and flabby. In old age, or after the child-bearing period has passed,
the glandular and ductular portions retrograde and disappear in the same manner, until in old age, they may be entirely absent. The glands are then represented by fibrous and adipose tissues.

Milk consists of minute globules of fat, 0.1 to 0.5 mm. in diameter, surrounded by a thin layer of casein. This prevents them from coalescing. They are formed in the cytoplasm of the cells of the acini, but the cell, after discharging them, does not die, as formerly supposed. At first colostrum is present in the glands; this consists of fat and colostrum corpuscles, which are either degenerated gland cells, or leukocytes.

The nipple, or mammila, consists of an outer covering of pigmented skin, and within it the individual ducts are found. These are separated from one another by fibrous tissue and involuntary, non-striated muscle. The muscle tissue is arranged circularly and vertically, extending to the apex of the mammila. By its contraction, an erection is produced. Such tissue is called false erectile tissue. At the base of the nipple is a pigmented area called the areola, which contains a ring of branched tubular glands called the glands of Montgomery. These resemble the mammary gland and are regarded as transitional forms between the sweat and mammary glands. Occasionally rudimentary hairs are found in the areola.

In addition to the general blood-vessels, the various appendages have special supplies. From the subpapillary arterial plexus, branches pass to the hair follicles, to form one plexus beneath the hyalin membrane, and another in the papilla. The venous radicals formed, empty into subpapillary plexus of veins. Around the sebaceous and sweat glands, the subpapillary arterial plexus forms a close network of capillaries which form venous branches that empty into the subpapillary venous plexus.

The blood-vessels of the mammary gland converge toward it, and pass into the organ in the partitions between the lobules. From these vessels, branches extend into the lobules, and form close plexuses around the acini.

The appendages are supplied with nerves from both sympathetic and cerebrospinal systems. The hair follicles receive myelinated fibers that branch freely, and end in spoon-shaped masses upon the glassy membrane. The sweat glands are supplied with sympathetic
fibers, that form a close network beneath the basement membrane, which they pierce, to end upon the gland cells. The mammary gland has both varieties of nerves. The sympathetic are the more numerous; these pass to the blood-vessels on the one hand, and to the acini on the other. In the latter, they form a plexus beneath the basement membrane, and from this plexus, branches end upon the gland cells. The nerve beginnings in the nipple are numerous.

The glands and hair follicles are surrounded by separate lymphatic plexuses that empty into the subcutaneous vessels. In the mammary gland, plexuses are found between the individual lobes, around the ampullae and in the nipple. These empty into the axillary lymph nodes.
CHAPTER XVII

THE NERVE SYSTEM

The nerve system comprises two main divisions, the central and the peripheral. The central division consists of the cerebrum, cerebellum, pons, oblongata and spinal cord; the peripheral portion consists of the cerebral and spinal nerves and their connected ganglia. The central portions are surrounded by three membranes, the dura, the arachnoid and the pia.

The dura is a tough membrane composed mainly of decussating bundles of white fibrous and a few yellow elastic tissues that contain lymph spaces between them. Sensor nerves are numerous. Within the skull the dura comprises an outer part that is the periosteum of the bones of the skull and this is quite vascular; the inner portion is tougher and denser and less vascular and represents the real covering of the brain. It continues in between the two hemicerebri to form the falx cerebri, between the cerebrum and cerebellum it forms the tentorium cerebelli; other derivatives are the falx cerebelli and the diaphragma sellae. It also forms the walls of the great venous sinuses of the skull and is continued upon the roots of the cerebral nerves for a short distance. At the foramen magnum the two layers become permanently and distinctly separated from each other, so that within the vertebral canal the dura hangs like a bag to the third division of the sacrum. Within this bag is the spinal cord. Within the spinal dura the bundles of fibers have chiefly a longitudinal direction.

Within the cranial cavity the internal surface of the dura is lined with mesothelial cells and the membrane forms the outer boundary of the subdural lymph space. Within the vertebral canal both surfaces of the dura are covered with mesothelial cells and the space between the dura and the bony canal is the epidural lymph space.

The dura contains few blood-vessels but the lymphatics are numerous and empty into the subdural space, or the epidural lymph
spaces. These lymphatics also communicate with the lymph spaces of the cerebrospinal nerves and the perivascular spaces. The dural lymphatics in this manner communicate with the lymph vessels of the eye, ear and nose.

The **epidural lymph space** is not a simple cavity but is crossed by trabeculae that connect the two layers of the dura. These trabeculae are covered with mesothelial cells. Within the vertebral canal where the two layers are well separated these trabeculae form a series of large and extensive lymph spaces, while within the cranial cavity, where the layers are close together, these spaces are fewer and smaller.

The dura contains amylinated cerebral and spinal fibers and also sympathetic fibers that pass to the blood-vessels.

The **subdural lymph space** is a clear-cut narrow cavity between the dura and the arachnoid. It is bounded by the mesothelial cells that line the inner surface of the dura and cover the superficial layer of the arachnoid. As the membranes of the brain and spinal cord are continued upon the cerebral and spinal nerves for a short distance and then blend with the epineurium of these nerves this lymph space extends into the nerves and becomes continuous with the perineural lymph spaces that represent drainage channels for this space.

The **arachnoid** is a delicate, web-like membrane that is composed of loosely interwoven bundles of white fibrous tissue and a few elastic fibers; it is said to be devoid of blood and lymph vessels and nerves. It is closely applied to the pia but does not follow it into the fissures and sulci except in the case of the sagittal and lateral cerebral fissures. The peripheral surface of the arachnoid is covered with mesothelial cells that are continuous with those lining the deep surface of the dura, but these two membranes are not connected to each other. The deep surface of the arachnoid is also covered by mesothelial cells. From this surface numerous bands or trabeculae pass to the pia so that instead of a clear-cut space between these two membranes a series of intercommunicating spaces is formed and these constitute the **subarachnoid lymph space**. The trabeculae are covered with mesothelial cells that are continuous with those covering the peripheral surface of the pia. The subarachnoid space does not communicate with the subdural space. The arachnoid forms a number
of reddish-brown structures that project into the venous sinuses. These are the *Pacchionian bodies* (*granulationes arachnoideales*) and although they appear to lie within the sinuses they are, however, covered with a thin layer of dura. Through these the lymph of the subarachnoid space may reach the venous circulation. In certain regions the arachnoid and pia are separated more extensively forming spaces called the *cisternæ subarachnoideales*.

The **subarachnoid lymph space** is broader in the vertebral canal than in the skull. It communicates with the canal of the spinal cord and ventricles of the brain through the foramen in the dorsal wall of the fourth ventricle and through the lateral apertures of this ventricle. It has a capacity of about 5 cu. c.c. and the lymph present constitutes the **cerebrospinal fluid**.

The **pia** is the **vascular membrane** of the brain and spinal cord as it contains all of the arterial vessels and some of the smaller venous channels. It is closely applied to the surface of the brain and spinal cord and enters into all of the fissures and sulci, more so in the cerebrum than in the cerebellum. It consists of two principal layers, an *outer* in which the fibers are longitudinal in the vertebral canal and the *inner* ones are circularly directed there. This layer formation is not so distinct in the pia of the cranial cavity as there is a tendency for the fibers to interlace. Between these two layers are the blood-vessels and the larger ones project into the subarachnoid space. The peripheral surface of the pia is covered with mesothelial cells that represent a part of the boundary of the subarachnoid space and are continuous with those of the deep surface of the arachnoid. This surface is connected to the arachnoid by numerous trabeculae, covered with mesothelial cells. The deep surface of the pia is closely applied and firmly attached to the surface of the brain and spinal cord. This attachment is due to the delicate trabeculae that extend into the nerve tissue accompanying the blood-vessels. In this deep layer are the smaller blood-vessels which enter the nerve substance from the outside.

Some sensor fibers are present in the pia but most of the nerves are of the sympathetic system and pass to the blood-vessels.

The nerve system is made up of two kinds of nerve tissue, **gray** and **white**. The gray substance is characterized by a grayish color.
In the cerebrum and cerebellum it is generally arranged in layers that are visible only under the microscope. In the spinal cord, brain stem and ganglia the arrangement is different as will be pointed out when these structures are considered.

**Gray nerve tissue** consists of nerve cells and their processes, myelinated and amyelinated nerve fibers and neuroglia, the special supportive tissue of the nerve system. The white substance of the central nerve system consists chiefly of myelinated nerve fibers, neuroglia and a small amount of white fibrous connective tissue that accompanies the blood-vessels but this is not supportive to the neural elements. The peripheral system consists of some ganglia and of nerve fibers, the latter are supported mainly by white fibrous tissue that forms the sheaths of the nerves. This portion of the nerve system has been considered under Nerve Tissues.

The nerve system consists of a series of inter-related and interconnected units that give a continuity of impulse from the central system to the periphery of the body and vice versa. These units are called neurons; each neuron consists of the nerve cell and its various processes. The nerve cell comprises the cytom, or cell body and the proximal portions of the dendritic and axonic processes. The distal portion of the axone and the distal portion of the principal dendrite, if it leaves the gray substance and becomes a nerve fiber as in the sensor system, constitute the nerve fibers. These fibers may be from a few millimeters to several feet in length.

Nerve cells vary in size and shape and may be unipolar, bipolar or multipolar, according to the number of processes. The main process is the axone, the others are the dendrites. If the axone leaves the gray substance the cells are classed as a cell of the first type, or Deiter's cell. If the axone remains within the gray substance the cell is of the second type, or Golgi cell.

The neuroglia consists of glial cells and glial fibers. The glial cells comprise ependymal cells and astrocytes of the spider and mossy types. For a detailed description of nerve cells, their processes, neuroglia and nerve fibers see Nerve Tissues.

In the cerebrum and cerebellum the gray substance is externally placed and constitutes the cortex; the white substance is internal, completely covered by the gray and is called the medulla. In the
spinal cord the gray substance is collected into a characteristic mass internally and completely surrounded by the white substance. In the brain stem (oblongata, pons and midbrain) there is no special arrangement as the gray and white are more or less intermingled with each other.

**THE SPINAL CORD**

The spinal cord (*medulla spinalis*) is the longest portion of the central nerve system and is that part within the vertebral column. It is suspended in the vertebral canal and is covered by the meninges of which the dura forms a bag. It is considerably smaller than the canal in diameter so that movements of the vertebrae do not injure it under normal conditions. It is somewhat cylindrical in shape and extends from the margin of the foramen magnum to the lower border of the first or upper border of the second lumbar vertebra. In the male it measures about 45 cm. and in the female about 43 cm. in length. Its weight, when stripped, is about 30 grams and with the nerve roots about 45 grams.

This portion of the nerve system is the longest. It is characterized by possessing the gray substance internally and the white substance externally. Its form varies in the different regions; in the cervical and lumbar areas, it is enlarged, and these enlargements are termed the **intumescentia cervicalis** and **lumbalis**, respectively. The cervical enlargement is at its maximum at the sixth cervical vertebra where its transverse dimension is 14 mm. and its dorsoventral measurement is 12 mm. The lumbar enlargement is greatest at the twelfth thoracic vertebra where it measures 13 mm. transversely and 11 mm. dorsoventrally. The outline in the cervical region is **oval**, in the thoracic region almost **circular**, and in the lumbar portion **oval**.

The increase in size at the enlargements is due to the added cells and fibers for the appendages. These enlargements vary in size according to the use of the appendages; in man, ourang and gibbon the cervical enlargement is the larger; in the kangaroo and ostrich the lumbar enlargement is the larger. In animals without appendages these areas are only slightly marked over the remainder of the spinal cord.
The cord ends in the neighborhood of the upper border of the second lumbar vertebra, and its termination is cone-shaped. This is called the conus medullaris. This includes the three lower sacral and the coccygeal segments. Its small size is due to the reduction of gray and white nerve tissues as by the time that this region has been reached most of the structures of the body have been supplied. Owing to the fact that the cord is shorter than the vertebral canal, the lower lumbar, the sacral and coccygeal nerves pass down for varying distances before reaching their respective foramina. This produces a mass of fibers in the lower part of the canal called the cauda equina. In the center of the latter is a fibrous band that extends toward the end of the canal. It is the filum terminale. This consists chiefly of pia and is about 25 cm. in length. One-half or two-thirds lies within the dural sac and the remainder extends beyond it. Its peripheral end is attached to the coccyx.

The cord, upon section, consists of two hemispheres separated ventrally by the ventral, or anterior median fissure, in which is seen a process of the pia. Dorsally no fissure exists, but a septum is present. This is the dorsal or posterior medium septum, or raphé.

The gray substance of the cord is arranged in the form of a letter H, the two side bars constituting the horns, and the cross-bar the gray, dorsal, or posterior commissure. The horns are further subdivided into ventral, or anterior, and dorsal, or posterior. In the thoracic region a lateral horn is described.

The ventral horns are large and blunt, and do not extend to the periphery. In them are found collections of large, multipolar ganglion cells having a motor function. The axis cylinders of the cells pass out of the ventral portion of the cord as the ventral root of the spinal nerve. These cells average 60 to 120 microns, and are quite numerous. Each is surrounded by a distinct lymph space. They are collected into various groups which vary according to the region of the cord. The following are the most important.

1. The ventromedian group is found in nearly all segments of the spinal cord (except in the fifth lumbar and first sacral segments). This apparently represents the nuclei of origin of the nerve fibers that supply the long trunk muscles.
Fig. 272.—Sections through Different Regions of the Spinal Cord.
(Morris after Schwalbe.)
2. The *dorsomedian group* is found in the upper cervical, the thoracic and first lumbar segments, that is where no limb muscles are represented.

3, 4. The *ventrolateral and dorsolateral groups* are the largest and represent the nuclei or origin of the motor nerves of the muscles of the limbs. They are found in the cervical and lumbar enlargements and the upper sacral segments (fourth to the eighth cervical and second lumbar to the second sacral segments).

5. The *central group* is found chiefly in the lumbar and sacral segments (second lumbar to the second sacral segments).

6. The *intermediate, or lateral group* is a thin continuous column of cells in the thoracic and first two lumbar segments with recrudescences in the upper cervical and third and fourth sacral segments. This group represents the *splanchnic efferent fibers (white rami communicantes)* that pass from the cerebrospinal system to the sympathetic ganglia.
Although many of the axones of the above cells form the nerve fibers of the ventral roots of the spinal nerves, the axones of other cells have a different course and function. Some of these axones as well as myelinated dendrites, pass to the medial and lateral sides of the ventral horns and form the ventral and lateral ground bundles. Upon entering these bundles the fibers branch T-like and the divisions pass up and down for one or two segments and then turn into the gray substance to end around the cells of the ventral horns of those segments. These fibers represent intersegmental association fibers and serve to connect several segments together for coordination of action of several muscles, or muscle groups. Other cells, especially those along the medial side of the ventral horns, send their axones and dendrites through the gray commissure to the other side of the cord as commissural fibers. The dendrites pass to the ventral horn cells of the same level and they do not leave the gray substance. The axones that cross enter the ground bundles of the opposite side, branch T-like, and the ascending and descending branches ultimately end in the gray substance a few segments above and below, terminating around the cells of the ventral horn.

The dorsal, or posterior horns are sharp and pointed, and usually extend to the edge of the cord. The cells here are small in number and size, averaging from 15 to 20 microns, and are scattered along the external margin. They comprise marginal cells that lie near the extremity of the dorsal horn and whose axis cylinders pass into the lateral columns after passing through the substantia gelatinosa; spindle-shaped cells are the smallest and neurits of these pass into the dorsal columns; stellate cells, the axis cylinders of which pass into the dorsal columns of Burdach. Generally the cells along the superficial part of the horn (medially and laterally) constitute the stratum zonale.

Along the median edge of the dorsal horn, near its junction with the gray commissure, lies the only distinct group of cells that extends from the seventh cervical to the mid-lumbar region. This is the nucleus of Clark. A similar collection, though less distinct, lies just ventral of Clark’s column and extends through a greater part of the cord. This is the nucleus of Stilling and is represented in the oblongata by the accessory cuneate nucleus. Most of the axones of
these cells pass to the dorsolateral columns of the same side forming the dorsal spinocerebellar tract; the rest pass through the gray com-

Fig. 274.—Cross-section of Human Spinal Cord at Lower Cervical Region. From Decapitated Criminal. (Dr. H. H. Cushing.)

1, Ventral spinal artery; 2, pial process in ventral fissure; 3, dura; 4, nerve fibers from ventral horn (motor root fibers); 5, stellate cells of ventral horn; 6, ventral horn; 7, dorsal horn; 8, nerve fibers of dorsal horn (sensor root fibers); 9, dorsal septum; 10, dorsal spinal artery and vein (arteria et vena fissurae posterioris); 11, fibers of the column of Goll; 12, tissue separating the columns of Goll and Burdach; 13, column of Burdach; 14, traces of the lateral horn; 15, fibers of the lateral columns; 17, central canal in the gray commissure; 18, ventral, or white commissure; 19, fibers of the ventral columns; 20, arteria et vena fissurae anterioris.

missure to the opposite side, possibly to the white substance, constituting axones of commissural cells.
The lateral horns are most marked in the thoracic and upper cervical and third and fourth sacral regions. Each is formed, chiefly, by the intermediate cell group. The axones of these cells probably do not pass into the ventral roots but terminate within the cord at various levels of the same and opposite sides. They are probably closely connected with the sympathetic system and are vasomotor and sweat-gland nerves.

In the dorsal horn is the substantia gelatinosa Rolandi, which consists of cells of the second type (Golgi).

The gray commissure consists of myelinated and amylabeled commissural fibers separated into ventral (smaller) and dorsal (larger) bands by the central canal of the cord. The ventral portion is called the ventral, or anterior gray commissure, while the other receives the name of dorsal, or posterior gray commissure. The
whole is the **gray**, or **dorsal commissure**, in contradistinction to the **ventral**, or **white commissure**.

The **canal** of the cord is the remains of the embryonal cavity within this portion of the nerve system. In childhood, it is lined by simple ciliated elements, the **endymal cells**. Above, it communicates with the fourth ventricle, and its form varies in the different portions of the cord. It becomes more or less obliterated with increasing age, partially by increased growth of the lining endymal cells and partially by the ingrowth of neuroglial processes.

Besides the nerve cells, processes and fibers, the gray substance contains that peculiar supportive tissue found only in the nerve system, called **neuroglia**. This substance is ectodermal in origin.

**Neuroglia** consists of two varieties of cells, **ependymal** cells and **astrocytes**, which are **spider** and **mossy**. The **spider** cells are composed of thin, flat bodies from which extend long, slender processes. The **mossy** cells have short, heavy processes. In addition to these, there are some cells that possess large bodies and few processes. Fibers that, apparently, have no connection with any cell are seen passing over or under cell bodies. These processes all interlace to form a network for the support of the nerve cells and their processes. This substance is the **substantia spongiosa**. Around the central canal of the cord, the substantia spongiosa becomes more modified and is called the **substantia gelatinosa centralis**. The network is much looser in this region. Around the dorsal horns, it forms a homogeneous, striated mass, in which a few nerve cells are found. This is the **substantia gelatinosa Rolandi**, **caput glio- sum**, or **gliosa cornualis**.

The **white substance** consists of myelinated nerve fibers, connective tissue, and neuroglia. Spider cells are especially numerous here. The nerve fibers possess no neurilemma, and are grouped into columns. Ventrally, they are separated by the fissure, and dorsally, by the septum, into the hemispheres. Ventrally, they are connected by a band of white substance that lies between the bottom of the fissure and the gray commissure. This is the **white**, or **ventral (anterior)** commissure. The **motor** fibers are usually large, measuring 15 to 20 microns in diameter. The **sensor** are smaller.
The following columns are not found in any one section of the cord but represent all that are definitely bounded. Fig. 276 represents merely a diagrammatic section locating all the columns.

The ventro-median columns that lie between the ventro-median fissure and the ventral roots of the spinal nerves; the lateral, that lie between the ventral and dorsal roots, and are subdivided into ventrolateral, or those ventral to the transverse midline, and the
dorsolateral, or those behind the same line. The dorso-median columns lie between the septum and the dorsal roots of the spinal nerves, subdivided into dorsomedian and dorsolateral.

These areas are further subdivided into individual columns. In the ventromedian region, there are several groups: (1) the direct pyramidal tract (fasc. cerebrospinalis anterior). This is a narrow band of fibers that lies near the fissure, and represents the non-decussating fibers (10 to 15 per cent.) from the motor regions of the
brain. The bundle is separated from the ventral fissure by the next tract. This tract usually disappears in the thoracic portion of the cord, though it may extend into the lumbar portion. These fibers decussate in the white commissure and end in the ventral horn of the opposite side. Hoche found that a few fibers of this tract terminate in the ventral horn of the same side. This tract is peculiar to man and certain monkeys and anthropoid apes. A descending tract.

2. The **sulcomarginal tract** (*fasc. tectospinalis*) is found only in the cervical part of the cord and consists of decussated fibers from opposite quadrigemina and represents a *descending tract*. It lies next to the fissure, in the cervical segments of the spinal cord and is concerned in optic reflexes. It is supposed to extend the entire length of the cord and may be called the *ventral tectospinal tract*.

3. The **vestibulospinal tract** (*fasc. vestibulospinalis*) lies at ventral surface of the cord and its fibers have been traced into the sacral portion of the cord. It consists of *descending* fibers, from the vestibular nuclei of the brain stem and is concerned in the maintenance of equilibrium.

The fibers are chiefly derived from the cells of Deiter's nucleus though some claim the superior and lateral nuclei also contribute fibers. Others state that some of the fibers come from the nucleus fastigii of the cerebellum. None of the fibers decussate.

4. **Ventral ground bundle** (*fasc. anterior proprius*). This consists of fibers that arise in the cord and end in the cord, extending up and down for short distances in order to connect the various segments of the cord. These fibers are *associative* in function, and are *ascending* and *descending*. Some of the fibers are exceedingly long and connect the brain and spinal cord. This bundle also contains the most commissural fibers of any of the ground bundles.

5. The **ventral spinothalamic tract** (*fasc. spinothalamicus anterior*) lies in the intermediate zone of the ventral column and consists of axones of the cells of the dorsal horn, of the opposite side, that pass through the white commissure to form this tract. These fibers *ascend* and end in the thalamus. They convey touch and pressure impressions from the opposite side of the body.

The fibers carrying *tactile sensations* pass into the dorsal column but do not terminate immediately in the cord. They pass up several
segments before giving off collaterals that terminate among the cells of the dorsal horn of the same side, while the main fibers pass up quite a distance before terminating in the same manner. The new fiber from the dorsal horn cell passes to the ventral region of the opposite side to help form the ventral spinothalamic tract. Some fibers carrying tactile impulses pass directly to the nuclei gracilis and cuneatus of the same side before terminating.

In the lateral region of the cord are the following tracts:

1. **Superficial ventrolateral spinocerebellar (Gowers')** lies in the superficial ventral portion of the lateral area and begins at a lower level than the spinocerebellar tract. These fibers arise from the cells of the same and opposite side of the cord and pass through the white commissure and ventral horn to form this tract. These fibers ascend to the cortex of the superior vermis of the cerebellum through the brachium conjunctivum and constitute ascending fibers that convey sensations from the muscles, joints and tendons that remain at a subconscious level. These come chiefly from opposite sides of the body. They are also concerned with reflex actions.

2. **Olivospinal or bulbospinal tract (fasc. olivospinalis)** lies just lateral to the ventral root and is found only in cervical and upper thoracic portions of the cord and represents descending fibers. This tract is probably related to the pyramidal tract. The fibers arise in the oblongata (inferior olivary nucleus) and terminate around the cell of the ventral horn of the spinal cord. These decussate near their source of origin. Long spinolivary fibers are said to be present.

3. **Direct spinocerebellar tract (fasc. spinocerebellaris posterior)** lies in the superficial dorsolateral area and consists of ascending fibers from the cells of the column of Clark of the same side on which the sensation arises. This tract is not found in the lower lumbar region of the cord. Its fibers terminate in the cerebellum reaching this organ through the inferior peduncles, (restiform body) they carry sensations from muscles, tendons and joints that remain at a subconscious level. These fibers are concerned with reflex actions.

4. **Crossed pyramidal tract (fasc. cerebrospinalis posterior)** is in the dorsolateral region of the cord. It is composed of fibers that arise from the pyramidal cells of the cerebral cortex, decussate (85 to 90 per cent.) in the oblongata, and end in the ventral horns of the
cord. In the cervical region it is internal to the direct cerebellar tract but in the thoracic area of the cord it comes partially to the surface, and in the lumbar region, where the direct cerebellar tract is absent, the crossed pyramidal tract lies entirely superficial. It is a descending tract.

5. **Lateral ground bundle** (*fasc. lateralis proprius*) lies against the gray substance and consists of associative fibers of both descending and ascending courses. It is the largest of the ground bundles and may be broken up into small bundles.

6. The **lateral spinothalamic tract** (*fasciculi spinothalamicus posterior*) consists of fibers that arise from the cells of the dorsal horns of the opposite side; these pass through the white commissure to reach these tracts and pass up the cord to terminate in the thalamus. They are *ascending tracts*. The lateral spinothalamic tract (scattered in Gowers' tract) conveys impressions of heat, cold and pain from the opposite side.

*Pain sensations* are brought from the surface of the body (a few from muscles) by amyelinated fibers of the dorsal root. These probably terminate around the cells of the substantia gelatinosa Rolandi of the dorsal horn; these cells are connected to those of the dorsal horn that form the dorsal spinothalamic tract by intercalated cells or neurons.

7. The **rubrospinal tract** (*fasc. rubrospinalis*) consists of axones that *descend* from the cells of the red nucleus of the midbrain to terminate about the cells of the ventral horn. It is part of the indirect motor pathway and extends to the sacral segments.

8. The **tectospinal tract** (*fasc. tectospinalis*) consists of descending axones from the cells of the quadrigemina. These terminate, after decussating, about the cells of the ventral horn. It correlates sensations of sight and hearing with body movements.

9. The **spinocephal tract** (*fasc. spinotectalis*) consists of ascending axones of the cells of the dorsal horn that decussate and then terminate about the cells of the corpora quadrigemina or tectum of the mesencephalon. Through this pathway general body movements may induce movements of the eyeball.

10. The **lateral vestibulospinal tract** is smaller than its ventral fellow and the axones arise from the cells of the nucleus of Deiter
of the area vestibularis, in the floor of the fourth ventricle. These fibers descend and represent the ventral part of the rubrospinal tract; they terminate around the ventral horn cells of the same side of the cervical and upper thoracic segments.

In the dorsal region are seen the following tracts:

1. **Fasciculus gracilis (column of Goll)** lies adjacent to the dorso-median septum and consists of *ascending* fibers that arise in the cells of the spinal ganglia (the axonic processes). These fibers end in the nucleus gracilis.

2. **Fasciculus cuneatus (column of Burdach)** lies peripheral to the preceding, and likewise consists of fibers (*ascending* axones derived from the cells of the spinal ganglia).

   As the fibers of both bundles enter the cord they branch into a shorter descending and long ascending branches. The longer ones have just been described. Most of the short ones soon end in the gray substance of the dorsal horns of the same side while the remainder cross to the opposite horn through the dorsal gray commissure.

3. The **comma tract of Schultze (fasc. interfascicularis)** occupies a position in the tract of Burdach at the boundary line with the tract of Goll. Its fibers are long *descending collaterals* that pass down three or four segments; these terminate around the ventral horn cells of the same and opposite sides and are thus concerned in reflex activities. Some may terminate around the dorsal horn cells. This tract also contains fibers derived from the dorsal ground bundle.

4. The **oval tract of Flechsig (fasc. cervicolumbalis)** situated along the dorsal septum, is another group of the *descending* fibers (collaterals) of the dorsal root fibers that pursue a long course. In addition there are many fibers derived from the dorsal ground bundle (*ascending and descending*). These are said to be the longest of the dorsal ground bundle fibers, extending more than half the length of the cord, probably even associating the conus medullaris with the cervical region (*lumbocervical tract*).

5. The **marginal tract, or tract of Spitzka, or Lissauer**, is located along the dorsal root or among its fibers. It consists of some of the axones of cells of the spinal ganglia, which traverse not more than three or four segments and end around the cells in the gliosa cornualis. Many of the axones are amyelinated and arise from the small cells
in the dorsal ganglia. It is sensor in function and is probably concerned with transmission of pain sense.

6. The septomarginal tract (Bruce) is also associative in function and lies along the dorsal septum. Its fibers ascend and descend, and some are derived from the dorsal ground bundle, crossing to cells of the opposite side of the spinal cord (commissural). Other fibers of this bundle represent collaterals of the dorsal root fibers that also cross to the opposite side of the cord. Both of these tracts are most distinct in the lumbar region of the cord.

7. The dorsal ground bundle (fasc. posterior proprius) lies next to the gray substance of the dorsal horn and consists of long and short fibers that ascend and descend; they are associative in function and are derived from the cells of the stratum zonale. The long fibers mainly pass into the oval and comma tracts.

The white commissure contains four sets of decussating and commissural fibers: 1, The decussating fibers of the ventral cerebrospinal fasciculus which decussate at various levels; 2, axones of the cells of one ventral horn passing to the opposite side to terminate about the cells of the ventral horn of the opposite side of the same level (commissural); 3, axones of cells of the ventral horn that form the ventral ground bundle that decussate to the other side and divide T-wise to pass up and down a distance before terminating in the ventral horn of this opposite side; 4, axones of the dorsal horn cells that decussate to form the spinothalamic, spinotectal, and spincerebellar tracts.

The dorsal columns are the most complex of the spinal cord. It will simplify them to consider the course of the fibers as they enter the dorsal horns.

1. Most of these fibers form the fasciculi cuneatus and gracilis; these fibers divide into ascending and descending branches. The former branches are of variable length, some ending soon in the gray of the dorsal horn and some ending in the same way at higher levels. Some of the ascending fibers of each spinal nerve continue to the oblongata and terminate round the cells of the nuclei cuneatus and gracilis. The descending fibers, that form the oval, comma and septomarginal tracts, terminate around the cells of the gray substance of the dorsal horns.
2. Some of the fibers after entering the dorsal root zone course along the medial side of the gray of the dorsal horn and then enter it to terminate about the cells of the same level. They are concerned in reflex actions.

3. Some fibers of the dorsal roots enter into the formation of the marginal tract and terminate around the cells of the substantia gelatinosa and perhaps around other cells of the ventral and dorsal horns.

The fiber tracts consist of extrinsic and intrinsic fibers. The extrinsic fibers are: (a) those that arise outside of the spinal cord and traverse it or end in it; (b) fibers that arise in the cord and pass out of it. Under (a) are the tracts of Goll and Burdach, the crossed and direct pyramidal tracts, the vestibulospinal, olivospinal, some of the mixed lateral and marginal tracts. The direct cerebellar and Gowers' tracts and parts of the mixed lateral tracts come under (b).
The intrinsic fibers are those that arise and end in the spinal cord as the three ground bundles.

The gray substance of the cord can be subdivided functionally into the following categories: (1) somato-motor; (2) viscero-motor; (3) viscero-sensor; (4) somato-sensor, as shown in Fig. 277. The course of the various components of the nerve-roots is likewise shown.

The spinal nerves consist of ventral, motor, or efferent, and dorsal, sensor, or afferent roots. Before these unite to form the nerve, a mass of gray substance is seen upon the dorsal root. This is the spinal ganglion. The fibers of the dorsal root are derived from the cells that lie in the ganglia, and where they enter the cord, a distinct depression is noted. The fibers peripheral to the ganglion represent myelinated dendrites and those that enter the dorsal root of the spinal cord represent the myelinated axones. Upon examining Fig. 277 it will be seen that the dorsal root is not purely sensor, but also contain viscero-motor fibers in some animals. The dorsal root contains quite a few amylated nerve fibers. According to Ranson these are pain fibers and are mostly for the cutaneous nerves. They probably terminate in the substantia gelatinosa Rolandi; here intercalated neurons conduct the impulse to then eurons in the dorsal horn proper. The axones from the latter cells form the ventral spinothalamic tract of the opposite side by immediate decussion. The ventral root is made up of fibers derived from the cells in the ventral horn, and where they emerge only a slight incurving of the surface is seen.

THE BRAIN

In order to consider the histology of the brain a brief and general description of its morphology will be first given.

The brain, or encephalon is the largest division of the central nerve system and is located in the cranial cavity. It is an ovoid mass of gray and white nerve tissue in which the white tissue predominates. Its weight is about 1400 grams in the male and 1200 grams in the female. At birth it weighs about 400 grams in the male and 380 grams in the female. By the end of the first year it has usually doubled its weight and by the end of the fourth or fifth years it is usually treble the weight at birth. It reaches its maximum weight
about the eighteenth or twentieth years. The weight of the brain depends upon age, sex, race, intelligence, body weight and skull form. Its dimensions are frontooccipitally 16 to 17 cm., height (ventral to dorsal surfaces) 12.5 cm. and laterally 13 to 14 cm.

**Fig. 278.—Diagram of the Ventral Surfaces of the Mid-brain and the Hind-brain. (Morris.)**

1. Optic nerve; 2. optic chiasma; 3. tuber cinereum; 4. corpus mammillare; 5. optic tract; 6. third nerve; 7. lateral geniculate body; 8. medial geniculate body; 9. fourth nerve; 10. fifth nerve; 11. sixth nerve; 12. seventh nerve; 13. eighth nerve; 14. ninth and tenth nerves; 15. twelfth nerve; 16. arcuate fibers; 17. lateral column; 18. decussation of pyramids; 19. infundibulum; 20. crus cerebri; 21. tractus peduncularis transversus; 22. posterior perforated space; 23. tænia pontis; 24. pons varolii; 25. fifth nerve; 26. flocculus; 27. biventral lobe; 28. cornucopia; 29. olivary body.

For convenience of description it is divided into *three divisions*, *cerebrum, cerebellum*, and *brain stem*. The parts will be described in order from the spinal cord end to the cerebral hemispheres. The **brain stem** comprises the oblongata, pons and its tegmental part and the mid-brain.
The oblongata (myelencephalon) measures about 25 cm. in length but the width varies; at the spinal cord extremity it is about 10 mm. in width and thickness while at the pontile end it measures about 17 to 18 mm. transversely and 15 mm. dorsoventrally. It represents a truncated cone that is flattened dorsoventrally. It is nearly vertical in direction and represents the connecting link between the spinal cord and the higher centers.

Upon its ventral surface is the ventromedian groove that is interrupted in part by the motor fibers that cross from one side to the other and form the pyramidal decussation. At each side of the groove is a tapering cylindrical mass called the pyramid; 90 per cent. of its fibers cross, as above mentioned, and the other 10 per cent. continue upon the same side for a variable distance into the spinal cord and then cross. The lateral area contains, near the pontile extremity, a small ovoid body about 12 mm. long called the olive. The remainder constitutes the lateral column which represents the continuation of some of the lateral tracts of the spinal cord (the dorsolateral cerebel-
lar, Gowers' and lateral ground bundle). The caudal end of the olive is crossed by the external (superficial) arcuate fibers. In the lateral area are seen the nerve roots of some of the cerebral nerves (hypoglossal, spinal accessory, vagal and glossopharyngeal). The dorsal area in its caudal portion, shows the dorsomedian groove which terminates above at the lower angle of the fourth ventricle. The latter is bounded upon each side by a club-shaped elevation, the nucleus gracilis lateral to which is the nucleus cuneatus. These two nuclei, on each side, are separated by a shallow groove, the intermediate sulcus. At the upper extremity of the nucleus is the tuberculum rolandi, an eminence that lies in the dorsolateral sulcus and causes that to fork at this point. The upper and median portion of the dorsal part of the oblongata is represented by the lower triangular portion of the fourth ventricle which is bounded upon each side by the restiform bodies that constitute the remainder of the dorsal area. These bodies consist of the fibers of the dorsolateral cerebellar tract (that enter them from the lateral columns of the oblongata) and the superficial and deep arcuate fibers.

THE PONS AND TEGMENTAL PORTION OF THE PONS

The pons represents the broad band of fibers seen upon the ventral part of the middle portion of the brain stem. It measures about 25 cm. from above downward and the lateral boundaries are indicated by the roots of the two trigeminal nerves. Beyond the roots the transverse fibers of the pons constitute the brachia pontis. These brachia constitute the lateral areas of the pons and the fibers continue into each cerebellar hemisphere. In the pons area are seen the auditory, facial, abducent and trigeminal nerves.

The tegmental part of the pons cannot be seen ventrally. It really represents a continuation of the oblongata and has been well called the preoblongata. If a knife be passed frontally just dorsal to the pons mass and this be lifted off then the tegmental portion, approximately, will be exposed. The dorsal surface of this part is the upper half, or triangle, of the fourth ventricle. This triangle is bounded laterally by the two overhanging, flattened masses of fibers that converge and form the apex of the triangle. These are the brachia conjunctiva. The so-called floor of the fourth ventricle is
a layer of gray nerve tissue in which are some of the nuclei of origin and termination of cerebral nerves. The real roof, or dorsal wall is represented by two thin membranes called the *superior* and *inferior medullary veli*, which consist of a layer of ependymal cells reinforced by the pia. In the inferior velum there is an opening called the *foramen of Majendie* and at the lateral angles of the fourth ventricle are small openings in the roof called the *foramina of Luschka*; at the sides of the ventricle are the *lateral recesses* that communicate with the subarachnoid space of the ventral surface. By means of these openings the cerebrospinal fluid within the ventricular system can pass out of the brain into the subarachnoid space and *vice versa*.

**THE MID-BRAIN**

The *mid-brain* (*mesencephalon*) is about 18 mm. in length and represents the upper portion of the brain stem. Upon its *ventral*
surface are seen two very large, whitish masses, of a cylindrical form, that diverge from each other. These are the crura cerebri (pedunculi cerebri). Each crus looks like a rope-like mass of white fibers that starts at the upper border of the pons, but at a more dorsal level, and then passes upward (frontally) and laterally into the cerebrum. Between these diverging crura is a triangular area called the interpeduncular space. From this the oculomotor nerves...
emerge. At each lateral area of the mid-brain are seen a part of the crus, the superior and inferior brachia. The dorsal surface of the mid-brain exhibits the corpora quadrigemina, or colliculi. These are four in number, two superior and two inferior. These are separated from one another by a longitudinal and a transverse furrow. The superior bodies are connected with eye muscle reflexes and the inferior are way-stations in the auditory pathway.

THE CEREBELLUM

The cerebellum lies in the posterior fossa of the skull and in man is completely covered by the occipital pole of the cerebrum. It weighs about 165 grams in the male and 155 grams in the female. It reaches its maximum weight between the twenty-fifth and thirty-fifth years. It represents an important coördinating center.

This structure consists of two lateral lobes, or hemispheres, and a middle lobe or the vermis. The lobes contain many fissures that have a transverse direction. The cerebellum is connected with the rest of the nerve system by three pairs of peduncles inferior, middle and superior. The inferior ones are the restiform bodies and serve to connect the cerebellum with the spinal cord, oblongata and cerebral nerve nuclei. The middle ones, the brachia pontis, are the largest and consist of fibers that mainly connect one cerebellar hemisphere with the other through the nuclei pontis. The superior peduncles are the brachia conjunctiva and serve to connect the cerebellar cortex with the mid-brain especially.

THE CEREBRUM

The cerebrum is the largest portion of the brain mass. It comprises the cerebral hemispheres, the corpora striata, the olfactory tracts and bulbs and these parts constitute the telencephalon. The thalami, optic chiasm, hypophysis, optic tracts and lateral geniculate bodies represent the diencephalon.

Ventrally are seen the corpora albicantia, or mammillary bodies, that are two, small whitish bodies one on each side of the inter-peduncular space. They are way-stations in the olfactory pathway. The tuber cinereum is a hollow conical structure just in front
of the preceding structures. To this the hypophysis is attached by a delicate stalk. This is a glandular structure that lies in the sella turcica of the sphenoid bone. The optic chiasm represents the convergence and decussation of some of the fibers of the optic nerves. These continue occipitally as two flattened bands called the optic tracts. The lateral geniculate bodies are small structures that represent way-stations in the optic pathway. Laterally and dorsally only the large cerebral hemispheres are to be seen. These constitute about six-sevenths of the brain and they are separated from each other in the midline by the median longitudinal fissure. Many fissures and sulci are seen upon the lateral and medial surfaces of each hemicerebrum. These tend to divide the surface into lobes and their subdivisions. The entire surface is made up of small folds called convolutions. At the bottom of the median longitudinal fissure is seen a broad band of white fibers that connects the two hemicerebri together. This is the callosum and it represents a commissure.

THE INTERNAL ANATOMY OF THE BRAIN

As was noted in connection with the histology of the spinal cord the gray nerve tissue was arranged in the form of an H-shaped, fluted column with the white nerve tissue completely surrounding it. At the lower part of the oblongata this relation is somewhat the same with alternations due to the motor and sensor decussations. The canal of the spinal cord continues into the lower portion of the oblongata gradually approaching the dorsal surface until it is finally exposed; it then spreads and constitutes the shallow fourth ventricle. This is formed by the failure of nerve elements to develop in the dorsal wall of the neural tube in this region and as all of these elements and fibers are developed laterally and especially ventrally the ventricle is superficially placed. In the lower part of the oblongata the gray nerve tissue continues in close relation with the canal and as this canal becomes exposed the gray nerve tissue is found forming the so-called floor of the ventricle and constitutes

1 The internal anatomy of the brain stem and the description of the various pathways are taken from Radasch’s “Manual of Anatomy” published by W. B. Saunders, Phila.
the ventricular gray substance. It is as though the cord had been split open along the dorsomedian septum and the two halves spread apart and the canal exposed as a diamond shaped fossa (fourth ventricle). As a result of this change the motor cells are still ventrally placed but mainly near the midline; the originally dorsal sensor cells have been moved to the lateral region of the floor of the ventricle.

As the fourth ventricle passes frontally into the aqueduct it is as though the slit cord had again been restored to its original condition and the gray nerve tissue again surrounds the entire canal; the ventral or floor gray represents the seat of cerebral nerve nuclei (chiefly motor), while the dorsal gray is sensor (connected with the optic and auditory nerves). It is to be remembered that all of the nerve cells ventral to a line drawn transversely through the spinal canal are motor and those cells that are dorsal to this line are sensor.

The motor cells of the brain stem do not form continuous columns as in the spinal cord but are grouped into three interrupted columns constituting the nuclei of origin of the cerebral nerves. The median (somatic) column represents the nuclei of origin of the hypoglossal, abducent trochlear and oculomotor nerves. The next column, somewhat lateral to the preceding, is the lateral somatic column and consists of the accessory, part of the vagal and the facial and trigeminal nuclei. The nerve fibers go to the voluntary muscles of the tongue, larynx and pharynx. The third, or splanchnic (visceromotor) column is located farthest from the midline of the motor columns. This consists of the glossopharyngeal, facial and part of the vagal nuclei. The cells of these last nuclei are concerned with the movements of the smooth muscles of the viscera and their axones pass to sympathetic ganglia. These cells represent the intermedio-lateral group of the spinal cord.

The sensor cells likewise form groups of cells and not a continuous column. These groups are more isolated and lie farthest from the mid-line. They represent the nuclei of termination of the nerve of ordinary and special sense. The olivary, arcuate and pontile nuclei represent connecting links between the cerebellum and the remainder of the nerve system.
THE OBLONGATA

The histology of the oblongata will be considered in three cross-sections in ascending levels, as at the motor and sensor decussations and the midolivary region.

Motor Decussation.—In the pontile extremity of the oblongata the motor fibers all lie in a compact bundle in the ventral portion; here they form the pyramid. In the spinal cord end, however, about 90 per cent. of the fibers cross from one side to the other in bundles that interrupt the ventromedian fissure. These represent the motor decussation. Sections of this level will show these fibers sweeping dorsolaterally from one side of the fissure through the substance of the oblongata to the dorsolateral regions where they form the crossed pyramidal tract of the spinal cord. The remaining fibers continue down upon the same side as the direct pyramidal tract of the cervical and upper thoracic levels of the spinal cord. Ultimately they cross
to the opposite side so that all of the fibers terminate upon the opposite side from which they originate in the cerebrum. The motor area of gray, represented by the ventral horn of the spinal cord, is thus cut into two portions: (a) the *isolated ventral mass* which is gradually pushed more laterally and is diminished in size at higher levels; (b) the *basal part* along the canal, that represents the motor gray of the floor of the fourth ventricle in higher levels.

Dorsally a change is also noticeable upon the peripheral part of the dorsal horn; here the *substantia gelatinosa* has become greatly increased and forms a projecting mass upon the lateral surface of the oblongata called the *tuberculum cinereum*. The remainder of the dorsal gray also shows alterations. Near the dorsal median septum an elongated aggregation of cells makes its appearance among the fibers of the funiculus gracilis and this is the *nucleus gracilis*. In this nucleus the fibers of this fasciculus terminate. As the nucleus increases in size higher up it produces the elevation upon the dorsal surface called the *clava*. A little lateral to this nucleus, and upon the dorsal horn, another collection appears. This is the *nucleus cuneatus* and as it increases in size it produces the elevation of the same name upon the dorsal surface. In this latter nucleus the fibers of the fasciculus cuneatus terminate. In the lateral portion of the section lie the *lateral columns* and these fiber tracts pass uninterruptedly into the cerebellum, quadrigemina and thalamus. They comprise the several spinocerebellar, spinothalamic, spinoptic, rubrospinal and vestibulospinal and converse tracts.

The **Sensor Decussation.**—This lies just cephalad of the motor decussation but is not evidenced upon the surface of the oblongata. The ventral area of the section shows the *two pyramids*, each a compact bundle at the side of the ventromedian groove. Dorsal to these are seen first, a thin flat band the beginning *lemniscus*, or *fillet* (*lemniscus medialis*) and dorsal to this the *decussating sensor fibers*. These fibers arise from the cells of the nuclei gracilis and cuneatus and cross over to the opposite side of the oblongata. Between these decussating fibers and the side of the canal lie the wedge-shaped remains of the filaments of the hypoglossal nerve sweeping ventrally close to the pyramid. Lateral to these fibers are seen the remains of the isolated portion of the ventral horn some-
what smaller than in the preceding section. In the dorsal half of the section, the gray substance has a peculiar arrangement. Near the mid-line is the slender nucleus gracilis and just lateral to this the more massive nucleus cuneatus and then the tuberculum cinereum. Superficial to the tuberculum are seen some nerve fibers and cells that represent the tractus spinalis nervi trigemini and nucleus tractus spinalis nervi trigemini. At this level practically all of the fibers of the fasciculi gracilis and cuneatus have terminated.

Between this and the next section the nuclei cuneatus and gracilis disappear, several new nuclear masses, olivary nuclei, appear; in addition a great mass of nerve fibers, the formatio reticularis appears between the canal and the lemnisci and raises the canal to a more dorsal level until it is practically exposed and forms the fourth ventricle.

Midolivary Level.—This section is markedly different. Upon each side of the ventromedian groove lies the large motor tract the
pyramids; these are covered superficially by some gray nerve tissue, the **arcuate nucleus**, and some nerve fibers, the **superficial arcuate fibers**. Of these arcuate fibers some arise from the nuclei gracilis and cuneatus of the same side and pass to the cerebellum; others arise from the nuclei of the opposite side, decussate in the raphé, course ventrally and pass over the surface of the pyramid. Many of these fibers are interrupted in the arcuate nuclei and then pass to the cerebellum by way of the restiform bodies.

Just dorsal to the pyramids lie the **medial lemnisci** forming quite a thick bundle of longitudinally coursing fibers. They are separated from each other by the median raphé which extends dorsally to the
ventricular gray substance. The raphé consists of a few nerve cells and fibers. Some of these fibers run longitudinally, others obliquely (the internal arcuate fibers) and still others course dorsoventrally (the external, or superficial arcuate fibers).

Dorsally between each lemniscus and the floor of the fourth ventricle, on each side of the raphé, is seen the formatio reticularis. This consists of bundles of nerve fibers that run longitudinally and transversely and some gray nerve tissue. The hypoglossal nerve divides this field into two parts. That which lies medial to the nerve is called the formatio reticularis alba, as it contains very few nerve cells; that lateral to the nerve is the formatio reticularis grisea, as it contains many nerve cells. The transverse fibers are chiefly internal (deep) arcuate and olivocerebellar while the longitudinal fibers are chiefly associative (short course) of the centers of respiration (nuclei of the facial, phrenic and vagal nerves) derived from the cells of the grisea. One especial group of longitudinal fibers just beneath the ventricular gray is called the median longitudinal fasciculus. This consists of longer association fibers that correspond to the ventral ground bundles of the spinal cord. They connect the various cerebral nerve nuclei together. The fibers just ventral to this bundle constitute the tectospinal tract.

Just dorsal to and a little to the side of the pyramid lies a crinkled mass of gray nerve tissue containing white fibers and surrounded by white fibers. This is the inferior olivary nucleus that produces the elevation upon the lateral surface of the oblongata called the olive. Its opening, called the hilus, is directed toward the raphé and of the fibers that leave and enter some pass to the olive of the opposite side while others pass to the cerebellum of the opposite side through the restiform body. Fibers of the converse course are also present. From the olive fibers also pass to the spinal cord and thalamus and vice versa. The dorsal and medial olivary nuclei are detached portions of the olive proper.

In the dorsal portion of this section is seen the fourth ventricle. The roof is thin and devoid of nerve tissue and constitutes the tela choroidea inferior. The floor consists of a layer of gray nerve tissue showing several aggregations of nerve cells, the nuclei of some of the cerebral nerves. On each side of the mid-line is the nucleus of the
The hypoglossal nerve. Just lateral to this lies a small group of cells, the nucleus intercalatus the function of which is not known. Lateral to this is one of the nuclei of the vagal nerve. That part of this nucleus nearest to the mid-line is motor (to the heart) and the lateral portion is sensor. In the lateral dorsal mass is seen a large group of fibers, the descending root of the auditory nerve; just beneath this are the nucleus and fasciculus solitarius. At the extreme dorsolateral portion is the restiform body. This structure contains the fibers of the direct spinocerebellar, cerebellospinal tracts of the spinal cord and the internal (deep) and external (superficial) arcuate fibers of the oblongata region. Beneath these structures is seen another nucleus of the vagus (the nucleus ambiguus) and fibers of the vagus. This nucleus probably represents the remains of the isolated portion of the ventral horn of lower levels. Near the side are seen the nucleus and fibers of the spinal root of the trigeminal nerve.

THE PONS AND PARS DORSALIS PONTIS

This portion practically represents a continuation of the oblongata with the pons added ventrally. Three sections, lower, middle and upper will be considered.

Lower Section.—The ventral portion of this section consists of a thick band of transversely coursing fibers (pars basalis pontis) and two large bundles of longitudinal fibers, the pyramids. The transverse fibers are more abundant in man than in any other animal and between the fibers are seen collections of nerve cells that are the nuclei pontis. Most of the fibers are ventral to the pyramids and they serve to connect the cerebellar hemispheres with each other. At the lateral boundaries of the pons these fibers collect into a compact bundle and enter the corresponding cerebellar hemisphere as the brachium pontis. Some of the pons fibers terminate around the cells of the nuclei pontis of the same side and others pass to the nuclei of the opposite side; new fibers then arise and go to the cerebellar hemispheres. Some of the cells of the nuclei pontis are also way-stations in the pathway of the cerebropontile fibers and new fibers arising here pass to the cerebellar hemispheres. The cerebropontile fibers have a longitudinal course.
In the area just dorsal to the pons fibers are the *pyramids*. Some of these longitudinal fibers terminate in the nuclei pontis and are the cerebropontile fibers. Dorsal to the pyramids are seen a variable number of *deeper transverse pontile fibers*. The arcuate nuclei and fibers of the oblongata are analogous to the pontile nuclei and fibers.

Dorsal to the pons lie the fibers of the *medial lemniscus* forming a rather compact bundle upon each side of the raphé. In higher levels these lemnisci diverge from the mid-line to make way for the trapezium.

**The Pars Dorsalis Pontis.**—The lemnisci separate the pons proper from the pars dorsalis (preoblongata). Dorsal to the outer side of the lemniscus is seen the *central segmental tract* and the *superior olivary nucleus* connected with the fibers of the trapezium (acoustic fibers). Between the superior olivary nucleus and the formatio reticularis lies a bundle of fibers (*trapezial*) that form the *trapezium* of the next level. This portion also shows the *formatio reticularis* on each side of the raphé with the *median longitudinal fasciculus* in the dorsal area; between the formatio reticularis and the cavity
of the ventricle is seen the *ventricular gray substance* in which certain cerebral nerve nuclei are seen.

Near the mid-line is seen the *nucleus incertus* (Streeter) that continues up to the aqueduct. To the side of this lies the *nucleus of the abducent nerve*; lateral to this the *principal vestibular nucleus* is noted and beneath the gray the *descending root of the vestibular nerve*; at the dorsal margin lies the upper end of the *restiform body*. Deeper ventral and over the superior olivary nucleus is the *nucleus of the facial nerve* while lateral thereto are some of the fibers of this nerve. Between the facial nerve and the restiform body are found the *substantia rolandi* and the *descending root of the trigeminal nerve*.

**Trigeminal Nerve Level.**—The ventral portion of this section shows the superficial and deep fibers of the pons embracing the two pyramids. At the sides the *brachia pontis* are present. At the junction of the pons with the tegmental portion the *medial lemnisci* have been pushed to the side and replaced by the *trapezium*, a set of transverse fibers (decussating) interspersed with nerve cells (the *trapezial nucleus*). These fibers arise from the ventral and some from the dorsal cochlear nuclei of the floor of the fourth ventricle and pass to the trapezium where some of the fibers terminate in the nucleus trapezoideus of the same or opposite side while some terminate in the olivary nuclei of the same or opposite side. The new fibers from the cells then cross to the opposite side (if the preceding have not) making the decussation complete; these fibers are then joined by new fibers from the cell of the opposite side and form the *lateral lemniscus*. The trapezium and lateral lemniscus are parts of the auditory pathway. Between the trapezium and the lateral surface of the section are seen the *superior olivary nucleus*, the *fibers of the motor root of the trigeminal nerve*, while more ventral are the *brachium pontis* and the *sensor root of the trigeminal nerve*. Near the surface lies the sensor root of the latter nerve.

Dorsal to the trapezium and in the midline is the *raphé* with the *formatio reticularis* forming a large field upon each side. Lateral to the formatio reticularis is the *motor nucleus of the trigeminal nerve* and upon the surface is the *superior cerebellar peduncle* (*brachium conjunctivum*) forming also the dorsal wall of this section. The peduncle is semilunar in shape, on section, and consists chiefly of
fibers from the cells of the dentate nucleus of the cerebellum while the remainder are probably from the cerebellar cortex of the opposite side, decussating to reach this side. These fibers pass chiefly to the red nucleus of the mid-brain, but some continue to the thalamus.

In the dorsal portion of this section the fourth ventricle is seen becoming narrower and is roofed by the valvula, or anterior medullary velum. Beneath the ventricular gray and near the midline is the median longitudinal fasciculus.

The Upper Level.—A section through this part is smaller and more compact. In the ventral area the pyramids are separated into small bundles by the transverse pontile fibers. The trigeminal nerve is seen at the side of the field. The tegmentum shows changes. In the midline and dorsal to the pons fibers the decussating fibers of the brachia conjunctiva replace the trapezium and the somewhat flattened medial lemniscus is seen at the side of the section. The formatio reticularis lies just dorsal to the decussating fibers and laterally is the deeply placed brachium conjunctivum, covered by the flattened band-

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**Fig. 286.—Section of the Pons at the Level of the Origin of the Trigeminal Nerve. (Radasch, "Manual of Anatomy.")**
like lateral lemniscus. In the lateral lemniscus are some nerve cells that constitute the nucleus to this tract and probably represent a continuation of the superior olivary nuleus. In this nucleus some of the fibers (from the ventral cochlear nucleus) terminate and new ones arise from the cells of the nucleus and continue in this tract to end in the inferior quadrigememinum and medial geniculate body and possibly in the superior quadrigememinum. The dorsal median area of the formatio reticularis is occupied by the median longitudinal fasciculus. Dorsal to this area is the ventricular gray substance. In this section the fourth ventricle is small and entirely roofed over by the valvula which contains a little nerve tissue. At the lateral boundary of the ventricular gray is seen the mesencephalic root of the trigeminal nerve.

THE MID-BRAIN

Two sections, one through the inferior and the other through the superior quadrigemina, will be described here.

**Inferior Quadrigeminal Level (Postgeminal).—** This shows a great change over the preceding section. In the ventral area are seen the two crura cerebri separated by the interpeduncular space. Each crus consists of a ventral area, the crus (basis pedunculi), containing only motor fibers in three groups: (a) the lateral one-fifth consists of fibers from the cortex of the temporal lobe to the nuclei pontis and they constitute the temporopontile tract; (b) the middle three-fifths consists of the fibers from the pyramidal cells of the motor area of the frontal lobe passing to the cerebral nerve nuclei and to the spinal cord, constituting the pyramidal tract previously mentioned; (c) the medial one-fifth consists of fibers from the cells of the frontal lobe passing to the nuclei pontis and these constitute the frontopontile tract. Dorsally the crus is bounded by a crescentic mass of pigmented gray substance called the substantia nigra. This separates the tegmentum from the crus; the cells send their axones in various directions but their function is unknown. The substantia nigra extends throughout the mid-brain. The tegmentum consists of transverse and longitudinal fibers with collections of nerve cells here and there. It represents a continuation of the tegmental portion of the pons. In the midline is seen the raphé and at the side, above the substantia
nigra, lies each *brachium conjunctivum* completing its decussation. Lateral to this is the *medial lemniscus*. Dorsal to the brachium, near the midline, is seen the *median longitudinal fasciculus*, while near the surface is located the *lateral lemniscus* covered by the inferior brachium. Dorsal to the raphé is the *aqueduct gray substance*, containing a small canal, the *iter*, or *aqueduct* (*aqueductus cerebri*). The gray substance surrounds the canal completely; in its floor and resting upon the median longitudinal fasciculus, is a collection of nerve cells, the *nucleus of the trochlear nerve*. At the side of the gray is the *mesencephalic root of the trigeminal nerve*. Dorsal to the aqueduct, on each side of the midline, is a rounded mass of gray nerve tissue covered by white fibers, the *inferior quadrigeminal body* (*colliculus inferior*). The nucleus of each body is separated from the aqueduct gray by the stratum lemnisci. This nucleus receives fibers from the lateral lemniscus. It represents a way-station in the auditory pathway and its cells send fibers to the thalamus.

**Superior Quadrigeminal Level (Pregeminal).**—At this level the substantia nigra and crusta are practically unchanged. Medially, at the junction of the crusta with the tegmentum, is the *oculomotor sulcus* from which the oculomotor nerve emerges. Near the midline of the tegmentum there is a large reddish collection of nerve cells called the *red nucleus*. This is circular in outline and receives fibers

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**Fig. 287.**—Transverse Section of the Mid-brain through the Inferior Quadrigeminal Bodies. (*Radasch, "Manual of Anatomy."*)
from the cerebral cortex, corpus striatum and cerebellar cortex (through the brachium conjunctivum): most of the fibers of the latter structure terminate here. From its cells fibers pass to the thalamus and cerebral cortex and to the spinal cord as the rubrospinal tract. These latter fibers decussate almost immediately and pass down the opposite tegmentum.

At the side of the red nucleus lies the *medial lemniscus* and it is smaller as many of its fibers terminate in the superior quadrigeminal body; the remainder pass to the thalamus and are a part of the general sensor pathway. At the side of the lemniscus lies the *inferior brachium*. Between the two red nuclei lies the *fountain decussation*. These decussating fibers are derived from the superior quadrigeminal bodies and cells of the aqueduct gray, cross the midline and join the median longitudinal fasciculus and pass to the nuclei for the nerves of the eye muscles and to the spinal centers for movements of the head and neck.

The *median longitudinal fasciculus* occupies, relatively, the same position as in preceding sections. Its fibers are associated in function with regard to many cerebral and spinal nerve centers and it is analogous to the ventral ground bundles of the spinal cord. It especially connects the quadrigemina and the sensor cerebral nerve nuclei with the oculomotor, trochlear, abducent and facial nerves. A *special nucleus* is located in the floor of the third ventricle at its

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![Fig. 288.—Transverse Section of the Mid-brain through the Superior Quadrigeminal Bodies. (Radasch, "Manual of Anatomy.")]
junction with the aqueduct. The fibers of the cells from this nucleus decussate immediately and cross to the opposite side through the posterior commissure.

In the dorsal part of the section are the aqueduct and the aqueduct gray which surrounds this canal. In the ventral part of the gray is the nucleus for the oculomotor nerve. Dorsal to the gray are the two superior quadrigeminal bodies (colliculi superiores). Each body consists of four layers of alternating white and gray nerve tissues. The white layers represent the fibers of the optic tract and some from the occipital cortex. Other fibers enter from the lateral and medial lemnisci representing a part of the acoustico-optic reflex pathway.

THE CEREBELLUM

The cerebellum, or little brain has a characteristic gross appearance when sectioned. Most of the gray substance is externally located while the white substance is internal. The gray constitutes the cortex and the white is the medulla. As the main fissures and sulci run transversely the cut edge of the cerebellum shows a peculiar arborescent appearance; this is called the arbor vitae cerebelli. In the hemispheres the white tissue predominates while in the vermis the gray is more abundant. There are four buried masses of gray nerve tissue in the white and these are the nuclei dentatus, fastigii, embolis and globosus. The nucleus dentatus is the largest and most important and lies in the medulla of the lateral hemisphere. It is a crinkled mass of gray substance containing white fibers that enter and emerge by the hilus. This nucleus is important in the indirect motor pathway.

The cortex consists of three sharply marked layers, the (1) molecular, the (2) ganglionic and (3) granule layers, from without inward.

1. The molecular layer consists of a network of neuroglia, in which the dendritic branches of the cells of the lower layers are found. They are mostly those of the ganglionic cells. These dendrites form a dense meshwork of fibrils the smaller ones of which show gemmules while the larger branches are smooth. In this network there are also some collaterals from the axones of the Purkinjé
cells that seem to terminate in little knobs upon the cell bodies of neighboring Purkinje cells. There are also a few small and large multipolar cells in the molecular layer. The smaller cells are more numerous in the superficial portion of the layer and are somewhat stellate in form with two to five slender dendrites. These divide into telodendrites that form part of the meshwork of the molecular layer. The axones are short, run a horizontal course and they, with
their collaterals, terminate in the outer part of this layer. The large stellate cells are more deeply placed. The dendrites are short and terminate among those of the Purkinje cells. The axones are rather long, run a horizontal course and give off five or six collaterals that with the terminal portion of the axone pass to the second layer and each division forms a series of delicate branches around the body of a Purkinje cell in the form of a basket, hence the name basket cells. These are synapses and the basket cells are association neurons. The axones of the cells of the granule layer all terminate in the molecular layer contributing to the arborization there.

1. The ganglionic layer, or layer of Purkinje cells is characteristic of the cerebellum. The bodies of these cells are very large, measuring 30 to 70 microns in diameter. The cytoplasm is fibrillar but contains no pigment granules. The nucleus is large, stains fairly well and the nucleolus is prominent and darkly staining. Two main processes extend from the body so these cells are of the bipolar type. The short heavy dendrite passes toward the molecular layer and quickly divides into two main divisions; these rapidly divide and redevide forming a dense network of fibrils that extends straight upward and laterally to the surface of the molecular layer. This network is peculiar in that it is tall and broad but not thicker than the diameter of the cell body. The appearance is more that of a line of hedge than a tree. The axones pass at a right angle to the body and enter the granule layer, where they become myelinated, and continue into the medulla of which they form a considerable part. Numerous axonic collaterals are given off and these return to the molecular layer where they terminate around the bodies of neighboring Purkinje cells. These cells are more numerous at the tops than at the bottoms of the convolutions.

Three kinds of axones terminate in relation with the cells of Purkinje: (1) those of some of the granule cells that end in relation with its dendrites; (2) those of the basket cells that terminate in a network around the cell body; (3) those of the climbing fibers the branches of which wind around all of the dendritic branches except the terminal ones.

2. The granule layer consists of a broad zone of small and large granule, stellate cells and solitary cells. The small granule cells are
the smallest nucleated elements in the body measuring as low as 4 microns in diameter. The axones of the granule cells are amyelinated and pass into the molecular layer where they branch T-like. These branches run parallel to the surface between the dendrites of the Purkinjé cells and are said to end in varicosities. The dendrites are short and remain in the granule layer where they terminate in fine branches around the eosin bodies. The latter are small masses of protoplasm, containing fine eosinophilic granules, and are supposed to represent synapses between the terminal teloneurites of the mossy fibers that come from the medulla and the teloden-

**Fig. 290.—Cross-section of a Fold of the Cerebellum (Semidiagrammatic).**

(From Bailey after Cajal.)

A, Molecular layer; B, Granule layer; C, Medulla; a, Purkinjé cell; b, basket cells forming investment synapses of the Purkinjé cells at d; e, stellate cells; f, Golgi cell; g, granule cells; i, dendrites of granule cells; h, mossy fibers; j, m, glial cells; n, climbing fibers.
drites of the granule cells. The large number of small cells and the large number of darkly staining nuclei give this layer its granular appearance and name.

The *large stellate cells* are few in number and are found mainly near the Purkinje cells. These are cells of the second type (Golgi); the axones are short, collaterals numerous and these terminate around the granule cells. The dendrites are numerous and pass to the molecular layer.

![Diagram of a section of the cerebellum](image)

**Fig. 291.—Diagram of a Section of the Cerebellum Lengthwise of the Transverse Convolutions. Golgi’s Method. (Koelliker.)**

*gr.* Cells of the granular stratum; *n*, their neuraxons in the granular layer and *n’,* in the gray stratum; *p, p’,* Purkinje cells. *(From Bailey’s “Histology.”)*

The *solitary cells* are some small, spindle-shaped cells the function of which is not known.

The granule layer is also thicker at the tops of the convolutions, diminishing as the base is reached.

In addition to the above structures and the neuroglia there are the *mossy* and *climbing fibers* in the cortex of the cerebellum. These represent the *afferent fibers* from the brain stem and spinal cord and they terminate in the cortex. The *mossy fibers* are very coarse fibers that branch in the medulla; these branches pass to different folds, or lamellae. Within the granule layer the branches divide,
become amelinated and terminate in a number of short teloneurites that pass to the eosin bodies and end in relation with the dendritic branches of the granule cells. These branches may present varicosities. The *climbing fibers* are also afferent fibers that enter the granule layer; they become amelinated and branch profusely and near the body of the Purkinjé cells these branches wind about those of the dendrites like a vine. They are thus in relation with all but the terminal telodendrites of the Purkinjé cells. These fibers come from the pons.

The **medulla** consists of myelinated nerve fibers supported by neuroglia and some white fibrous connective tissue. The fibers are *centrifugal* and *centripetal*. The *former* represent the myelinated axones of the Purkinjé cells that pass from the cortex to the various nuclei of the cerebellum but not out of the cerebellum directly. The *centripetal* fibers are those that come into the cerebellum from outside sources and represent the fibers from the spinal cord and brain stem; these are the mossy and climbing fibers mentioned as terminating in the cortex.

The **glial tissue** is considerable in quantity in both cortex and medulla. The glial fibers form a meshwork for the support of the nerve cells and processes and the nerve fibers. In the cortex the mossy cells predominate while the medulla contains only the spider type. The extreme superficial portion of the molecular layer possesses no nerve cells and very few processes and here the neuroglia forms a rather dense *marginal layer*.

### THE CEREBRUM

Besides the **cerebrum**, there are other masses of nerve tissue to be considered here. These are the **olfactory lobes**, the **pituitary** and **pineal bodies**.

The **gray substance**, or **cortex** of the **cerebrum**, is divided into layers that are not sharply limited from one another. In some regions, five can be made out, on others three, while four form the average number. In the occipital lobes eight layers can be demonstrated. The **cortex** is made irregular by the formation of fissures and convolutions. The latter consist of a central mass of white substance, **medulla**, covered by the gray substance, or **cortex**.
The cortical layers of the motor area are, from without inward: (1) molecular, (2) outer polymorphous, (3) small pyramidal, (4) large pyramidal, (5) inner polymorphous layers.

1. The molecular layer consists chiefly of neuroglia and cell processes; the latter are chiefly dendrites derived from the deeper layers. The neuroglia forms a meshwork within which these
dendrites form networks tangential with the surface so that this layer is sometimes called the layer of tangential fibers. The cellular elements are few in number and of the second type and represent cells of the next layer that have entered the molecular layer. Their processes all remain in the molecular layer. Peripherally the neuroglia forms a rather dense layer as in the cerebellum.

2. The outer polymorphous layer consists of a narrow band of irregular cells that may be collected in small groups. These cells are polygonal, stellate and spindle-shaped and of the second type. The axones remain in the gray substance and the dendrites pass to the molecular layer where they form the tangential fibers. These cells are best developed in the hippocampal gyre (olfactory area) and are sometimes called the cells of Cajal.

3. The layer of small pyramidal cells is composed of several layers of cells, apical dendrites of which extend into the molecular layer while the other dendrites remain in this layer. Some of the axis cylinders partially pass to the molecular layer (second type) and others pass into the medulla (first type, or Deiter cell). In the latter case, the axis cylinders give off branches called collaterals. The cells themselves are small, measuring 10 to 12 microns in diameter, and triangular in outline. The dendrites arise from the angles, while the axis cylinder or neurit, has its origin at the middle of the base.

4. The layer of large pyramidal cells constitutes the widest and most important layer. The cells are usually 20 to 50 microns in diameter, though some may exceed this. The dendrites pass to the molecular layer, while the neurit becomes myelinated nerve fiber. These cells are, therefore, cells of the first type. Their outline is triangular, and the nucleus is large and prominent. This layer is usually as broad as all the others together.

Among the cells of this layer there are groups of very large pyramidal cells called the giant cells of Betz; some of these may also be in the small pyramidal cell layer. These are cells of the first type and their myelinated axones pass into the medulla and later form the pyramidal tract (fasc. cerebropinalis). This constitutes the pyramid of the pons and all oblongatal regions and the direct and crossed pyramidal tracts of the spinal cord. It is a part of the direct motor
FIG. 293.—Diagram of the Cerebral Cortex.

The cells on the right are drawn from Golgi preparations of an adult man.  (Lewis and Stöhr.)
pathway and is concerned with the movements of the voluntary striated muscles of the body.

5. The **inner polymorphous layer** is fairly broad and consists of cells of various shapes. These are small and large pyramidal, spindle-shaped, oval, polygonal and granule cells. The **polygonal cells** seem to predominate. The **granule cells** are small and resemble those of the cerebellum. The other cells are somewhat larger than the average cells of the small pyramidal layer. Most of the dendrites of these cells pass to the molecular layer while the others remain in this layer. The axones are of two types; some pass through the white for a short distance to the neighboring convolutions and these are the **association fibers**; others also become myelinated and enter the medulla and these are the **projection fibers** that pass to distant parts of the nerve system. These cells are of the first type.

The **cells of Martinotti** are second type cells that are found in all of the layers but are most numerous in the inner polymorphous layer. These are small polymorphous elements the axones of which pass to the molecular layer and assist in forming the tangential fibers.

In the last three layers, bundles of myelinated nerve fibers having a radial course are seen. They begin in the small pyramidal layer, increase in number as they approach the medulla, and contain, beside those fibers derived from the immediate cortical cells, others whose origin is not definite.

In addition there are other myelinated nerve fibers that form layers practically parallel with the surface. The **striation of Baillarger** is composed of such fibers that lie in the large pyramidal cell layer. The **striation of Bechtereff** consists of myelinated fibers between molecular and small pyramidal cell layers. These represent afferent fibers and are best marked in the temporal and occipital lobes (olfactory and visual areas).

The **cortex of the occipital lobe** (**cuneus** or **visual area**) consists of eight layers and these are: (1) molecular, (2) outer polymorphous, (3) small pyramidal cell, (4) large pyramidal cell, (5) outer striation of Baillarger, (6) granule cell, (7) inner striation of Baillarger, (8) inner polymorphous layers.

The layers of pyramidal cells are quite thin and the giant cells of Betz are absent. The granule cells are numerous in the outer layers
and so may almost prevent a separation into layers in that part of the cortex. The striations of Baillarger are very distinct and the tangential fibers are well developed. Some very large multipolar cells called the solitary cells of Meynert occur within the last two layers.

The medulla consists of myelinated nerve fibers from various sources; those that pass to the periphery of the body from the pyramidal and polymorphous cells (projection fibers); others from the pyramidal cells that pass from one hemisphere to the other (commissural fibers); those that connect different areas of the same side (pyramidal cells), and whose axis cylinders are "T"-branched, and pass into the cortex sooner or later (association fibers); lastly, fibers that come from distant parts of the same or the other hemisphere, or other parts of the nerve system (centripetal fibers).

The various pathways will now be considered.

The Direct Motor Pathway.—This comprises but two neurons. The parts concerned are the two pyramidal tracts and the motor portions of the cerebral and spinal nerves.

The pyramidal tract of each side consists of efferent fibers that arise from the large and small pyramidal cells of the motor area of the cerebral cortex. They pass down through the corona radiata into the internal capsule occupying the middle portion thereof; they enter the crista of the crus cerebri (middle three fifths) then the tegmentum of the pons and the ventral area of the oblongata; in these three regions some of its fibers pass to the cerebral nerve nuclei of origin. At the caudal end of the oblongata 85 to 90 per cent. of the fibers decussate to the opposite side of the spinal cord as the crossed pyramidal tract and then end at various levels around the cells of the ventral horn. The remaining fibers continue down the same side of the spinal cord, as the direct pyramidal tract, to various levels in the cervical and upper thoracic region and then pass through the ventral, or white commissure, to end in the ventral horn of the opposite side. Ultimately all fibers decussate before they end. This ends the first neuron. The second neuron comprises the cells of the ventral horn and their processes that form the motor root of the spinal nerves, on the one hand, and in the case of the cerebral nerves comprises the cells of the various nuclei of origin and their processes that form the motor portion of the cerebral nerves. These axones pass out of the
gray substance, become myelinated and ultimately end directly in a voluntary striated muscle fiber. This is the end of the second neuron.

**Fig. 294.**—Diagram of the Neurons in the Direct and Indirect Motor Pathways and the Connections of the Cerebellum with the Brain Stem and the Spinal Cord.

Direct.—Neuron 1, A to B; neuron 2, B to C. Indirect.—Neuron 1, A (cerebral cortex) to D; 2, D to E; 3, E to F; 4, F to g; 5, g to B; 6, B to C. (Radasch, "Manual of Anatomy.")

*First neuron,* a pyramidal cell in the motor cortex of the cerebrum and its axone that forms a part of the pyramidal tract and that
ends in a cerebral nerve nucleus, or the ventral gray of the spinal cord.

Second neuron, the cell in the nucleus of origin or in the ventral gray of the spinal cord, and its axone that ends in a voluntary striated muscle fiber.

The Indirect Motor Pathway.—This is more complex and comprises six neurons. First, from the motor area of the cerebrum (say right side) through the pyramidal tract, as above, to the nuclei pontis of the same side (right); second, from the nuclei pontis through the branchium pontis to the cerebellar cortex of the opposite (left) side; third, from the cerebellar cortex to the dentate nucleus of the cerebellum of the same (left) side; fourth, from the dentate nucleus through the brachium conjunctivum to the red nucleus of the opposite (right) side; fifth, from the red nucleus of that side through the rubrospinal tract to the cerebral nerve nucleus, or ventral horn of the spinal cord of the opposite (left) side. The fibers of the rubrospinal tract cross to the opposite side almost immediately after leaving the red nucleus. Sixth, from the cerebral nerve nucleus, or the ventral horn gray to the voluntary striated muscle fiber. As seen above there are three crossings, or decussations, the next to the last neuron terminating upon the opposite side of the body.

The Direct Sensor Pathway.—In the trunk the impulses arise at the periphery and are conveyed by the sensor spinal nerves to the ganglia on the dorsal roots. From there they are conveyed into the dorsal column of the spinal cord to end in the nuclei gracilis and cuneatus of the oblongata of the same side. Some collaterals are sent into the dorsal horn gray. New fibers arise in the nuclei cuneatus and gracilis and immediately cross, or decussate to the opposite side, forming the sensor decussation, that lies just above, or cephalad of the motor (pyramidal) decussation. These decussated fibers form the medial lemniscus that continues through the oblongata, pons and mid-brain to end in the thalamus of that side. From the thalamus new fibers convey the impulses through the internal capsule (occipital limb) to the somatic sensor area of the cerebral cortex (postcentral gyre). In this pathway three neurons are required, the first, from the surface to the nuclei gracilis, or cuneatus (the cell body lying in the dorsal ganglion); the second, from these nuclei to the
thalamus; and the third, from the thalamus to the cerebral cortex. This is the pathway of conscious muscle sense.

Pathway for Touch, Temperature and Pain.—In the trunk and extremities, the first neuron cells lie in the ganglia of the dorsal roots.
of the spinal nerves. The peripheral fibers (dendrites) bring the impulses from the periphery (organ or skin) and it is then conveyed by the axone into the spinal cord through the dorsal root; the axones end in the gray substance of the dorsal horn. The second neuron cells lie here and their axones cross through the ventral gray commissure to the opposite side and form the spinothalamic tract in the spinal cord and in the oblongata they join the medial lemniscus to end in

Fig. 296.—Diagram of the Various Tracts of the Spinal Cord and Their Origin or Termination. (Radasch, "Manual of Anatomy.")

the thalamus. The third neuron cells lie in the thalamus and the axones pass through the internal capsule (sensor limb) to the cortical area of somatic sensibility (postcentral gyre). Some of the impulses of touch and contact sensibility are conveyed through the dorsal column of the spinal cord (same side) to the nuclei cuneatus and gracilis. The new fibers from these nuclei decussate and join the opposite medial lemniscus to end in the thalamus of that side; thus some of the sensibility fibers cross in the spinal cord at their entrance and others do not cross until the above nuclei have been reached.
In the head most of the impulses are conducted to the nuclei of the trigeminal, glossopharyngeal and vagal nerves of each side to the ganglia of the sensor divisions; then they are conducted to the nuclei of termination of these nerves, in the fourth ventricle. This course constitutes the first neuron. The second neurons connect these nuclei with the thalamus by way of the medial lemniscus. The third neurons connect the thalamus with the cerebral cortex as above.

The muscle sense (deep sensibility) impulses of the trunk and extremities are conveyed as follows: The first neuron connects the periphery with the spinal cord where some of the fibers continue on the same side through the dorsal column to the nuclei cuneatus and gracilis. From here the fibers of the second neuron convey the impulses by way of the opposite medial lemniscus to the thalamus. The third neuron connects the thalamus with the cortical area.
Some fibers pass from the nuclei gracilis and cuneatus to the cerebellar cortex; new fibers pass from here to the dentate nucleus of the cerebellum from which new fibers pass to the thalamus through the brachia conjunctiva.

Some of the fibers, only, of the first neuron, have the above course. Others, after entering the dorsal roots of the spinal nerves, do not enter the dorsal column but join the spinocerebellar tracts (ventral and dorsal superficial) to end in the cerebellar cortex of the same side. The impulses are then carried to the dentate nucleus and from here through the branchium conjunctivum to the opposite thalamus; from the thalamus the impulses are conveyed to the cerebral cortex.

Respiration.—Although respiration is apparently controlled by the respiratory nucleus that lies in the formatio reticularis of the oblongata, it is maintained by stimuli carried to this center by the blood vascular system and reflex impulses from the sensor portion of the vagus through cells in the nucleus of termination of the vagal nerve and by impulses from the higher respiratory centers. The respiratory nucleus is connected with the following motor nuclei: Facial, vagal, accessory, cervical plexus, phrenic, brachial plexus and thoracic nerves. Axones from the higher centers and from the sensor vagal nucleus end in the respiratory nucleus. The cells of the respiratory nucleus send their axones directly, or by means of collaterals, in the formatio reticularis, to the nuclei of the above-mentioned motor nerves so that through this connection a number of cerebral and spinal nerves are caused to act.

OLFACTORY LOBE

The olfactory lobe, that portion of the nerve system devoted to the sense of smell, is comparatively small in man. There are five layers present, which are best marked in the central part of the organ. These are the layer of peripheral fibers, the glomerular layer, the molecular layer, the layer of mitral cells and the granule layer.

The layer of peripheral fibers consists of a plexus formed by the fibers of the olfactory nerves. These fibers are the axone processes of the nerve cells (olfactory cells) of the olfactory mucosa and are on their way to the next layer.
The **glomerular layer** lies internal to the above, and is made up of peculiar round, or oval, bodies 100 to 300 microns in diameter. They are said to be masses of *interlacing telodendria* of the olfactory and mitral cells. In addition there are some Golgi cells (periganglion cells). This layer constitutes the end of neuron I and the beginning of neuron II of the olfactory pathway.

The **molecular layer** is made up of large and small spindle-shaped ganglion cells whose dendrites end in the glomeruli; the axis cylin-

![Diagram of the Olfactory Bulb and the Cells of the Olfactory Mucosa.](image)

- **C.** Olfactory cells; **N.F.**, layer of peripheral nerve fibers; **Gl.**, glomerular layer; **M.**, layer of mitral cells; **Gr.**, granular layer through which the axones of the mitral cells pass to the olfactory tract giving off collaterals to the bulb; **a**, afferent nerve fiber terminating in the olfactory bulb. (After Schäfer.)

...orders of the small cells (Golgi cells) pass to the **fifth or granule layer** and these cells are associative in function. The axones of the large (*brush*) cells pass to and through the granule layer to continue as a part of the olfactory tract with the fibers from the mitral cells. Both of these sets of axones represent neuron II.

The **layer of mitral cells** consists mainly of large **pyramidal** cells varying in size from 30 to 50 microns. Their dendrites pass to the glomeruli and the axis cylinders through the granule layer to the olfactory tract to end ultimately in the brain. Also neuron II.
The **granule layer** consists of *nerve cells* and *fibers*. The cells are stellate, ganglion elements, and peculiar granule cells; the *latter* appear to have no axis cylinders (amakrine cells). Some of the nerve fibers are derived from the mitral cells, some from the molecular layer, and others from the outside. The deeper bundles enclose granule and stellate cells.

**THE HYPOPHYSIS**

The **hypophysis**, or **pituitary body**, is a small organ that lies in the sella turcica of the sphenoid bone and is connected to the infundib-
the cytoplasm contains coarse granules but the nuceli are the same. On the one hand the granules respond to the *plasmatic stains* and on the other to the *basic stains*, hence acidophilic and basophilic cells. The latter are the more numerous. A small lumen may be noted within the cell groups. The capillaries are in close relation with the

![Figure 300](image)

**Fig. 300.—Section of the Epithelial Lobe of the Hypophysis.**
The large dark cells are the *basophils*; The large lighter cells are the *acidophils*; the smaller light cells are the *clear cells*. (Photograph Obj. 4 mm., oc. 5 ×.)

epithelial cells as in other glands of internal secretion. The *nerves* of this lobe consist of a very few fibers with numerous branchlets and ramifications that follow the arteries and are distributed mainly to the epithelial cells. Here they terminate in ball-like enlargements.

The *pars intermedia* occupies the interval that is represented by a cleft between the two main lobes, in lower animals. The epithelial cells are smaller and less granular. The cells of its anterior area
are flattened while those of its posterior area are columnar in shape. Various-sized masses of colloid, or hyalin material are found here. This is not true colloid substance as is formed in the thyreoid body as it contains no iodin. It is derived from the cells of the pars intermedia and like the cytoplasm of these cells it contains glycogen.

The pars nervosa consists chiefly of neuroglia and a few nerve fibers that terminate in the epithelial portions. The glial cells may contain pigment that is of a lipoid nature. Hyalin substance is found in this lobe most abundant near the pars intermedia. It may extend into the infundibular cavity on its way to the third ventricle. This hyalin substance comes from the pars intermedia and seems to be sent to the cerebrospinal fluid via the third ventricle.

The arteries reach the organ by means of the infundibulum. As they reach the pars intermedia branches pass to the pars anterior and form plexuses around the cell groups. The capillaries are most numerous in the pars anterior and are of the sinusoidal type. The veins have a corresponding course.

The lymph spaces are numerous. In the pars anterior they surround the epithelial cells and lead to the subarachnoid space and the perivascular lymph spaces of the base of the brain. As mentioned previously the lymph spaces of the pars nervosa and intermedia seem to communicate with the third ventricle.

The anterior and posterior lobes are supposed to have different functions. Extract from the posterior portion, when injected, seems to stimulate smooth muscle, especially that of the uterus and blood-vessels; this is accompanied by increased excretion of urine and by an increase of blood pressure. Reduced secretion from the posterior lobe results in the active deposition of fat and excessive sugar metabolism. Increased secretion may cause emaciation and mental disturbances. The anterior lobe seems to control skeletal development, excessive secretion resulting in gigantism and acromegaly while reduced secretion results in dwarfs and infantile types.

THE EPIPHYSIS

The epiphysis, or pineal body, is a small, apparently unimportant organ in man. In some lower animals, it is a visual organ. This rudimentary structure consists of a number of tubules lined by
polygonal cells supported by fibrous tissue and neuroglia in the lower part.

The organ is surrounded by a capsule of areolar tissue derived from the pia. Trabeculae pass into the organ and divide it incompletely into lobules; these trabeculae also give rise to the reticulum that supports the blood-vessels and the functionating epithelium. Neuroglia is abundant, the glial cells forming one of the cellular elements of the organ. The glial fibers are interlaced with the reticulum fibers. The glial cells are stellate, or spindle-shaped and their nuclei are long and stain deeply. The epithelial cells are rather large and oval, or polygonal in shape with a large pale vesicular nucleus. Pigment granules may be present in old age and these occur in groups between the cells. The epithelial cells may form tubule-like structures in which the brain sand, or acervulus cerebri, may be found. This substance consists of peculiar concretions of phosphate and carbonate of magnesium, ammonium and calcium. These may be found in other parts of the nerve system as well.

Functionally the epiphysis is not prominent. In animals injections of extract of pineal body seem to cause a slight transitory fall in blood pressure. It seems to antagonize the hypophysis. In the young the pineal body seems to have to do with nutrition, general growth and the development of the genital organs.

The circulation of the nerve system is carried on chiefly by the vessels in the pia. In the cerebrum, the vessels of the cortex enter vertically, and form a close plexus of capillaries most plentiful where the cells are. Those intended for the medulla are larger, and, passing through the cortex, form capillary networks between the fibers and parallel to them. Other branches supply the basal ganglia.

In the cerebellum, the capillaries are few in the outer portion of the molecular layer, but in the granule layer and around the cells of Purkinje, close meshes are formed.

In the spinal cord, there are two sets of vessels, those that enter at all points of the periphery and supply chiefly the white matter, and those derived from the artery lying in the ventromedian fissure; the latter set goes to the gray substance. The smaller peripheral vessels remain in the white substance, and run parallel to the fibers,
while the larger penetrate the gray substance and supply the outer part. The artery in the fissure sends branches into the gray commissure; these divide right and left, and form dense plexuses in the gray substance. The arteries of the spinal cord are terminal as their capillaries do not anastomose.

The blood is collected by venous radicals that have the same general course. Those of the brain empty into the large venous sinuses of the dura. In the spinal cord they form the large ventral and dorsal median veins.

Lymph vessels are absent in the brain and spinal cord. Lymph spaces, pericellular and perivascular are very numerous and communicate with the subarachnoidean lymph space. The subarachnoidean lymph space continues as the perivascular lymphatics that accompany the blood-vessels.
CHAPTER XVIII

THE EYEBALL AND LACRIMAL SYSTEM

The eyeball (*bulbus oculi*) is one of the most important organs of the special senses. The eyeball occupies the anterior portion of the orbital fossa and is protected by the orbital margins and the eyelids. The anteroposterior and transverse diameters are 24 mm, while the vertical dimension is 23.5 mm, so that the eyeball is not quite a sphere at the equator. At birth the eyeball is about 17.5 mm. in diameter and is nearly spherical in shape. It increases about 3 mm. between birth and puberty and soon thereafter attains its adult shape and size.

The apparent difference in the size of the eyeballs of different individuals is not due to a real difference in size but to a difference in prominence of the eyeball and width of the palpebral fissure. When viewed from the side the eyeball is seen to consist of parts of two spheres. The smaller, anterior corneal portion (about one-sixth) represents part of a sphere of 14 mm. diameter, while the larger posterior portion (five-sixths) represents the greater part of a sphere of 24 mm. diameter. The *optic axis* is represented by a line connecting the anterior and posterior poles, that is the central points of anterior and posterior curvatures, respectively. The *equator* is the line around the eyeball midway between the poles. The *visual axis* is a line that passes from the first nodal point of the cornea to the fovea centralis of the retina.

The eyeball is called the organ of vision (*organon visus*). In reality it makes an image like a camera, while nerve impulses that are generated by the cells of the retina travel to the brain and these impulses are then translated into photic impressions.

The eyeball is operated by a number of *extrinsic muscles* that are of the voluntary striated variety. Within the eyeball are some smooth, *intrinsic muscles* that are concerned with the actions of the iris and the process of accommodation.
The eyeball alone does not occupy the entire orbit but in addition the extrinsic muscles, orbital fat, capsule of Tenon, vessels and nerves are found here. The orbital fat forms a soft bed or cushion for the eyeball and the quantity differs in various individuals. If it is above the average amount the eyeballs protrude somewhat; if it is less than the average condition then the eyeballs have a sunken appearance. This is especially noticeable after a long illness and the sunken appearance is due to the fact that some of the fat here has been used as food. During convalescence the fat is restored.

The **capsule of Tenon** (fascia bulbi) forms a lymph space, or bursa within which the eyeball moves as free from friction as possible. This lies behind the equator of the eyeball and consists of a two layers of a serous membrane which are continuous with each other. This covers the posterior portion of the eyeball and extends as far forward as the reflection of the conjunctiva. The layers are practically in apposition and are pierced posteriorly by the optic nerve and is continued thereon. It is likewise pierced further forward by the tendons of the ocular muscles and is prolonged upon each as a tubular sheath. That portion of the fascia under the eyeball is formed like a swing, or hammock and seems to support the eyeball; it has therefore been called the **suspensory ligament**.

The eyeball is composed of **three coats** and contains **four refractive media**. The coats are the external, or corneo-sclera; the middle, or choroid, ciliary body and iris; and the internal, or retina.

The refractive media are the cornea, the aqueous and vitreous humors and the lens. Of these, the cornea and lens alone are of importance.

The corneo-sclera is the protective and transparent coat of the eyeball.

The sclera constitutes about five-sixths of this coat. It is composed of coarse bundles of white fibrous tissue that interlace to form a dense, tough coat. These bundles although arranged chiefly longitudinally and transversally interlace somewhat. Between the bundles are spaces that contain large, stellate cells. These spaces communicate with the lymph spaces within the cornea. On its external surface, the sclera is in relation with the capsule of Tenon, and, anteriorly, the conjunctiva. To it are attached the ocular muscles.
The visible portion of the sclera constitutes the white of the eye; in the young it may be bluish in color, in the adult it is white, while in old age it may show yellowish patches.

The inner surface of the sclera is somewhat modified and contains a variable amount of pigment. The connective tissue bundles become flatter and the elastic fibers become more numerous and thicker. Finally along the inner surface there is a layer of mesothelial cells. The connective tissue cells contain a brownish pigment and this especially arranged part of the sclera is called the lamina
The eyeball and lacrimal system

It is continuous with the lamina suprachorioidea. At the exit of the optic nerve the sclera is pierced by a number of small openings through which the fila of the optic nerve pass; this forms a sieve-like area in the sclera and is called the lamina cribrosa. At this region the sclera is thickest. Pigmentation of the cells occurs here as well as at the corneoscleral junction.

The cornea is a specialized portion of the sclera modified for the transmission of light. It is practically a concavo-convex lens with the convex side externally placed. At its junction with the sclera there is a shallow groove called the sulcus sclerae externus. It is about 1 mm. in thickness. The posterior, or internal surface is more extensive than the anterior as the transition from cornea to sclera begins sooner on the external surface. It consists of five layers: anterior epithelium, anterior limiting membrane, substantia propria, posterior limiting membrane, and posterior mesothelium.

The anterior epithelium is a continuation of the epithelium of the conjunctiva. This is of the stratified squamous variety, and the tunica propria beneath is not papillated. Superficially the layer is more regular than epithelium anywhere else in the body. The layers of cells, usually five or six, are more numerous at the corneoscleral junction than in the center and mostly from 37 to 58 \( \mu \) thick. The basal cells are long and columnar, about 18 microns high and 10 microns wide; the basal surface is perfectly flat while the superficial extremity is somewhat rounded. The second layer, or wing cells, are polyhedral elements whose deeper edges are wing-like. The surface cells are flattened elements measuring about 4 microns in thickness and up to 45 microns in length. The middle layers are prickle-cells, and the spaces between are lymph channels. Sensor nerve fibers are numerous in the epithelial layers.

The anterior elastic lamina, or Bowman's membrane, is a clear prominent band serving as a basement membrane to the epithelial cells 10 to 16 microns in thickness. Although called elastic it does not consist of elastic tissue. It is thickest in the center of the cornea and becomes thinner as the corneoscleral junction is approached, where it ends about 1 mm. from the corneoscleral junction. This narrow portion of cornea possessing no Bowman's membrane is called the limbus corneaee. It is unusually prominent for a basement
membrane and because, like elastic tissue, it does not respond to the ordinary stains the older observers were lead to believe that it consisted of elastic tissue. It does not respond to the elastica stains. Its anterior, or superficial layer is sharp and its curvature corresponds to that of the anterior epithelium. It is smooth, apparently structureless, showing neither nuclei nor fibrillation. Its posterior, or deep surface is not so sharply defined and blends with the stroma of the cornea. It contains pores for the perforating nerve fibers of the cornea.

The substantia propria forms the bulk of the cornea, and consists of a number of layers (about sixty) of white fibrous tissue arranged parallel to one another. Each lamella measures from 1.3μ to 2.5μ microns in thickness. It is due to this arrangement that this organ is transparent. In the center of the cornea the bundles of fibers of the successive layers cross one another at right angles. In addition to these fibers, there are others that penetrate the organ at a right angle to the layers, and bind all together. These are the perforating fibers. Elastic fibers are said to exist between the lamellae and an especially thick layer of these fibers is said to be present just in front of the membrane of Descemet; this is the lamina elastica corneae. Between the various layers are a large number of irregular spaces called the corneal lacunae. These contain large stellate cells that are the original connective tissue cells of the organ. They are the corneal corpuscles. The spaces communicate with one another by means of little canals called canaliculi, into which their processes extend. The existence of these canals is denied by some. These spaces are readily shown by the gold chlorid method of staining.

The posterior limiting membrane, or membrane of Descemet, is analogous to the anterior membrane; unlike this one, however, it is thicker peripherally 8 to 10μ than centrally (5 to 7μ), and seems more independent of the substantia propria than the anterior. It does not respond to the elastica stain, and, consequently, is not made up of elastic tissue, as its name would seem to indicate. It is structureless and can readily be detached from the stroma so that both of its surfaces are sharply marked. Descemet’s membrane regenerates while Bowman’s does not. It becomes the pectinate ligament. According to Stöhr the pectinate ligament consists of
fibers passing from the iris to the cornea. It is said to prevent the passage of lymph from the anterior chamber to the corneal spaces.

The **mesothelial layer** consists of a single layer of well-defined regular cells, which cover the posterior surface of this organ, and continue over the anterior surface of the iris. These cells are hexagonal, and possess a fibrillar cytoplasm that seems to extend through several layers. They measure 18 to 20µ in width and about 5µ in height and rectangular in vertical section.

The cornea possesses **blood-vessels** during the developmental period. These, however, disappear before birth, so that none are then present. Lymph, which circulates through the many large spaces and canaliculi, nourishes the cornea. Lymphatic vessels are absent.

The sclera possesses but few vessels, and these are found chiefly at the corneo-scleral junction, where a circular network is formed. They anastomose with the vessels of the chorioid. The short posterior ciliary arteries may give off branches that form an anastomotic ring around the optic nerve and this constitutes the **circle of Zinn**, or **Haller's vascular circle**.

The **nerves** are sensor; at the corneoscleral junction a circular plexus is formed, from which fibers pass into the substantia propria, while others penetrate the anterior elastic (Bowman's) lamina to pass into the epithelial layer. Some of these fibers extend almost to the surface. Bulbs or corpuscles occur near the scleral margin of the cornea.

The **middle coat**, or tunic, also called the **uveal tract**, is the vascular coat. It contains the main vessels of the eyeball, except the central artery of the retina, and consists of the **chorioid**, **ciliary body** and **iris**.

The **chorioid** is the vascular portion, and is divided into four layers, the **lamina suprachorioidea**, the **stroma layer**, the **choriocapillaris**, and the **glassy membrane**, from without, inward.

The **stroma layer** is sometimes referred to as the layer of large vessels, as they are found only in this portion. It consists, externally, of delicate fibers that connect with those of the subscleral tissue (lamina fusca) and form a complete space, the **suprachorioidal**, or **subscleral lymph space**. In this tissue are found pigmented
connective-tissue cells, and it has received the name of lamina suprachorioidea.

The lamina suprachorioidea is a transparent membrane that consists of 6 to 8 lamellae which, in the ciliary region, disappear between the muscle bundles. In the posterior part of the perichorioideal space the lamellae are shorter. These lamellae connect the chorioid proper to the scleral coat and the union is closer posteriorly than anteriorly. The lamellae are fused together in some places and in other regions large openings occur. As a result of this latter condition the lamellae are more like trabeculae that bridge the suprachorioidal lymph space and join or become continuous with the fibers of the lamina fusca. The lamina fusca is covered with mesothelial cells and these are continued over the suprachorioidal lamellae. In the lamellae are pigmented connective tissue cells called chromatophores. Those at the periphery are plump and have short processes like those of the lamina fusca; deeper in, these cells are flatter and the processes are longer and more slender. They may be scattered or
in groups. Their cytoplasm contains coarse brownish granules of pigment.

The suprachorioidal lymph space is a narrow cleft between the chorioid proper and the sclera. It is limited anteriorly by the ciliary muscle and posteriorly by the optic nerve, though it may possibly end a short distance from the nerve. It is bridged by the layers of the lamina suprachorioidæ so that in reality it is more of a series of spaces and meshes rather than a clear cut space. This space is traversed by the ocular vessels and at such points the sclera and the chorioid are more adherent. Mesothelial cells cover the adjacent surfaces of the sclera and chorioid and also the lamellæ connecting these two structures.

The main portion of the stroma layer consists of bundles of white fibrous tissue and elastic fibers. The outermost part contains many mesothelial cells and flat chromatophores and therein resembles the suprachorioidal lamina. Deeper in, the chromatophores seem to be more in relation with the blood-vessels. The elastic fibers become finer and the collagenous fibers increase in amount. In the networks formed by these are the venous trunks, externally, and the arterial trunks, internally; the latter are accompanied by bundles of smooth muscle tissue. Pigmented cells exist between the bundles.

The inner portion of this layer is a narrow dense zone and is called the boundary zone; the bundles are arranged into several layers in herbivorous animals, so as to give a peculiar metallic reflex, and constitute the tapetum fibrosum. This area is usually free from pigment cells. In the carnivorous animals the fibers are replaced by distinct cells that contain crystals. The metallic reflex, however, is the same. This forms the tapetum cellulosum.

The choriocapillaris contains little stroma, and is composed chiefly of a dense capillary formation. The capillaries are broadened out into one plane but do not form a meshwork. The capillaries have a large diameter and at intervals sac-like dilatations are noted. This layer is thickest in the region of the fovea centralis. No pigment cells are seen. The capillaries are most numerous around the macula lutea.

The glassy membrane or membrane of Bruch, lies at the inner boundary of the chorioid, and consists of refractile, homogenous
tissue. It is a very thick basement membrane, and supports the pigmented cells of the retina, which form small depressions in its surface. This membrane increases in thickness in old age. It is composed of two layers the outer of which is called the elastic layer. This is dark and granular in appearance under the higher power. It is said to consist of a dense network of elastic fibers. The inner layer or cuticular lamella is homogeneous, straight and uniform.

The chorioid extends to the ora serrata, a peculiar, serrated line, at which the neural portion of the retina ceases. At this point, the choroid continues as the ciliary body.

The ciliary body is composed of three main portions, the ciliary ring, the ciliary processes and the ciliary muscle. It is thicker than the chorioid, which is due especially to the addition of the muscle tissue.

The ciliary ring is practically the continuation of the stroma layer of the chorioid and the glassy membrane, and consists of dense white fibrous tissue, which forms a circular band about 4 mm. in breadth. The outer bundles mix with the bundles of fibers of the ciliary muscle. The vessels have a longitudinal course.

The ciliary processes are projections of the stroma, covered by pigmented epithelial cells, from 60 to 80 in number. They arise at the junction with the chorioid, and extend toward the iris, increasing in height, ending abruptly at that point. At this place they are about 1 mm. in height. Each process consists of a core of stroma (connective tissue) supporting blood-vessels and covered by the pigmented epithelial cells of the retina, the pars ciliaris retinae. This is said to be the most vascular region of the eyeball. These cells rest upon a continuation of the glassy membrane. There are two layers, the outer, or basal of which consists of low columnar or cuboidal elements that are the continuation of the true pigmented cells of the retina. The cytoplasm is usually filled with brownish pigment granules but the nucleus is not invaded. The inner layer is composed of cells that are columnar, possess little or no pigment. The cytoplasm is usually clear or only slightly granular and may show fibrillation or contain delicate rods. These cells are the representative of the optical portion of the retina. In places gland-like evaginations of the pigmented epithelium are noted. These are
the so-called ciliary glands. These clear cells are said to secrete the aqueous humor.

The ciliary muscle is of the nonstriated variety, and lies external to the ciliary ring, just beneath the sclera. The fibers are arranged in meridional, radial and circular sets. The meridional are the outermost, and extend from the canal of Schlemm, in the corneoscleral junction, to the ciliary ring. The fasciculi vary in length and represent the bulk of the ciliary muscle. These are the tensor muscles of the chorioid. The radial fibers, which compose the middle layer, extend peripherally, and, spreading fan-like, are inserted into the ciliary ring and processes. These fibers are less numerous and run a shorter course. Although they start out like the meridional fibers they soon are arranged parallel to the radii of the eyeball. The circular fibers are the inner ones, and their direction is equatorial. The fibers are arranged in small bundles that are mixed with the radial fibers and pectinate ligament. These fibers are said to be increased in number in hypermetropic eyes and reduced or absent in myopic eyes. They constitute Müllcr's ring-muscle. The ciliary muscle is important in the process of accommodation.

The ciliary region is indicated, externally, by a band about one-fourth of an inch broad, starting at the corneoscleral junction. It
is called the danger zone of the eyeball, as injuries here usually result fatally to sight.

The iris is the continuation of the stroma layer and glassy membrane of the chorioid. It receives also the posterior lamina and the endothelium of the cornea, and consists of the anterior mesothelium, stroma layer, posterior lamina and pigment layers.

The anterior mesothelium is a continuation of that of the cornea, and covers the anterior surface of the iris. The cells are neither so regular nor distinct as those of the cornea. In areas they are wanting and permit of a direct communication between the intercellular spaces of the iris with the anterior chamber.

The stroma layer is composed chiefly of a coarse network of white fibrous tissue, some of which is circularly arranged around the bloodvessels, which possess no muscular coat. Anteriorly, this stroma is very much reticulated and forms a support for the mesothelial cells. According to some authors, this portion constitutes an anterior limiting membrane. The connective tissue cells are unusually numerous. In the stroma layer, pigment cells are found in varying quantities; in gray eyes, very few are seen; as the color passes to blue, brown and black, the number increases, the last possessing the most. In albino eyes not only are the pigmented connective cells of the stroma layer absent, but the pigment that is usually present in the posterior epithelial cells continued from the retina is also absent. As a result of this, the retinal blood-vessels cause a peculiar red reflex, the retinal reflex. In the other eyes the pigment obscures it.

The stroma is quite vascular; the large vessels have a meridional direction. These vessels usually produce slight ridges upon the anterior surface of the iris and between these are slight grooves. The anterior surface has therefore an uneven appearance.

In the stroma is found muscle tissue of the involuntary nonstriated variety. This is arranged circularly and radially. The circular fibers are near the anterior part of the iris, and contract the pupillary aperture when stimulated; these form the sphincter pupillæ muscle. The radial fibers lie near the posterior part, and when they contract, the pupillary aperture is dilated; they constitute the dilatator pupillæ muscle. According to Schäfer this muscle covers the poste-
rior surface of the iris stroma as a single layer of thin, flat cells. At the periphery of the iris is two to three cells thick. No basement membrane intervenes between this muscle and the pars iridica retinae.

The posterior limiting membrane, or membrane of Bruch, is a continuation of the glassy membrane. It supports the pigmented cells, the pars iridica retinae.

The pigmented layer, a continuation of the pars ciliaris retinae, and called the pars iridica retinae, is usually pigmented, and consists of two layers of cells. The cells are filled with pigment and with adults the individual elements cannot be distinguished. It continues to the anterior margin of the pupil.

The pupil is the aperture in the iris. Its size is regulated automatically by the amount of light entering.

The iris is an automatic curtain that is suspended in the aqueous humor. It regulates the amount of light that enters the lens and divides the anterior and posterior chambers from each other.
The corneoscleral junction is the region in which cornea, sclera, ciliary body and iris come together. The sclera passes over into the cornea, but the line of transition is not abrupt, but gradual, and forms an oblique line that extends from before, backward and inward so that the posterior surface of the cornea is greater in extent than the anterior surface. Beneath the posterior margin, usually within the sclera, is a circular canal, the canal of Schlemm, which extends around the corneoscleral junction. Through this canal the lymph of the cornea, spaces of Fontana and anterior chamber enters the scleral venules. In this region, the membrane of Descemet is seen to divide into a large number of fibers that extend to the base of the iris. Some of the ciliary muscle fibers arise here and assist in forming a network. Between the fibers are found many intercommunicating spaces called the spaces of Fontana. These spaces lie around the angle formed by the cornea and iris, called the infiltration angle, and communicate with the anterior chamber and the canal of Schlemm. The network is called the pectinate ligament, and is covered by mesothelial cells. It is more prominent in some lower animals than in man.

THE RETINA

The retina forms the internal, or neural coat of the eyeball. It is thickest at the border of the optic nerve (0.4 mm.) and gradually tapers peripherally to about 0.14 mm. It may be divided into two portions, the pars optica, that portion capable of vision, and the pars ceca, or the blind part, possessing no nerve elements. The latter portion is further subdivided into pars ciliaris and pars iridica retinae. The simplest division of the retina, however, is pars optica, pars ciliaris and pars iridica retinae.

The pars optica lines almost the entire optic cup, and extends forward to the end of the chorioid. Here the neural portion ceases, and the coat becomes abruptly thinner, and forms an irregular serrated line, the ora serrata. From this point, the last two portions of the retina continue.

The optical portion consists of eleven layers, counting the pigmented layer. These layers are classed as neuro-epithelial and
The **neuro-epithelial** portion consists of the first layers within the pigment layer, and the **cerebral** portion the remaining divisions. The pigmented part is derived from the outer layer of the optic cup, and the other parts from the inner layer.

### Optic Vesicle

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1. The **pigment layer** of the retina consists of a single layer of polyhedral cells (16μ) that contain a black, granular, mobile pigment (*fuscín*). The position occupied by this pigment depends upon whether the eyeball was fixed in the presence or absence of light. The cells possess some processes that extend around the bodies of the rod and cone cells. If the eyeball is fixed in the presence of light the pigment granules seem to collect in these processes while the remainder of the cytoplasm is practically free. If the eyeball be removed and fixed in the dark the pigment granules lie in the body of the cell. The *nucleus* occupies that portion of the cell near the basement membrane (glassy membrane of the chorioid) and is devoid of these pigment granules. These pigment granules apparently absorb the excess rays of light and convert them into heat and are also said to replace the rhodopsin of the rod cells as this becomes bleached through the action of the light. These cells continue over the ciliary body and iris as the pars ciliaris and pars iridica retinae. In the iris both layers are pigmented but not in the ciliary region. This layer of cells is derived from the outer layer of the optic cup.
The neuro-epithelial elements and the nerve cells and fibers are supported by neuroglia, of which there is a great deal present, but this is unevenly distributed.

2. The layer of rods and cones is the most important of the retina.

The cone cells consists of cone-body and cone-fiber. The cone-body varies in length and consists of two segments, outer and inner. The outer segment is the shorter, conical and may be striated. This
portion rests upon the external limiting membrane and apparently consists of discs. The *inner segment* is striated and flask-shaped. The cytoplasm of this portion, at its junction with the outer segment, is granular while the remainder is fibrillar. The *cone-fiber* is the continuation of the cell-body, lies within the internal limiting membrane and passing inward terminates in the outer reticular layer. At its junction with the body it is slightly enlarged (*cone-foot*) and this portion contains the nucleus. The nucleus stains less deeply than the nucleus of the rod cell. The length of the cones varies in different parts of the retina. Near the ora serrata they are about 22 microns long; midway between the ora and the optic papilla, 31 microns; at the edge of the fovea centralis, 44 microns; in the center of the fovea, 88 microns. The cone bodies average about 35 microns in length and 7 microns in thickness.

The *rod bodies* are longer on the average than those of the cone cells and more nearly uniform in size. They average about 60 microns in length and 2 microns in thickness. Each consists of an *outer* and an *inner segment* which react differently to stains. The *outer segment* does not respond well to the ordinary stains and is anisotropic and is brighter in appearance than the inner segment. This portion contains the *rhodopsin*, or *visual purple*, which after having been bleached by the action of light is rapidly replaced by the pigment cells of the retina. This segment is said to be surrounded by a delicate neurokeratin sheath. The *inner segment* is somewhat spindle-shaped and at the junction with the outer segment the cytoplasm is granular. The rest of the cytoplasm is fibrillar. The *rod-fiber* is the continuation of the cytoplasm and contains the nucleus. The fiber is far more delicate than that of the cone cell, markedly varicose and the various nuclei are at different levels. In the case of the nuclei of the cone cells they are all placed at the same level and lie next to the limiting membrane. The nuclei of the rod cells are far more numerous than those of the cone cells and so are scattered to the best advantage in the outer nuclear layer. The nuclei of the rod cells are peculiar in that the chromatin seems to be distributed in the form of several transverse bands, giving the nucleus, thus, a striated appearance. The rod-fiber terminates in the outer reticular layer.
There are usually three or four rod cells to one cone cell; a recent estimation of the cells, however, would place the proportion about two to one, i.e., 130 million rods and 70 million cones. The rod and cone cells constitute parts of three layers, the rod and cone layer (cell bodies), the outer nuclear layer (rod and cone-fibers and nuclei) and a part of the outer reticular layer (terminal branches of the fibers).

The rod and cone cells seem to have different functions. The cone cells contain no rhodopsin and so this as well as the rod cells is unessential to sharp vision in human beings. In some animals the visual purple is said to be wanting. In birds and reptiles it is said that the cones are more numerous than the rods and in lizards there are no rods. In the owl and most nocturnal animals the cones are very few in number, poorly developed or entirely absent. The cones are said to have to do with color perception and in color blindness they are defective. The rods are concerned with light perception so that in night-blindness these elements are defective.

3. The outer limiting membrane is a part of the supportive tissue of the retina. This is neuroglia and comprises the glial cells and fibers. The glial cells are called the sustentacular cells, or fibers of Müller. These are irregular column-shaped elements that are radially placed and extend almost throughout the entire thickness of the retina.

![Fig. 306.—Cells from Retina of an Ape. (Stöhr's Histology.)](image-url)

1. Cell of ganglionic layer. 2. Cells of inner granule layer. 3. Rod-cells—a, Outer segment; i, inner segment; k, rod granule; x, fiber apparatus. Below are rod-cells and fragments. 4. Cone-visual cells—a, Outer segment; i, inner segment; k, cone-granule; f, cone-fiber; x, fiber apparatus. 5. Radial fiber; Müller’s fiber; k, nucleus; r, pyramidal base.
Their outer extremities fuse to form the outer limiting membrane, from the peripheral surface of which delicate fibrillae extend between the rod and cone-bodies forming the rod and cone sockets. This outer limiting membrane is perforated for the bodies of the rod and cone cells. The inner extremities of the sustentacular cells fuse to form the inner limiting membrane the most internal layer of the retina. From these cells of Müller lateral branches are given off. These assist the glial fibers in forming the general supportive tissue of the retina. In the meshwork thus formed there are some astrocytes in the ganglion cell layers.

4. The **nuclear** or **granule layer** consists of four or five layers of nuclei that represent the nuclei of the rod and cone cells and the bulk of the fiber processes of these cells. The cone nuclei are all in a single row along the outer limiting membrane and form only about one-fourth of the thickness of the layer. The remainder is made up of the nuclei of the rod cells that are scattered throughout the inner three-fourths of this layer. Glial fibers are present as are also some of the dendritic branches of some of the small cells of the outer ganglionic layer.

5. **Henle's fiber layer** is best developed in the macular region from which area it diminishes peripherally. It is usually considered a specialized portion of the outer reticular layer but differs from it in that its fibrils are radially arranged while the others are irregular.

6. The **outer reticular**, or **molecular layer** is a meshwork of fibrils from different sources. On the one hand, the rod and cone fibers (really axones) terminate here in teloneurites; these form synapses with the telodendrites, or process that come from the cells of the outer ganglionic layer and constitutes the end of the first neuron of the visual pathway.

7. The **outer ganglionic**, or **inner nuclear layer** consists of several varieties of closely packed cells. The outermost cells are horizontally placed. They are stellate, or pyramidal cells of two sizes mainly. The dendrites of the large cells pass to the reticular layer and terminate in relation with the filaments of the rod-fibers. Those of the smaller cells end in relation with the filaments of the cone-fibers. The axones of both large and small cells pass to the inner reticular
layer where they form synapses with the dendritic processes of the large ganglion cells. It is said that the smaller cells are of an associative function.

The middle portion of the outer ganglionic layer contains the bipolar cells that are the most numerous of this layer. They may be called rod bipolars and cone bipolars as they form synapses with these cells. These are placed vertically and the small amount of
cytoplasm present continues internally as an axonic process that terminates in the inner reticular layer in relation with the process (dendritic) of the large ganglion cells. The peripheral processes of the oval cells are the dendrites and they terminate in telodendrites in the outer reticular layer in relation with the terminal fibrils of the rod and cone-fibers, forming synapses.

The inner cells are the amakrin cells of Cajal, and these form a continuous layer near the inner boundary of the ganglionic layer. These pear-shaped elements (10 to 13 μ) send their dendrites to form a part of the outer reticular layer. Some writers classify them as stratified, disseminate and association amakrin cells. They were called amakrin cells because it was believed that they possessed no axones, but they do. Some of these axones pass to the inner reticular layer and terminate in relation with the terminal fibrils of axones that come from the brain through the optic nerve. Little is known about the other axones.

The nuclei of the cells of Müller lie in this layer.

8. The inner reticular, or molecular layer consists of a dense reticulum of fibrils. These fibrils represent the teloneurites of the cells of the outer ganglionic layer and of some of the axones of the fibers of the optic nerve (centrifugal) and the telodendrites of the cells of the inner ganglionic layer. These fibrils may give the layer a striated appearance. Sometimes five secondary layers may be recognized.

9. The inner ganglionic layer, or layer of large nerve cells is composed of a single layer of large multipolar ganglion cells. These vary in size in different parts of the retina from 12 to 30 microns. The cell bodies are flask-shaped, spheroidal, or even stellate and their axones form the greater part of the nerve fiber layer. The dendrites pass peripherally and form a part of the inner reticular layer. In the region of the macula lutea these cells form a layer seven to eight cells deep; in the fovea centralis they are absent.

10. The layer of nerve fibers represents the expanded portion of the optic nerve. These fibers arise mainly from the large ganglion cells and are at first amyelinated. They converge from all parts of the retina toward the optic nerve area, or blind spot, become myelinated and pass through the cribriform lamina. By virtue of
this convergence of the fibers at the blind spot the nerve fiber layer is thickest here and forms a ridge-like elevation at this region. This layer decreases in thickness as the ora serrata is approached and at this region ceases entirely. The fibers may interlace somewhat within the layer. Some of the fibers within this layer are derived from the brain and carry impulses into the eyeball. Some of these axones terminate in relation with the axones of the amakrin cells.

II. The inner limiting membrane is a delicate structure formed by the fusion of the internal extremities of the cells of Müller. This limits the retina internally and is in contact with the hyaloid membrane of the vitreous humor.

The retina contains a rich capillary plexus derived from a special vessel, the central retinal artery. This enters the eyeball through the center of the optic nerve and within the eyeball divides into a whorl-like set of vessels from the center of the blind spot. Venous channels form the central retinal vein that passes out of the eyeball by the side of the artery. These vessels anastomose with some of the others that supply the eyeball.

There are three important areas in the retina: (1) the optic nerve exit, optic papilla, or blind spot, (2) the macula lutea, or yellow spot, and (3) the ora serrata.

1. In the blind spot, only the layer of nerve fibers is present. It lies about one-eighth of an inch to the nasal side, and about one-tenth of an inch below the optic axis. In the center is usually a shallow depression; around the edge it is raised and forms the papilla nervi opticæ.

2. The yellow spot is not in the direct visual axis. The color is due to the presence of a diffuse yellow pigment. Its edge is raised, owing to the great thickness of the inner ganglionic layer. From the edge to the center, all the layers decrease and disappear, so that in the center, the fovea centralis, the cones alone are present. Here vision is most acute.

3. At the ora serrata all of the neural layers end abruptly, and are continued as a single layer of cuboidal or columnar cells. Beyond this point, there is no vision.

The light rays falling upon the retina are not transmitted to the brain by a direct route. The impressions are received by the rods
and cones, which send impulses to the outer reticular layer (end of the first neuron); here the impulses are received by the processes of the outer ganglionic layer, conveyed through the bodies of the cells of that layer to the inner reticular layer (end of the second neuron); here they are relayed to the processes of the cells of the inner ganglionic layer and to its cells (cells of the third neuron) and thence to the

Fig. 308.—Longitudinal Section of the Optic Entrance of a Human Eye. X 15. (Lewis and Stöhr.)

Above the lamina cribrosa is seen the narrowing of the optic nerve, due to its loss of myelin. The central artery and vein have been for the most part cut longitudinally, but above at several points transversely. 1, Hyaloid membrane loosened; 2, retina; 3, choroid; 4, sclera; 5, bundles of the optic nerve; 6, pial sheath; 7, arachnoidal sheath; 8, dural sheath; 9, fibers of the lamina cribrosa; 10, central artery; 11, central vein.

nerve fiber layer; the latter makes up the optic nerve by means of which the impulses are then conveyed to various parts of the brain. The cells of the lower centers (pulvinar, lateral geniculate body and superior calliculus) represent the fourth neuron cells and the axones of the first two terminate in the cuneus.

The optic nerve consists of a single bundle of nerve fibers that possess no neurilemmae. It is said to contain from 450,000 to 800,000 nerve fibers. It is surrounded by the dura, arachnoid, and
The nerve fiber layer, like all the layers, is thicker on the side toward the papilla of the optic nerve than on the opposite side; in the latter situation the nerve fibers are seen in transverse section as minute dots. The section is not through the exact center of the fovea, for there only cone cells are present; no remnants of the confluence of the inner granule and ganglion cell layers are found. 1, Cones; 2, external limiting membrane; 3, nuclei of cones; 4, Henle’s fiber layer; 5, outer reticular layer; 6, inner nuclear layer; 7, inner reticular layer; 8, layer of ganglion cells; 9, nerve fiber layer; 10, internal limiting membrane.
The lymph spaces included within these, communicate with those of the eyeball. The dura and pia pass over into the sclera, but the arachnoid, as such, is lost before this occurs; as a result, the two lymph spaces between these three layers become one. The nerve fibers penetrate the sclera through the lamina cribrosa. As they pass through this coat, they lose the myelin sheath, so that they become amyelinated fibers when they connect with the retina.

**VITREOUS BODY AND LENS**

Of the **refractive media** of the eyeball, the **vitreous** and **aqueous humors** and the **lens** are yet to be described.

The **vitreous humor**, or **body**, occupies the optic cup, or **vitreous chamber**. Upon its anterior surface is a deep depression in which the posterior surface of the lens rests. This is the *patellar fossa*. This body consists of a fine limiting membrane, the *hyaloid membrane*, a delicate homogeneous structure enclosing the substance of organ, which is composed of about 98 per cent. water and 2 per cent. solid elements. The latter comprise connective tissue and wandering cells, and some fibrils. The vitreous body is jelly-like in consistency. It really consists of a framework of hard substance in the meshes of which is the fluid part. Sometimes upon fixation a lamellated structure is shown; again radially directed fibers from a thickened outer layer, at the region of the ora serrata, pass into the center of the organ to form its framework.

This structure is traversed by a small canal, called the **canal** of Stilling, or **hyaloid canal**. This extends from the optic nerve to the lens, and in intrauterine life is occupied by a branch of the retinal artery, the **hyaloid artery**, that passes to the lens.

The **aqueous humor** is practically lymph. It occupies the anterior and posterior chambers, and as a refractive medium is unimportant.

The **crystalline lens** is the most important refractive medium of the eyeball. It is a solid, biconvex body measuring about 9 to 10 mm. in its transverse dimension and from 3.5 to 4 mm. antero-posteriorly. The latter dimension varies with the amount of accommodation. In the adult it weighs about 180 milligrams and
at birth about 120 milligrams. The curvature of the posterior surface is the greater but is practically fixed. The anterior curvature is chiefly the one that changes in accommodation.

The lens consists of a capsule within which is the lens substance. The capsule is a transparent and apparently homogeneous membrane that is about twice as thick upon the anterior surface as upon the posterior. The posterior surface is in contact with the hyaloid membrane of the vitreous humor while the anterior surface touches

![Fig. 310.—Capsule and Epithelium of a Lens of Adult Man. (Lewis and Stöhr.)](image)

C, Tangential section. D, Meridional section across the equator of the lens: 1, capsule; 2, epithelium; 3, lens fibers. × 240.

the posterior surface of the iris. To the capsule the fibers of the suspensory ligament are fastened.

The lens substance consists of the lens cells and lens fibers. The cells are columnar in the early childhood and gradually reduce in height as age advances so that in the elderly individuals they may be flattened elements. These cells are few in number and are found only on the anterior surface of the lens substance, just beneath the capsule; here they form a single layer of cells. Toward the equator of the lens these cells successively lengthen so that at the equator they are lens fibers.

The lens fibers are simply the elongated and modified lens cells. This change is permanent and the fibers cannot reproduce them-
selves. As the fibers become older the nucleus is gradually lost and the substance of the fiber seems to lessen and become hardened, forming dense tough structures. The nuclei are said to be left at the equatorial region of the lens where they form the nuclear zone.

The suspensory ligament of the lens is in reality a portion of the hyaloid membrane. This latter structure is thin over the bulk of the vitreous humor but over the ciliary body it is considerably thickened by radially disposed fibers. This forms a band-like structure that bridges over the ciliary depressions and is called the zonula ciliaris. This rests upon and seems to be fastened to the tops of the ciliary processes, for when stripped therefrom the pigmented epithelium usually adheres to the zonular tissue, forming radial blackish streaks. Between the processes it sags slightly into the recesses (the radial extensions of the posterior chamber). As the zonule approaches the equator of the lens it separates into two layers, the thinner posterior division lining the patellar fossa of the vitreous humor constituting its hyaloid membrane here. The thicker anterior division passes to the front of the lens capsule and blends therewith, constituting the suspensory ligament of the lens, which is band-like in form. Many individual fibers separate from this ligament and extend independently to the equatorial region of the lens capsule, some also attaching in front and behind the equator. The wedge-shaped space around the equator of the lens, between these two layers of the zonula ciliaris, constitutes the spatia zonularis (canal of Petit) one of the lymph spaces of the eyeball.

The convexity of the lens is controlled by the suspensory ligament and the radial ciliary muscle. When the latter contracts the ciliary processes and the attached zonula are drawn forward causing the suspensory ligament to relax and the anterior capsule to sag permitting the lens to increase its convexity. Relaxation of the muscle renders the capsule tense, thereby flattening the convexity and returning the lens to its resting state.

The chambers of the eyeball are anterior, posterior and vitreous or optic cup. The anterior lies between the iris and cornea, the posterior between the iris and capsule and suspensory ligament of the lens, and the vitreous is occupied by the vitreous body. These
FIG. 311.—Vessels of the Eye.

External tunic, stippled; middle tunic, white; internal tunic and optic nerve, stippled criss-cross; arteries, light; veins, dark.

Central vessels of retina; a, artery; a', vein; b, c, d, anastomoses with vessels of sheath, short posterior ciliary arteries and chorioidal vessels, respectively. A, inner, B, outer sheath vessels; 1, short posterior ciliary artery; I', vein; II, episcleral artery; II', veins; III, capillaries of choriocapillaries: 1, long posterior ciliary artery; 2, circulus iridicus major; 3, branches to ciliary body; 4, to iris. (Stöhr's Histology.)
are large lymph spaces, and are connected with one another, and with the other spaces of the eyeball.

The circulation of the eyeball is carried on by the central artery of the retina, the long and short posterior and the anterior ciliary arteries.

The retinal artery passes into the eyeball through the center of the optic nerve, and forms a whorl of branches upon its entrance. These vessels extend to the ora serrata. The layer of rods and cones and the macula lutea possess no blood-vessels. The arterioles are terminal and do not anastomose with one another. The blood is collected by venous stems, which form the central vein of the retina that has a course parallel to the artery.

The short posterior ciliary arteries are about twenty in number. They pierce the sclera near the exit of the optic nerve in a circle called the circle of Zinn and pass into the choroid. As they pass through the sclera, they give off branches that supply the posterior half of this coat. In the choroid these vessels form the layer of large vessels and the choriocapillaris. Their branches anastomose with branches of all others, including those of the central artery of the retina.

The long posterior ciliary arteries pierce the sclera near the optic nerve, and pass to the ciliary region between the choroid and sclera: At the base of the iris, they form a circle of vessels, the circulus arteriosus iridicus major, which sends branches to the ciliary processes, the choroid and the iris; the latter branches pass to the pupillary region, where they form the circulus iridicus minor.

The anterior ciliary arteries are derived from the vessels of the recti muscles. These penetrate the sclera near the corneoscleral junction about 2 mm. from the margin of the cornea. Their branches nourish the anterior half of the sclera, the conjunctiva, the ciliary muscle, and the anterior half of the choroid; they connect with the circulus iridicus major, and form a network of capillaries at the corneoscleral junction. Around the optic nerve, there is some anastomosis between the branches of the ciliary arteries.

Most of the blood is returned by the veæ vorticosæ, which are four to six in number. These run a course entirely different from that of the arteries. Each is formed by a whorl of veins, and passes
through the sclera to empty into the ophthalmic veins. The blood from the anterior ciliary arteries is carried by the anterior ciliary veins that run parallel to the arteries. These also receive the blood from the episcleral spaces.

The **lymphatics** are extensive, and form a series of intercommunicating spaces.

*Anteriorly*, the spaces in the cornea communicate with those of the sclera, and with the canal of Schlemm and the anterior chamber, by means of the spaces of Fontana.

The *anterior chamber* communicates with the posterior chamber, and through this, with the canal of Petit.

*Posteriorly*, the lymphatics of the optic nerve communicate with the subarachnoideal space, on the one hand, and the hyaloid canal and perivascular spaces of the retina, on the other.

The *space of Tenon* lies external to the sclera, and receives lymph from the subscleral space, directly, and by way of the channels around the venæ vorticosæ; the lymph is sent to the spaces around the optic nerve. The latter communicate with those of the central nerve system.

Some describe the *lymphatic spaces* under two sets, *anterior* and *posterior*. The *anterior* include the canal of Petit, the lymph spaces of the ciliary region and iris, the spaces of Fontana, anterior and posterior chambers and the corneal spaces. The *posterior set* includes the spaces of the vitreous humor, retina the subscleral, or suprachorioidal spaces, the perivascular spaces of retina and choroid, the capsule of Tenon and the subarachnoid and subdural spaces of the brain continued along the optic nerve to the eyeball. These communicate freely with each other through the zonule of Zinn region and through the lymph channels around the vessels.

The *nerves, long and short ciliary*, supply the choiroid and pass between it and the sclera; at the ciliary body, they form the *ciliary ganglion plexus*, that supplies the ciliary muscle, iris and cornea and vessels. Those of the iris form a circular plexus. The nerves of the cornea have been considered.

**THE APPENDAGES OF THE EYEBALL**

The **appendages** are the *eyelids, conjunctiva* and the *caruncle*. The *eyelid* consists of a double fold of skin, the under surface
of which has become modified to form a **mucous membrane**. This is the **conjunctiva**, which is composed of **stratified columnar** cells

That rest upon a **basement membrane** and **tunica propria**. These cells are four or five layers in number and the basal elements are the smallest. The surface cells are somewhat pyramidal in form with
the bases forming the surface and the apices buried among the other cells. These cells seem to be distensible. Among the epithelial cells some goblet cells are seen. The tunica propria is thin and firmly attached to the eyelid. Over its greater extent, the conjunctiva is smooth, but toward the region opposite to the free edge, folds are formed. There may be some small tubuloalveolar glands in the tunica propria here. They are the glands of Waldeyer.

Beneath the tunica propria is found a dense plate of white fibrous tissue called the tarsal plate (incorrectly called cartilage). This is wedge-shaped, with its thicker edge at the margin of the lid. It extends a little over one-half the height of the lid, and at its end an accessory tear gland is found, the gland of Krause. It contains a number of compound racemose glands, the ducts of which open upon the free margin. These are the Meibomian, or tarsal glands, and number about thirty in the upper, and about twenty in the lower lid. They resemble sebaceous glands in structure and the alveoli are filled with cells that are in varying stages of fatty change; the ducts are lined by stratified squamous cells. At the margin of the lid muscles fibers marginal muscles are seen behind the ducts. These glands secrete an oily substance that lubricates the edges of the lids, prevents them from uniting, and ordinarily keeps the tears from overflowing.

Between the tarsal plate and the skin surface, is found the subcutaneous fibrous tissue. In this layer is the muscle of the eyelid, which is chiefly of the voluntary variety, although some smooth muscle is present. This smooth muscle tissue constitutes the Superior and Inferior
tarsal muscles. Some voluntary muscle fibers are found between the cilia and Meibomian gland; these constitute the *musculus ciliaris Riolani*. In the tarsal connective tissue are found smooth muscle fibers that are attached to the proximal end of the tarsal plates; these constitute the **lid-muscle of Müller**. *Diffuse lymphoid tissue* and even solitary nodules may be seen in varying quantities in the tunica propria.

The **skin** covers the outer surface. Its structure is the same as in other places, and it contains many sebaceous and sweat-glands and

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**Fig. 314.—Section of an Eyelid of a Child at Birth.**

A, Accessory tear gland; C, conjunctiva; P, palpebral margin; S, skin surface; T, tarsal gland. (Photograph Obj. 32 mm., oc. 5 X.)

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fine hairs. Pigmented cells are found in the corium. Very little fat is found in the loose subcutaneous tissue.

At the edge of the lid, are seen two rows of heavy hairs, the **cilia**, or **eyelashes**. They pass deeply into the corium, and last about four months. Between the cilia and the ducts of the Meibomian glands, are some **coiled tubular** structures called the **glands of Moll**. These are **ceruminous glands**, and resemble those of the external ear. Their ducts at times are seen to open into the follicles of the cilia.

The skin at the conjunctival margin forms an acute angle, while above the ciliary region the angle is obtuse. This serves to distinguish these two margins.

The **conjunctiva** lines the internal surfaces of the eyelids, and is then reflected over the eyeball from the insertion of the muscles to
the cornea. It is loosely attached to the eyeball. Here the stratified cells alone continue upon this organ. It consists of peculiar *stratified columnar cells*, *basement membrane* and *tunica propria*. In the latter lymphoid tissue is often present in abundance. That part of the conjunctiva which is reflected from the eyelids to the eyeball is called the *fornix conjunctive*. Here the conjunctiva is loose, attached to the underlying tissues as well as to the eyeball. This laxity and the presence of the orbital fat permit the great freedom of motion of the eyeball.

At the inner angle, or **canthus**, of the lids is seen, in lower animals, a **third eyelid**. This is called the *plica semilunaris*, or *membrana nictitans*. In lower forms, a *distinct tarsal plate is present*, which is seldom present in man. Here it is usually a small fold, covered by *stratified squamous* cells, in which some glands may be found.

The **carnucle** is a little patch of skin at the inner canthus. It contains hair follicles, sweat-glands, adipose and muscle tissues within its corium, and is covered by *stratified squamous* cells. A little voluntary striated and some smooth muscle tissues are present.

Within the eyelid, **two arterial arches** are formed, one at the proximal edge of the tarsus, the **external**, and the other at the edge of the lid, the **internal**. These arches are produced by the vessels coming from the inner and outer canthi. The smaller branches pass to the glands and conjunctiva of the lid, where they form delicate plexuses.

The **lymphatics** form a close, delicate plexus beneath the conjunctiva, and a loose set at the upper margin of the lid, that communicate with each other. The branches of the latter possess valves.

The **nerves** give off branches to the muscles and skin, and then form a plexus beneath the conjunctiva. The latter supplies the glands, cilia and conjunctiva, forming, in the latter, a subepithelial plexus and sensor organs, such as *conjunctival corpuscles* and *bulbs*.

**THE LACRIMAL APPARATUS**

The **lacrimal apparatus** consists of the **lacrimal gland**, the **canaliculi**, the **lacrimal sac** and the **nasolacrimal duct**.

The **lacrimal gland** is a *compound tubular* organ of a serous character. Like the mammary gland, it is a *multiple compound gland*, as
it is composed of six or seven individual glands merely bound into one mass. Each has its own duct that opens upon the conjunctival surface.

Each gland is covered by a delicate capsule of white fibrous tissue that divides it into lobes and lobules. The lobules consist of the tubular acini, which are lined by simple columnar, or cuboidal cells. The cytoplasm of these is granular, and the nuclei have a basal position. The cells that have just discharged their secretion are small and the cytoplasm is granular. During the resting stage the cell becomes swollen and the cytoplasm is usually clear. The nucleus has a basal position. With the discharge of the secretion the cells are again smaller and more granular. These cells rest upon a basement membrane, containing basket cells, which is supported by interstitial connective tissue of a fibroelastic nature. The intra-lobular and interlobular ducts are lined by simple columnar cells; the main ducts are lined with stratified columnar cells.

The blood-vessels are numerous and form close capillary plexuses around the tubules.

The nerves form a subepithelial plexus, but the exact mode of ending is not known.

Each canaliculus has a lining of stratified squamous cells that rest upon the tunica propria and fibroelastic layer. Outside of the
tunica propria is seen some voluntary striated muscle, chiefly longitudinally arranged.

The opening of the canaliculus is called the punctum, and at this point some of the muscle fibers are circularly disposed, forming a sphincter muscle.

The sac and duct are lined by stratified columnar cells. In the tunica propria, considerable diffuse lymphoid tissue is found. Occasionally, in the lower end of the duct, ciliated epithelial cells are present.

Within the orbit, the eyeball is surrounded by a serous membrane called the capsule of Tenon. The space enclosed is the space of Tenon, or the episcleral lymph space. This space aids in the movement of the eyeball.
CHAPTER XIX

THE EAR

The ear (*orgonan auditus*) is made up of three parts, the *external*, *middle* and *internal*.

The *external ear* receives the sound waves and conducts them to the *middle ear*. The vibrations of the *drum* are carried across the middle ear and conducted into the *internal ear*, where they are translated into the proper nerve impulses and conveyed to the temporal lobe of the cerebrum.

The *external ear* consists of the *pinna* and a short *canal*, the *external auditory canal*.

The *pinna*, or *auricle* is covered upon both surfaces by skin and in the center is a mass of elastic cartilage. It is very irregular but is adapted to catch the sound waves. The skin is in no way different from that of the general body surface and possesses fine hairs and some sweat glands. Connected with the small hairs are large sebaceous glands. The irregular mass of elastic cartilage occupies the pinna proper and does not extend into the *lobule*. The latter is the lower, soft portion and this is very vascular. The *cartilage* is surrounded by a perichondrium to which the derma and the intrinsic aural muscles are attached. The firm attachment of the derma prevents movements of the cartilage. The *matrix* consists of chiefly elastic tissue that forms a network in which are groups of large cartilage cells imbedded in a small amount of hyalin substance. The elastic tissue is less prominent in the child than in the adult. In the child at birth this reticulum responds readily to the reticulum stain and not to the elastica stain. Adipose tissue is not present in the pinna.

The *external auditory canal* consists of *outer cartilaginous* and *inner bony portions*. Both portions are lined by skin which is an extension of that of the pinna. This consists of *stratified squamous*
cells that rest upon a *basement membrane* and *derma*. In the skin of the outer part there are numerous, large, stiff hairs, sebaceous glands and some coiled tubular glands that secrete the *ear wax*. These *ceruminous glands* are analogous in structure to the sweat glands; the functionating cells, however, contain some fine brownish pigment granules. The *derma* is attached to the tube-like continuation of the elastic cartilage of the pinna.

The skin of the inner part is thinner and is attached to the bony wall of the canal. Some very fine hairs may be present in the outer part but near the tympanic membrane part of the canal hairs and glands are absent. The uppermost layers, at least, of the external auditory canal move constantly from within, outward. By this means the cerumen is ordinarily moved to the outlet.

**THE MIDDLE EAR**

The [middle ear](#) comprises the *tympanum*, *membrana tympani*, *auditory ossicles* and *auditory tube*.

The [tympanum](#) (*cavum tympani*) consists of the *tympanic cavity proper*, the *attic* and here may be added the *mastoid cells*. The *tympanic cavity proper*, or *atrium* is a narrow space that is nearly parallel to the sagittal plane of the body. It measures about 15 mm. in height and length, but the distance between the lateral and medial walls varies; at the top it is 6 mm., in the middle 2 mm., at the bottom 4 mm. About the level of the tympanic membrane the tympanic cavity forms a recess called the *attic*, or *epitympanum*. This contains most of the incus and half of the handle of the malleus and communicates with the mastoid antrum. From the lower part of the anterior wall the auditory tube extends to the pharynx. Upon the medial wall are *two openings*, in dried specimens. The *upper* is oval in shape and is called the *fenestra vestibuli*. This measures about 3 mm. horizontally and 1.5 mm. vertically. In the fresh condition this opening is blocked by the foot of the stapes and its annular ligament. Beneath this is the *second opening* that is circular in outline. This is the *fenestra cochleae* and in the fresh condition it is closed by the *membrana tympani secundaria*.

The *tympanic antrum* is about 8 mm. by 10 mm. and connects the epitympanum with the mastoid cells. The *mastoid cells* vary
in number and size and may extend almost to the tip of the mastoid process. They are usually quite numerous in the adult and are said not to be developed until the sixth year. These cells are lined by an extension of the mucous membrane of the tympanic cavity and the epithelium is more of the flattened or squamous type.

The *tympanic cavity* and its extensions are lined with a *mucous membrane* that is continuous with that of the pharynx through the auditory tube. The *cells* are of the pseudostratified ciliated variety, chiefly, though parts of the cavity may possess nonciliated cells and even stratified squamous cells. Upon the ossicles, ligaments and tympanic membrane the cells are nonciliated. These cells rest upon a delicate *basement membrane* and *fibroelastic tunica propria*. The latter is attached to the periosteum of the bony boundaries very firmly. Small mucous glands are found in the *tunica propria* and diffuse lymphoid tissue may also be present. The *antrum* and
Mastoid cells are lined by low polygonal or flattened epithelial cells. The tunica propria throughout is quite vascular.

The tympanic membrane is an elliptical, disc-like membrane that slopes downward, medially and backward. It is about 10 mm. in its vertical dimension and about 9 mm. from side to side. It separates the middle ear from the external auditory canal. Its circumference is thickened by the circularly directed fibers of the annulus fibrocartilagineus, that attaches it to the circumference of the medial end of the external-auditory canal. The handle of the malleus is attached to its medial surface and above this attachment and prominence the membrane is flaccid (pars flaccida). The bulk of the membrane is tense (pars tensa). The central part of the membrane is drawn slightly inward by the attached handle of the malleus and this part of the membrane is called the umbo. Externally, it is covered by stratified squamous cells continued from the skin. In this location, the stratum corneum is nucleated, and the corium is thin, except in the region of the handle of the malleus. The middle portion consists of white fibrous tissues arranged as radial, or external, and circular, or internal fibers.

The former becomes thinner toward the center of the tympanum and disappears entirely. The circular fibers are more numerous externally, and become thinner toward the handle of the malleus, where they disappear. Between these two layers is a small amount of loose connective tissue. Peripherally, the fibrous layer becomes thickened to form the annulus fibrosus. The internal surface is covered by simple squamous, or columnar cells that rest upon a basement membrane. In the flaccid area of the drum, the middle layer is absent, so that the internal and external layers touch each other.

The ear bones are the malleus, incus and stapes. These are small masses of osseous tissue, by means of which the sound waves are transmitted from the drum to the internal ear. In the thickest portions they possess Haversian systems. Their articular surfaces are covered with hyalin cartilage. The stapes alone possesses a marrow cavity.

The malleus is the largest having a length of 8 to 9 mm. The main parts are the head and handle. By means of the former it
articulates with the incus and by means of the latter it is attached to the tympanic membrane. The incus is next in size and by means of the body it articulates with the head of the malleus, and by means of the long process it articulates with the stapes. The stapes is the smallest and most delicate of the ossicles. Its head articulates with the long process of the incus and its foot, or base rests in the fenestra vestibuli, to the boundaries of which it is attached by means of the annular ligament.

The muscles of the middle ear are the stapedius and tensor tympani. The stapedius lies entirely within the tympanic cavity and is inserted into the neck of the stapes. By the contraction of this muscle the anterior end of the base is tilted laterally and the posterior end medially, compressing the lymph within the vestibule. It is the smallest muscle in the body. The tensor tympani muscle comes into the tympanic cavity through a special canal and is inserted upon the medial edge of the anterior surface of the handle of the malleus in such a manner that when the muscle contracts the handle is drawn medially and the membrane is made tense.

The auditory tube, or better pharyngotympanic tube, extends from the lower part of the anterior wall of the tympanic cavity to the pharynx. It is about 36 mm. in length and is directed downward at an angle of about 30° to 40° to the horizontal plane and forward and medially at an angle of about 45° to the sagittal plane. It opens in the lateral wall of the nasopharynx. The first part, about 12 mm. is called the bony portion as the tunica propria is attached to the periosteum of the bony boundary. The medial two-thirds, about 24 mm. is called the cartilaginous portion because outside of the tunica propria there is a І-shaped mass of elastic cartilage. At the pharyngeal extremity the cartilage bulges the pharyngeal mucosa in a hook-like manner and this peculiar ridge is called the torus tubarius.

The osseous portion of the auditory tube is lined by a thin mucous membrane that is closely adherent to the periosteum. The lining cells are pseudo-stratified ciliated elements. Glands are absent. In the cartilaginous portion, the mucosa is thicker, and is lined by stratified ciliated cells, among which there are a large number of goblet cells. In the tunica propria, mucous glands and diffuse
lymphoid tissue are seen, and the latter may be formed into solitary nodules near the pharyngeal end. These constitute the tubal tonsils.

The membrana secundaria tympani closing the fenestra rotunda that leads to the internal ear (to the cochlea) consists of connective tissue. This membrane relieves the tension in the cochlea when the perilymph in the scala tympani and scala vestibuli are set into motion by the foot of the stapes. Its middle ear surface is covered by nonciliated cells, while that which lies in the internal ear is covered by mesothelial cells. The base of the stapes with the annular ligament that attaches it to the edge of the foramen, completely occludes the fenestra ovalis, that leads to the vestibule.

The blood supply to the tympanic membrane is important. Its external surface is supplied by capillaries derived from the vessels of the external canal, while the inner surface receives vessels from those of the middle ear. The mucosa of the auditory tube receives blood from both the middle ear and pharyngeal vessels.

Lymphatic vessels follow those of the circulatory system. Those of the external surface of the membrana tympani empty into those of the external canal, while those of the inner surface empty into those of the tympanum. The latter lie in the deeper portions of the tunica propria, and at intervals possess dilatations.

The nerves of the external surface of the tympanic membrane are derived from the auriculotemporal and the auricular branches of the vagus. Both form a close plexus. This supplies the external surface by a subepithelial plexus. The inner surface is supplied by the tympanic plexus, which sends branches to the epithelial layer. Occasionally, minute ganglia are present. The auditory tube receives fibers from the tympanic, as well as from the pharyngeal plexuses.

THE INTERNAL EAR

The internal ear, or labyrinth, consists of two main divisions, the osseous labyrinth and the membranous labyrinth. The osseous labyrinth comprises the vestibule, semicircular canals and the cochlea. The membranous labyrinth consists of the sacculus, utriculus, semicircular ducts and the cochlear duct.
The labyrinth consists of the osseous and membranous portions, which are separated from each other by a lymph space. The bony labyrinth surrounds the membranous portion, and is separated from it by the perilymph. Within the membranous part is the endolymph.

SACCULUS AND UTRICULUS

The vestibule lies between the semicircular canals behind, and the cochlea, in front. It is about 6 mm. anteroposteriorly, from 4 to 5 mm. from above downward and 3 mm. from without inward. Upon its lateral wall is seen the fenestra vestibuli that is closed by the base of the stapes and its ligament. It lodges the membranous sacculus and utriculus.

The bony walls of the vestibule are covered by periosteum, which is lined by a layer of mesothelial cells continued over the trabeculae, that extend from the periosteum to the membranous labyrinth. From this point the mesothelium continues over the external surface of the membranous labyrinth.

The sacculus and utriculus are two membranous sacs of unequal size, that occupy the vestibule and do not communicate with each other directly, but with the ductus endolymphaticus by two small
canals. The **sacculus** is the smaller, and lies anterior to and below the utriculus. It measures about 2 by 3 mm. and is ovoid in form. The **utriculus** is connected with the ampullae of the superior and lateral semicircular canals, while the **sacculus** communicates with the cochlear duct of the membranous labyrinth by means of the **ductus reuniens**.

The walls of the membranous saccule and utricle are composed of bundles of white fibrous tissue arranged into two layers of variable thickness, 5 to 15 microns. The thickest portions are where the nerve fibers leave the maculae acusticae and maculae cribrosae. The cells lining these vesicles consist of *simple polygonal* epithelium, 3 to 4 microns in height, except over the **maculae acusticae**, where they are of the **neuro-epithelial** variety. Upon approaching these areas, the polygonal change to *cuboidal* and become progressively higher until a height of 30 microns is reached. These cells are of two varieties, **sustentacular**, or **supportive**, and **special, neuro-epithelial**, or **hair-cells**.

The **sustentacular** cells are very long, irregular columns, the basal portions of which are branched. The large nuclei, located at various levels in the inner half of the cell, produce a bulging of the cell-body. The granular cytoplasm possesses *pigment granules* of a yellowish color.

The **special**, or **hair-cells**, are also columnar, but not as long as the preceding, and extend through only one-half of that layer. The basal portion of these cells is broad, and contains a large round nucleus; the basal part is continued between the sustentacular cells toward the basement membrane for a variable distance and usually ends in a small knob. In the epithelial layer the terminal fibrils of the vestibular nerve form a plexus and the fibrils of this plexus terminate around these extensions of the hair cells. The distal end is rounded and possesses a cuticular border, the **cupola**, from which projects a **conical cilium** 20 microns long. This extends into the endolymph. Closer examination shows that the cilium consists of many fine hairs. The cytoplasm of these cells is granular and contains a yellowish pigment.

The **otoliths**, or **otoconia** are small, prismatic calcium carbonate crystals, 1 to 15 microns long, occurring in the vesicles, and imbedded
in a gelatinous substance the *otolith membrane*, that covers the neuro-epithelial cells. This *otolith membrane* contains many of these prisms.

The *ductus endolymphaticus* and its dilated extremity, the *sacculus*, have the same structure as saccule and utricle.

A *plexus of nerve fibers* is found beneath the neuro-epithelium. The fibers extend into the epithelial layer, and as they pierce the basement membrane, the myelin sheath blends therewith, and leaves the dendrite free. These latter form fibrillae that are terminate in relation with the neuro-epithelial (hair) cells; some pass higher between the supportive cells.

In these areas, the *capillary plexuses* are especially numerous.

**THE SEMICIRCULAR CANALS**

The *osseous semicircular canals* are behind and above the vestibule. They are *three* in number and are called *superior, lateral* and *posterior*. Each forms about two-thirds of a circle and is about 1.0 to 1.5 mm. in diameter. One extremity of each is dilated and this dilation is an ampulla that is about 2 mm. in diameter. These canals communicate with the vestibule by five openings. The *superior canal* is vertical and is placed transversely to the long axis of the petrous portion of the temporal bone. Its length is about 18 mm. The *lateral canal* is placed almost horizontally and measures 12 to 15 mm. in length. The *posterior canal* is 20 mm. in length. The opposite lateral canals lie in the same plane while the superior canal of one ear is parallel to the posterior canal of the other ear.

The *semicircular ducts*, or *membranous semicircular canals* are united to the periosteum by *trabeculae*, as in the preceding, and the mesothelial cells pursue the same course in the lymph space. The epithelium resembles that of the saccule and utricle, being polygonal, but slightly larger, varying from 12 to 16 microns. Specialized areas, *cristae acusticae*, are found in the floor of the *ampullae* (dilated portion at the end of each canal). Here the thickened fibrous wall forms the *transverse septum*. The specialized areas resemble those of the saccule and utricle. The hairs of the neuro-epithelial cells are un-
usually long, some reaching to the middle of the lumen. They are called the **auditory hairs**, and arise from the **cupola** of the cells.

The **nerve** fibers pass to the thick transverse septum, and form a plexus from which finer fibers follow the same course as in the saccule and utricle.

The **blood-vessels** are distributed in the same manner.

**THE COCHLEA**

The **cochlea** represents a tapering tube of 20 to 30 mm. length spirally wound for about two and three-quarters turns about a vertical bony axis, the **modiolus**. The broad portion is the base that measures about 9 mm. across and is in relation with the inferior fossula of the internal auditory meatus. The end of the coil is the apex, or **cupola**; it is about 5 mm. above the base and 2 mm. above the modiolus. The basal end of the tube is 2 mm. in diameter. The **modiolus**, or **axis** is a conical mass about 3 mm. high and is pierced by many foramina for the transmission of nerve fibers. Upon the tube side the modiolus sends out a bony shelf that extends about halfway across the tube and is called the **lamina spiralis (ossea)**. The division of the tube is completed by the **basilar membrane** that extends from the spiral lamina to the lateral wall of the osseous tube. As a result of these shelves two passageways are formed, the **upper** the **scala vestibuli** and the **lower** the **scala tympani**. At the modiolus edge of the spiral lamina there is a canal that extends the length of the spiral shelf and in this spiral canal the **ganglion of Corti** (ganglion spirale) is lodged. The spiral lamina and the basilar membrane extend to within a short distance of the end of the cochlear tube and at this point the two scala communicate with each other. This communication is called the **helicotrema**. Both contain **perilymph**.

The **ductus cochlearis**, or **scala media**, is a delicate, triangular, membranous canal that lies in the **scala vestibuli** its outer basal angle is attached, **externally**, to the outer wall, and the inner angle, **internally**, to the lamina spiralis. It contains the endolymph, and has an important epithelial lining. The **basilar membrane** separates it from the **scala tympani**, and the **membrane of Reissner**
from the **scala vestibuli**. The *latter* membrane is quite thin, about 3 microns, and extends from the lamina spiralis (internal to the crista) to the bony wall of the scala vestibuli at an angle of about 45°. Upon its vestibular wall, it is covered by a layer of *pigmented mesothelial cells* which rest upon the middle connective tissue layer, in which capillaries may be found in the child but not in the adult. The epithelial lining of its inner surface consists of a single layer of **polygonal cells**. The **outer wall** of the scala media, for about two-thirds of its distance from the upper angle, is covered by **cuboidal cells**, within which there are quite a number of capillaries, a *very unusual condition*. This is the **stria vascularis**. At the lower margin of the latter is a small projection, the **prominentia spiralis**; this, with the lower part of the outer wall, is covered by flattened cells that become columnar as the basilar membrane is reached. The tissue external to these cells is quite thick, and extends over the vestibular wall above the attachment of Reissner's membrane, and below the attachment of the basilar membrane. This is the

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**Fig. 318.—Horizontal Section of the Cochlea of a Kitten. X 8.** *(Stöhr's Histology.)*

The winding ductus cochlearis, x, crossed the plane of section five times. Above it in every case is the **scala vestibuli**, and below it is the **scala tympani**.

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ligamentum spirale. At the attachment of the basilar membrane this ligament forms a projection called the crista basilaris.

In that portion of the ligamentum spirale, between the prominencia spiralis and the crista basilaris (called the sulcus spiralis externus) groups of epithelioid cells may be found. These Shambaugh has shown possess tubules that connect with the sulcus and he considers them branched tubular glands. He believes that the endolymph of the ductus cochlearis is derived from these glands and to a certain extent from the stria vascularis.

The floor of the ductus cochlearis (tympanic side) consists of the basilar membrane that unites the spiral prominence to the
spiral lamina; this is completed by the **limbus** that extends from the end of the spiral lamina to the attachment of Reissner's membrane.

The *outer* portion of the **limbus** is thicker near the membrane, due to an increase in the periosteum. This portion contains clefts and depressions that deepen toward the inner half, at which point the cleft is quite deep, and little projections, separated by lateral clefts, give rise to the **auditory teeth**, which number about 2500. These teeth and projecting areas are covered by *simple polygonal cells*, while the clefts are lined by *columnar elements*. The *inner* half of the **limbus** consists of a slightly projecting mass, the **superior lip**, due to the sudden decrease in thickness, and a lower portion that continues over the bony lamina toward the basilar membrane; the latter is the **inferior lip**. Between these lies a little space, the **sulcus spiralis**, due to the sudden decrease in thickness of the periosteum. The **sulcus** is lined by *flat cells*.

The **basilar membrane** is covered on its tympanic surface by the **tympanic lamella**, made up of spindle-shaped cells and delicate fibers, representing an incomplete change to mesothelial cells. This is continuous with the periosteum of the scala tympani. Above this layer is the **membrana propria**, that consists of fibers radially placed and which extend from the crists basilaris to the ligamentum spirale. As the modiolus, or axis of the cochlea is thickest at its base the basilar membrane is narrowest at the base of the cochlea. This membrane gradually becomes wider as the apex of the cochlea is reached; thus the fibers of the basilar membrane are shortest at the base of the cochlea and gradually increase in length toward the apex, where the longest are found. These fibers have been called **auditory strings** and are said to number about 24,000. The shortest are the coarsest and the longest are the finest. This structure is covered by a homogenous basement membrane. This membrane seems to support the epithelium upon its upper surface. The basilar membrane, according to Hardesty, is a flat tendinous structure in which these fibers are too rigid to permit of vibrations of a resonant type. The outer end of the basilar membrane is covered by the **cells of Claudius** that continue toward the outer wall and pass into columnar and flattened elements that are found upon the basilar crest. These cells possess spherical nuclei imbedded in a slightly
granular and pigmented cytoplasm; they represent a continuation of the cells of Hensen. Between the limbus and the cells of Claudius lies the organ of Corti, composed of neuro-epithelial and sustentacular cells. This organ is divided into an inner portion, the membrana tectoria, and an outer part, the zona pectinata.

The cells of the organ of Corti are the pillar, hair and sustentacular cells.

The pillar cells are peculiar S-shaped elements possessing a striated body, surrounded by a narrow band of cytoplasm. The latter is thickened at the base (tunnel side), and in this part is seen the nucleus. The lower end rests upon the basilar membrane and is expanded to form the foot; the upper end likewise undergoes an expansion, termed the head. These cells form two rows, inner and outer; they articulate above, and form a triangular canal called Corti's tunnel. This contains a semi-solid intercellular substance. The inner cell, being shorter, is more nearly vertical, and its head bears an articular facet for the reception of the articular head of the outer cell. The inner cells are more numerous and thinner than the outer, about 6000 to 4500, respectively. The head process of both cells continues externally as a thin, shelf-like process called the head-plate. Of these, the inner head-plates lie above, but are shorter than the outer. The outer are called the phalangeal processes, and by their union with the cells of Deiter, form the membrana reticularis.

The neuro-epithelial cells are distributed upon the inner and outer surface of the pillar cells. They are the hair cells, and of these there are two rows, inner and outer. Like the hair cells of the preceding, and the neuro-epithelial cells of the nasal mucous membrane, they are about half the length of the sustentacular, or pillar cells, and are columnar elements containing a granular cytoplasm and an oval nucleus. The outer end has a cuticular border, from which about twenty hairs extend. The outer cells are longer and narrower than the inner, and more numerous. There are about 12,000 outer and 3500 inner hair cells. Usually one hair cell is present for each two pillar cells. The outer hair cells are found in three or four rows, which are separated by the ends of phalanges of Deiter's cells and the membrana reticularis. The inner row rests upon the outer pillar cells; the cells of the next row lie opposite to the rods,
and the third row alternates, producing a peculiar *checker-board*
appearance, the ends of the hair cells being separated from one
another by the ends of the Deiter cells.

The *sustentacular*, or *Deiter* cells are *internal* and *external*.
Each cell consists of a thin *pyramidal process* and a large *basal*
part that contains the nucleus. The *intercellular spaces of Nuel*,
between the cells of the organ of Corti, contain a substance like that
in the tunnel of Corti. Internally, Deiter’s cells pass through the entire layers, and are continuous with the cells of the sulcus. Externally, they form the phalanges that help produce the membrana reticularis. A surface view will show both sustentacular and neuroepithelium; a basal view, however, will show only sustentacular elements. Just external to the Deiter cells are other sustentacular elements, the cells of Hensen. These extend to and continue with those of Claudius. Extending over the organ of Corti and arising from the upper lip of the limbus is a membrane composed of delicate fibers and interfibrillar substance. This is the membrana tectoria, or Corti’s membrane. At one time this was part of the cells beneath, those of the sulcus and auditory teeth; it represents a cuticular border. According to Hardesty the membrana tectoria of the pig is about 3 mm. long and its basal end is only about one-fifth the thickness and breadth of the apical extremity. It consists of fibers that are fine but of equal size, imbedded in a jelly-like mass of keratin. Most of the fibers are free from attachment at both ends.

The divisions of the auditory nerve are vestibular and cochlear. The vestibular arises from the sacculus, utriculus (maculae) and the semicircular canals (cristae). These fibers are the dendrites of the cells in the ganglion of Scarpa which lies in the internal auditory meatus. The axis cylinders of these cells pass to the oblongata. The cochlear portion arises mainly in the cochlea, receiving some fibers from the sacculus and posterior semicircular canal, and is made up as follows:

In a little bony canal in the lamina spirale is a strip of gray nerve tissue that is called the ganglion spirale (Corti’s ganglion). This consists of bipolar cells, one branch, the dendrite of which passes outward into the organ of Corti, while the other, the axis cylinder, passes through a minute canal in the axis to the central canal, where it meets other fibers from different levels. These pass to the base and to the internal auditory meatus, as the cochlear branch, and then to the oblongata. The dendritic branches of these ganglion cells form a plexus in the minute canal of the spiral shelf. Toward the organ of Corti the lamina is pierced by many canals called the foramina nervosa through which numerous fibers, the myelinated
dendritic branches, pass, along its inner epithelium, to the organ of Corti. Upon entering these canals, the myelin sheaths and neurilemmae are lost, and the naked dendrites, in bundles, continue. Each bundle separates into two, one of which remains at the inner surface and the other passes along the outer side of the pillar cells. The latter lies in the tunnel. Other dendrites cross the tunnel and pass to the outer side of the outer pillar cells and form several bundles between the Deiter cells. From these various bundles, fibrillae terminate in relation with the hair cells.

The blood-vessel supplying the internal ear is the internal auditory artery that passes into the internal auditory meatus with the acoustic nerve. Its two main branches are the cochlear and vestibular arteries. The cochlear artery gives off a branch, the vestibulocochlear artery that sends branches to the maculae of the sacculus, the posterior ampulla and neighboring portions of the posterior semicircular canal, first part of the cochlear duct and utricle. The main portion of the artery passes into the modiolus and supplies almost the entire cochlea.

The vestibular artery supplies the sacculus, utriculus and semicircular canals; the capillary plexus is especially well developed in the neuro-epithelial areas.

The blood is collected by venules that have a course that corresponds somewhat to that of the arteries. The blood of the cochlear artery is carried from the organ by the vena aqueductus cochleae and is emptied into the internal jugular vein. Some of the blood of the cochlear artery is carried by the internal auditory vein and emptied into the inferior petrosal sinus. The blood of the vestibular artery is carried by the vena aqueductus vestibuli and is emptied into the superior petrosal sinus.

Lymph vessels are few but lymph spaces are numerous and large in the internal ear. The space between the osseous and membranous labyrinths is an extensive lymph space and contains the perilymph. This space communicates with the subdural lymph space by peri-neural lymph vessels and vessels around the aqueductus cochleae. The membranous labyrinth contains the endolymph and this can get to the subdural space through the endolymphatic duct and the aqueductus vestibuli.
When the tympanic membrane is caused to vibrate by sound waves its vibrations are transmitted to the internal ear by the flexible, jointed rod of ear bones which stretches across the middle ear from the tympanic membrane to the fenestra ovalis. Here the foot of the stapes transmits the vibrations or oscillations to the perilymph of the scala vestibuli and the waves produced are carried up this scala to the apex of the cochlea and then over the end of the lamina spiralis, through the *helicotrema*, to the scali tympani; the waves continue down the scali tympani, under the basilar membrane, and spend themselves against the *membrana tympani secundaria*. Helmholtz believes that the waves set into motion the auditory strings of the basilar membrane, which are tuned to various pitches and therefore respond to certain sound waves only.

According to Hardesty and others the *membrane of Reissner* and *membrana tectoria* are responsible and as the waves first travel up the scala vestibuli Reissner's membrane is set into motion and the endolymph of the *scala media*, or *cochlear duct*, is set into corresponding waves. These waves cause the membrana tectoria to vibrate synchronously. As a result the hair cells tuned up to each certain wave pitch is stimulated and an impulse is started toward the brain.
CHAPTER XX

THE SENSES OF SMELL, TASTE, AND TOUCH

THE ORGAN OF SMELL

The nasal mucosa is divided into respiratory and olfactory portions. The lower portion of the respiratory area, called the vestibule, is lined by stratified squamous cells to the turbinated bone. Here a great many hairs, sebaceous and mucous glands that extend for a short distance, are encountered. Above the turbinated bone, the epithelium is of the stratified ciliated variety, and many goblet cells are present. The hairs at the external meatus are large and are called vibrissae. The tunica propria contains much lymphoid tissue and an extensive venous plexus. Mucous and serous glands are also present in great numbers in the region of the turbinated bone and nasal septum; they are largest near the floor. The mucosa is 4 mm. thick in this area.

The olfactory mucosa is usually prominent on account of its yellow color, but this does not indicate the entire olfactory membrane. It is very thick, and ciliated cells no longer exist. It lies in the superior and part of the middle meatus of the nose covering the superior conchal process and the nasal septum. The epithelium is of three varieties, the sustentacular, neuro-epithelial elements and basal cells.

The sustentacular cells are irregular, and possess a peripheral segment which is cylindrical, and a basal that is narrow and irregular. The peripheral segments form a row of columnar elements. The oval nuclei form a regular band or row. The cytoplasm contains granules and pigment near the inner end, the former being arranged in rows. A cuticular border is present, and forms the membrana limitans olfactoria. The inner segments are irregular, and usually branch at their internal ends.
The neuro-epithelial elements, or olfactory cells, consist of peculiar, inconspicuous strips of protoplasm possessing an enlargement near the middle, in which lies a large, round nucleus. The latter form a band or zone of spherical elements. These cells are bipolar elements. The peripheral ends of the rods extend, between the supportive cells, to the free surface as cylindrical processes that project beyond the surface. The terminal part really consists of six or eight delicate, hair-like processes called the olfactory hairs. At their connections with the process proper there is a hemispherical vesicle that connects the hairs and process. The basal ends are varicose and pass to the basement membrane. This end continues through the basement membrane into the tunica propria and continues as an amyelinated nerve fiber to the olfactory bulb. It represents an axone and an olfactory cell is a real nerve cell. In the
olfactory bulb all of these processes terminate in and form part of the glomerular layer.

The basal cells are small and irregular elements that send processes between the upper layers and, internally, rest upon the basement membrane. The cytoplasm is finely granular and may send short processes between the branches of the sustentacular cells.

The tunica propria consists of a loose, thick network of fibroelastic tissue. This supports the racemose (serous) glands of Bowman whose functionating epithelium possesses a brownish, or yellowish pigment. These glands are numerous, forming a continuous layer. It also contains a plexus of myelinated nerve fibers.

The accessory nasal cavities, or paranasal sinuses, are lined with an extension of the mucosa from the nasal fossa. The mucosa is seldom over 0.02 mm. in thickness and is firmly attached to the periosteum of the bony boundaries. It is readily thickened by pathologic processes especially at the openings of the maxillary and sphenoidal sinuses, as the tunica propria here is looser. Glands are not numerous in these cavities but in the sphenoidal and maxillary sinuses the glands are most numerous around their outlets.

The cells are usually pseudostratified ciliated elements that rest upon a basement membrane that is supported by a thin tunica propria. The latter consists of areolar tissue and is attached to the
periosteum of the bony boundaries. Any glands present are located in this layer. The cilia in all of the sinuses wave toward the outlet so that they drain into the nasal fossa.

The blood-vessels are numerous. The arterial branches form a dense subepithelial plexus, including a network around the glands. The veins are large in number and size, especially upon the inferior turbinate.

The lymphatics lie in the lower part of the tunica propria; in the olfactory area, an extra set of vessels occurs in the superficial portion. These communicate with the channels around the nerves.

The nerves are those of ordinary and special sensation. The former are derived from the trigeminus and do not connect with the cells. The latter form the olfactory fila, or nerves. The fibers of the olfactory nerves are the axone processes of the neuro-epithelial elements; these pass through the basement membrane to the tunica propria, to form small bundles that are surrounded by perineural lymphatic sheaths; from this position in the tunica propria they pass through the openings in the cribiform plate of the ethmoid bone and terminate in the glomerular layer of the olfactory lobe. These fibers possess neither myelin sheaths nor neurilemmæ.

THE SENSE OF TASTE

The sense of taste is due to the taste-buds. These are not restricted to the circumvallate papillæ of the tongue, but are found in the papillæ foliatae, in the ventral surface of the epiglottis, at times in the fungiform papillæ and in the soft palate and uvula.

The organs are barrel-shaped, lie entirely within the epithelial layer of the mucosa and consist of three kinds of cells, the sustentacular, gustatory and basal cells.

The sustentacular, or supporting cells are elongated elements; the outer extremities are pointed and form the boundary of the gustatory pore. The basal extremities are broad and irregular and rest upon the basal cells, to which they may be connected by delicate protoplasmic processes.

The gustatory cells are of the neuro-epithelial type. These are slender, irregular strips of protoplasm in which the large centrally
placed nucleus produces quite a bulge. The basal extremity of each cell is branched and connected to the basal cells by delicate protoplasmic processes. The peripheral extremity is continued as a delicate hair-like process that extends into the epithelial canal beyond the taste-pore and almost to the surface of the epithelium of the mucosa. The finely granular cytoplasm contains a deeply staining, rod-shaped nucleus.

The basal cells are flattened elements that lie at the base of the taste-bud. The cytoplasm is small in amount and extends as many processes that connect with the other cells of the taste-bud. The nucleus contains but little chromatin and the cells are supposed to be supportive in function.
The nerve fibers arise from the subepithelial plexus of nerve fibers. These terminal fibers end in three ways. Some enter the organ (intragemmal) where they divide into fibers that are varicose and end in knobs between the neuroepithelial cells. Others surround the taste-bud (circumgemmal) and the fibrils terminate upon the sustentacular cells. Others terminate between the epithelial cells of the neighboring mucosa (intergemmal).

THE SENSE OF TOUCH

The sense of touch is not limited to any special region, but it is best developed in certain areas, as the palm and sole. It is restricted to the skin, and represents a modification of general sensibility. In the papillae of the skin, especially that of the sole and palm, are found the tactile corpuscles of Meissner.

These are elongated structures that measure from 100 to 180 microns in length and 35 to 50 microns in diameter. Each consists of a capsule of white fibrous tissue that encloses a number of flattened masses of protoplasm with transversely placed nuclei. One, or more, nerve fibers is connected with each organ and upon contact with the corpuscle the neurolemma is lost. The myelin sheath soon follows and the naked fiber, after a spiral course, divides into a number of varicose fibrils that terminate in small bulbous enlargements near the capsule. These structures are found throughout the skin but are most numerous in the derma of the palmar surface of the finger tips. They may be as numerous as 20 to the square millimeter and are in the papillae of the stratum papillare, just beneath the basement membrane. They are also found in the derma of the plantar surface, in the nipples, lips, glans clitoris and glans penis and the conjunctiva. They convey sensations of pain, pressure, warmth and cold. It is said that two sets of sensor fibers pass to them, one for light pressure and slight temperature changes and the other for pain and extreme temperature changes.

The Pacinian corpuscles (Vater) are also called lamellar corpuscles. Each consists of a capsule, inner bulb and end-knob. The capsule is composed of a great number of lamellae of white fibrous connective tissue concentrically arranged and bound together by an intracap-
sular ligament. These lamellæ are from forty to sixty in number and the outer ones are more widely separated from one another than the inner ones. Each lamella is said to consist of both white fibrous and yellow elastic tissues and is covered upon both surfaces by mesothelial cells, thus forming a series of lymph spaces.

The inner bulb, or core is a cylindrical mass of protoplasm that may show striations and nuclei. It is thought to consist externally of flattened nucleated cells surrounding the more homogeneous central portion. A single nerve fiber enters each corpuscle. As it pierces the capsule the neurolemma blend with this and the myelin sheath is lost when the inner bulb is reached. The naked fiber, showing its fibrillation, in properly stained sections, passes through the core at the end of which it expands into a knob-like structure, the end-knob. In this the terminal fibrils form a dense meshwork. If the fiber divides in the core, the latter also divides. A small amyelinated nerve fiber has been found, by Solokoff, passing to the core and terminating upon it in a reticular manner.

A small artery and vein accompany the nerve into the corpuscle. The artery forms capillary vessels that form loops between the lamellæ; one capillary accompanies the nerve and courses along the outer surface of this for a variable distance. The blood is collected by a small vein that leaves at the nerve entrance.
These organs are visible to the unaided eye, measuring usually 2.5 mm. in length and 1 mm. in diameter. They are found in the deep parts of the derma, along tendons, around joints, in the peritoneum, in the mesentery (in lower animals) and in the pancreas of the cat.

The conjunctival corpuscles, or bulbs are spherical, oval or pear-shaped bodies in which the cells are not regularly arranged. The nerve fiber, upon piercing the structure, becomes amyelinated and passes through a central core of homogeneous protoplasm and terminates in a bulbous manner. The core is surrounded by a capsule that is composed of flattened cells. These organs average from 60 to 400 microns in length and may have as many as ten nerve fibers connected with one organ.

The genital corpuscles, or bulbs are more complex. Each is divided into two to six knob-like parts. The nerve fiber enters
the organ and divides into numerous branches each of which passes to a segment; here it may continue undivided or form a series of branches. These are surrounded by the capsular cells. These organs measure from 60 to 400 microns in length and 40 to 100 microns in diameter. They are found in the mucosa of the glans penis and glans clitoris and neighboring structures.
CHAPTER XXI

DEVELOPMENT OF FACE AND TEETH

The development of the face is a complicated process, a number of different fetal structures taking part therein. Just after the formation of the head-fold of the amnion there is an area, just precephalad to this groove, in which the ectoderm and entoderm are in contact. This is the buccopharyngeal area. As the head-fold of the amnion advances this buccopharyngeal area is folded ventral so as to form the ventral part of the blunt-head process (see Fig. 254, A, and C, p. 430). By this time this area has become a depression, the oral depression, or stomodeum, the floor of which is the buccopharyngeal membrane. This depression is present at about the twelfth day of intrauterine life. The floor of this depression sinks deeper and the margins become more pronounced.

At about the fifteenth day the lower boundary of the depression becomes formed upon each side into a finger-like process, called the first branchial arch, that soon divides into a shorter upper portion, the maxillary division, and a lower part, the mandibular division. The upper division forms now the lateral boundary and the lower the inferior boundary of the oral depression. At about the same time the tissues in the frontal region become projected in the form of a blunt mass between the maxillary divisions of the first arch, constituting the nasofrontal process. Thus the stomodeum has become a pentagonal fossa. At about the eighteenth day a second finger-like process makes its appearance beneath the mandibular portion of the first arch; this is followed by a third arch about the twenty-first day, a fourth by about the twenty-fourth day, and the fifth and last arch is formed by the twenty-eighth day. The last are less highly developed than the first, and while the lower ones are forming the upper ones are undergoing metamorphosis into their adult structures.
The changes that occur in the branchial arches will be considered first: Each arch consists of a core of mesoderm containing a rod of cartilage and a blood-vessel called the branchial arch vessel; externally the arch is covered by ectoderm and internally by entoderm. The arches are separated from each other by a groove or depression, internally, and externally, and spanning the groove is the visceral cleft membrane consisting merely of ectoderm and entoderm, so that no real complete cleft exists in the early stages of development; in aquatic animals these membranes do rupture to form the gill-clefs. On each side there are four external and four internal visceral grooves or, better, branchial pouches.

The first arch, as previously mentioned, divides into two portions, maxillary and mandibular; the maxillary part unites with nasofrontal process to complete the upper jaw; it itself gives rise to the bulk of the maxilla and most of the palate. The upper jaw is completed by about the fortieth to the forty-second day. The mandibular process unites with its fellow of the opposite side to form the entire mandible, union being completed by the end of the fifth week, or thirty-fifth day. In addition, the cartilage of the mandibular process gives rise to incus and malleus, and sphenomandibular ligament.

The rod of cartilage of the second arch gives rise to the stapes styloïd process, stylohyoid ligament and lesser cornu of the hyoid bone.

The cartilage of the third arch forms the body and greater cornu of the hyoid bone.

The cartilage of the fourth and fifth arches unite and form a single mass, the thyroid cartilage of the larynx.

The first external branchial pouch persists only at its dorsal end to form here the external auditory canal. From both first and second arches in this region the pinna of the ear is developed. The remaining pouches are lost as the arches overlap each other from above downward. Occasionally part of a pouch persists as an enclosed cyst of ectoderm and this is called a branchial cyst. In case a pouch membrane ruptures and permits of a passage-way from the outside to the pharynx it is called a congenital cervical fistula.

The first internal pouch is formed into a tube with its outer end dilated into an irregular cavity, the tympanic cavity; the tube-like
portion connecting this with the pharynx is called the *auditory tube*. That part of the first pouch membrane separating the external auditory canal from the tympanic cavity is the future *tympanic membrane*, or *ear drum*. In the middle of the ventral portion of the first pouch is found a projection, the *tuberculum impar*, which later becomes the anterior, or apical two-thirds of the tongue.

From the region of the second pouch (representing the ventral ends of the second and third arches) we find the tonsil and lateral recess of the pharynx developed, dorsally, while ventrally in the median line the entire thyreoid body is formed, and just lateral of this the dorsal, or basal one-third of the tongue by two masses (one on each side).

In the third pouch region (third and fourth arches) the thymus body, as two lobes, appears and also the inferior parathyreoids.

From the fourth pouch (fourth and fifth arches) the postbranchial bodies and the superior parathyreoids.

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**Fig. 329.—Face of an Embryo of 8 mm. (McMurrich, after His.)**

- *pg*, Globular (median nasal) process of nasofrontal process; *np*, nasal pit bounded externally by the lateral nasal process; *os*, oral pit; *mxp*, maxillary process of first branchial arch.
The nasofrontal process is at first a blunt mass of tissue projecting from the frontal region. As it grows down between the maxillary divisions of the first visceral arch, it becomes thickened along its margins, forming here the median nasal processes; each process contains a little depression that constitutes the nasal pit. In addition, two masses, the lateral nasal processes, develop from the nasofrontal process, at the orbital region, to form the lateral boundary of the nasal pits. Usually by the fortieth or forty-second day the nasofrontal process has filled the gap between the two maxillary processes of the first arch, and union of these parts is completed. As a result the nasal pits are separated from the mouth cavity. The derivatives of the nasofrontal process are the middle of the upper jaw (intermaxillary bones), the middle of the upper lip, the tip, septum, alae and bridge of the nose and the vomer. The crevice between lateral nasal processes and the maxillary division of the first arch extends from the orbit of the nose cavity. When this crevice is closed a cord of epithelium is inclosed, and by hollowing out this cord of cells forms the nasolacrimal duct. If the lip portions of the nasofrontal process and first arch fail to unite, a malformation, unilateral, or bilateral hare-lip, is produced. If the bony parts within are affected, various forms of cleft-palate result.

The palate is developed in the form of three shelves, two lateral from the maxillary processes of the first arch and one frontal, triangular, from the nasofrontal process.

At about the eighth week union between the lateral shelves at the front end and the nasofrontal portions begin; by the ninth week union as far as the posterior border of the future hard palate is completed, by the eleventh week the soft palate is finished and by the end of the third month the uvula is complete. Various malformations may occur here, as partial, or complete cleft-palate and bifid uvula. Then after the upper jaw is completed two ridges appear upon each jaw, the inner represents the gum and the outer the lip.

The Teeth.—The teeth are developed partially (enamel) from the ectoderm and partially (dentin, cementum, pulp, and peridental membrane) from the mesoderm.

There are two sets of teeth in the mammals, temporary, or deciduous, or milk teeth, and permanent, or succedaneous teeth.
Such animals are *diphyodonts*. Animals that may develop teeth successively without regard to number are *polyphyodonts*.

**Fig. 330.—Four Stages of Tooth Development.**
(After Böhm, Davidoff and Huber.)

A, Formation of the enamel from the dental shelf; B, later stage with early formation of the dental papilla; C, later stage showing enamel sac with its layers differentiating and the dental papilla well advanced; D, enamel sac completed (just preceding enamel formation) connected to dental shelf; dental papilla completed.

1, 1, 1, 1, oral epithelium; 2, 2, 2, 2, basal layer of same; 3, 3, 3, 3, mesoderm of jaw; 4, 4, 4, 4, outer layer of enamel organ; 5, 5, 5, 5, middle layer; 6, 6, 6, inner layer; 7, 7, 7, dental papilla; 8, layer of odontoblasts; 9, dental shelf; 10, follicular sheath.

In the former case the teeth are unlike, and the animals are *heterodonts*, while in the latter case the teeth are all alike and the class is that of *homodonts*.
The deciduous teeth are considerably smaller than the permanent teeth. Their enamel caps are thicker and the neck is more constricted in the temporary teeth.

The teeth begin to develop during the sixth week (shortly after the completion of the lower jaw). From the under surface of the thickened epithelium of the jaw a band of epithelial cells grows into the mesodermal core of the jaw. This is the dental shelf, the earliest indication of the developing teeth. Shortly after the formation of this shelf the epithelium at the area of thickening sinks in forming the dental groove. The dental shelf extends from one end of the jaw to the other and leans toward the median plane of the head, and from the outer free or labial surface ten little germs or buds develop, called the enamel germs. There are ten in each jaw, and they represent enamel organs of the temporary teeth. These buds appear successively; those for the central incisors first, then lateral incisors, first molars, canine, and second molars. The earliest buds appear during the seventh or eighth week. The enamel bud is at first flask-shaped, and its connection with dental shelf becomes smaller. Gradually the surface opposite to the dental shelf connection becomes invaginated by condensing mesoderm; the concavity deepens and a sac is thus formed, while at the same time the dental shelf connection becomes more attenuated. The sac consists of three layers, inner, middle, and outer. The mass of condensed mesoderm that has caused the sac formation of the enamel, but which lies now in the enamel sac, constitutes the dental papilla. During about the tenth week mesoderm in the immediate neighborhood of the enamel sac condenses to form a sheath for the whole structure, and this is called the dental follicle. Meanwhile the dental shelf becomes attenuated and tends to disappear.

The succeeding changes will be described under Enamel Formation, Dentin Formation and Cementum Formation.

Enamel Formation.—The enamel organ now consists of three layers: the outer layer is composed of simple columnar epithelial cells continuous with the inner layer of cells at the base of the organ. They play no part in the formation of enamel. The middle layer consists of a mass of stellate cells varying in thickness as Fig. 330 shows; these cells make up the bulk of the enamel organ and the
meshwork formed by them is filled with a fluid. This layer likewise has nothing to do with the direct formation of enamel, but seems to have a nutrient function. Along the innermost portion of this reticular mass is a group of cells forming a layer called the stratum intermedium. This layer consists chiefly of spherical cells mixed with some columnar elements. Apparently the spherical cells have elongated to the columnar type, probably for the purpose of replacing cells that fail in the innermost layer. This stratum intermedium is looked upon as the reverse layer to the enamel-forming cells; the cells of this stratum are most numerous where enamel formation is most active.

**Fig. 331.—Section of a Developing Tooth of a Cat Embryo.**

(After Piersol.)

A, Outer, B, middle, C, inner layers of enamel organ; D, formed enamel; E, formed dentin; F, layer of odontoblasts; G, follicular sheath; H, dental papilla, mesoderm.
The inner layer is composed of a single row of tall slender, columnar elements; these form a closely packed unbroken layer surrounding the dental papilla and are termed the ameloblasts. The nuclei lie in the peripheral portion of the cells.

Enamel deposition begins during the sixteenth week of intrauterine life, in the temporary teeth. According to Tomes and others, the inner ends of the enamel cells become calcified and converted directly into enamel. An organic matrix is formed in which the enamel is deposited, probably in the form of calcoglobulin globules. The organic matter disappears, leaving the homogeneous, inorganic material representing, no doubt, the fused globules of calcoglobulin. According to Andrews and others, the enamel is secreted from the cell in some form (calcoglobulin), and this solidifies and forms outside of the cell. The first, however, seems to be the more acceptable explanation. Enamel is formed from within outward, so that the youngest enamel is upon the surface while the oldest is next to the dentin.

Capillary blood-vessels have been noted in the enamel organ by Bromell. It seems that before calcification begins that vessels are absent; with the formation of enamel vascularization of the enamel organ begins and is said to persist until the tooth erupts. By the time that the tooth begins to erupt, or, at the latest, when completely erupted, the enamel is fully formed.

Between the enamel organ and the surface of the dental papilla is a layer of homogeneous substance called the membrana preformativa. Reference to this will be made later.

Dentin Formation.—The dentin is derived from the dental papilla; this structure is composed of embryonic connective tissue in which four different kinds of cells are found. Upon the surface of the papilla will be found a single layer of flask-shaped cells, the odontoblasts. These form the membrana eboris from which the dentin is derived. The basal portion of each cell is directed toward the papilla, or centrally, and contains the nucleus. Each cell possesses processes; those which are directed toward the enamel organ constitute the ultimate dental fibers. These cells are differentiated shortly before the formation of dentin begins. Just beneath the layer of odontoblasts the papilla is practically devoid of cells; beneath
this, however, there is a cellular area of mixed cells and then again a central area containing but few cells.

Dentin is first formed at the cutting, or occlusal surface and during the sixteenth week of intrauterine life. The dentin seems to be a secretion from the peripheral ends of the odontoblasts so that the processes in this region are surrounded by the lime salts, thus forming the dental sheaths and tubules; the odontoblasts are always beyond the area of dentin formation. The dentin is laid down from without inward, and in areas where dentin formation is incomplete spaces, that are called the interglobular spaces, remain. As the dentin becomes thicker (by encroachment upon the dental papilla) the dental fibers elongate and the tubules become correspondingly longer. The dentin in the crown portion is formed first, the root portion being completed last. When the teeth begin to erupt their roots are partially formed; by the time that the whole crown is exposed the fang is usually completed. In the case of the incisor

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**Fig. 332.**—Longitudinal Section of a Developing Tooth.  
a, Bone of the alveolar process. (Photograph Obj. 32 mm.)
teeth the roots are usually completed by the time that the tooth begins to erupt.

**Cementum Formation.**—The cementum is also of mesodermal origin. As the enamel organ becomes invaginated by the dental papilla, the mesoderm immediately surrounding the enamel organ condenses to form a sac-like covering, the dental follicle. This structure gives rise to the cementum and the alveolar process of the jaw and its remains constitute the peridental membrane. The follicle is formed shortly after the tenth week. During the earlier stages of development the dental follicle covers the entire enamel organ and is connected with the dental papilla at its base. The follicle upon its outer surface forms bone, and upon its inner surface forms the cementum of the tooth. As the enamel organ grows the follicle seems to recede from the cutting edge until the neck portion is reached; at this point it remains, and as the root is formed by the dental papilla the follicle forms the cementum until the full length of the root is reached. The process of cementum formation is like that of bone, a secretion, and layers are formed as described in the section on the structure of cementum. The cementum and bone of the jaw are developed from the dental follicle, or peridental membrane, at the expense of the latter, it becoming thinner as the cementum and alveolar bone increase in thickness.

The temporary teeth begin to erupt from the sixth to the eighth month after birth and the set is usually completed by the twenty-fourth to the thirtieth or thirty-sixth month. The order of eruption and loss is as follows:

Medial incisors, sixth to eighth month.......................lost about 7th year.
Lateral incisors, seventh to ninth month (7-12).............. 8th year.
First molars, twelfth to fourteenth month (14-15)........... 10th year.
Canines, sixteenth to eighteenth month (18-19).............. 10th year.
Second molars, twenty-fourth to thirty-sixth month (20-24).. 12th year.

The permanent teeth are thirty-two in number. The difference in number of the two sets and later appearance of added teeth is due to the fact that the jaw at certain periods will accommodate only a certain number of teeth, and any attempt to hurry their appearance will interfere with the dental arch. Of these permanent teeth, the molars, twelve in number, are not succedaneous teeth at all, but
primary teeth as will be explained later. The germs for most of the permanent teeth are formed during intrauterine life.

During the sixteenth week a bud appears at each end of the dental shelves; these buds are the germs for the first permanent molar teeth. During the seventeenth week the germs for the central incisors appear from the lingual surface of the dental shelf, opposite the point of

Fig. 333.—Section of Jaw Showing the Temporary (a) and Permanent (b) Tooth Germs. (Photograph Obj. 32 mm., oc. 5 ×.)

formation of the corresponding temporary tooth; the remaining succedaneous teeth follow in order of their eruption. The enamel organs undergo the same changes as previously described, with the exception that the process is somewhat slower, making their eruption somewhat later. As was stated above, the germs for the first permanent molars appear at the ends of the dental shelves and so have no forerunners; the germs for the second molars are developed from the neck of the enamel organs of the first molar during the third to the
fifth month after birth; the enamel sacs for the third permanent molars appear from the neck of the enamel sacs of the second molars during the third to the fifth year after birth. All of the molar teeth, therefore, have no predecessors, and, are then, primary and not succeedaneous teeth.

The first permanent molar tooth is the first one of the second set to appear; the order and times are as follows:

- First molar, sixth year (6–6.5).
- Medial incisors, seventh year (6.5–7).
- Lateral incisors, eighth year (8–8.5).
- First premolars, ninth year (10–11).
- Canines, eleventh to twelfth year (10–11.5).
- Second premolars, tenth year (10–11.5).
- Second molars, twelfth to thirteenth year (11.5–12.5).
- Third molars, seventeenth to twenty-fifth year.

According to Pierce the teeth begin to calcify and the roots are completed as given in the following table:

<table>
<thead>
<tr>
<th>Temporary teeth</th>
<th>Calcification begins</th>
<th>Roots completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial incisor</td>
<td>17th week (fetal)</td>
<td>18th month</td>
</tr>
<tr>
<td>Lateral incisor</td>
<td>17th week (fetal)</td>
<td>14th month</td>
</tr>
<tr>
<td>Canine</td>
<td>17th week (fetal)</td>
<td>22nd month</td>
</tr>
<tr>
<td>First molar</td>
<td>18th–19th week (fetal)</td>
<td>18th–19th month</td>
</tr>
<tr>
<td>Second molar</td>
<td>18th–19th week (fetal)</td>
<td>22nd month</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Permanent teeth</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial incisor</td>
<td>1st year</td>
<td>10th year</td>
</tr>
<tr>
<td>Lateral incisor</td>
<td>1st year</td>
<td>11th year</td>
</tr>
<tr>
<td>Canine</td>
<td>2nd year</td>
<td>13th year</td>
</tr>
<tr>
<td>First premolar</td>
<td>3rd year</td>
<td>12th year</td>
</tr>
<tr>
<td>Second premolar</td>
<td>4th year</td>
<td>12th year</td>
</tr>
<tr>
<td>First molar</td>
<td>25th month (fetal)</td>
<td>9th–10th year</td>
</tr>
<tr>
<td>Second molar</td>
<td>5th year</td>
<td>18th year</td>
</tr>
<tr>
<td>Third molar</td>
<td>8th year</td>
<td>19th year</td>
</tr>
</tbody>
</table>
The eruption and succession of the teeth are by no means simple processes. As the tooth germs develop they at first lie in a groove of the jaw, covered merely by the gum; gradually transverse partitions of bone form so that the entire tooth is ultimately incased in the bone of the jaw. The bone intervening between the tooth and the gum amounts to but a thin lamella that is completed shortly before the tooth is to erupt, except in the region where the gubernaculum passes to the gum. As eruption is to take place, that bone which is last formed (over the cutting edge) is resorbed so that there is on interference with eruption.

The process of eruption is as follows: The bone covering the labial surface of the crown is resorbed until fully one-half of the surface is exposed; this is followed by the resorption of the bone on the lingual surface but here the process is slower and less complete, leaving some bone to protect the germs of the permanent teeth underneath. As a result of this process the crown apparently grows through the gum when in reality the gum becomes stretched over the tooth by the disappearance of the bone beneath. As the resorption continues until the crown is exposed, new bone is laid down about the base of the tooth to strengthen its position. According to some writers the tooth erupts by the growth of the root forcing the crown above the gum surface. When one considers that in the temporary and permanent incisor teeth the roots are completed by the time eruption occurs, this force cannot be counted upon as a factor in the eruption of the teeth. It might play some part in the eruption of the other teeth, but even this is doubtful.

From the eruption of the second temporary molar tooth until the fourth year the teeth are practically quiescent. From the fourth year on the temporary teeth begin to decalcify and drop out to make room for the permanent teeth. The process of decalcification is one of absorption; it begins in the apical portion of the tooth and advances to the enamel line. The central incisors are the first affected, at about the fourth year, and the others follow in order of their eruption. As a result of this process the root becomes absorbed and the hold of the tooth upon the jaw becomes weakened; ultimately merely an enamel cap remains; this process extends over a period of about three years for each tooth, going on simultaneously
or successively in the various teeth. Some claim that the process of resorption of the roots is due to the pressure exerted upon the root by the permanent tooth beneath. This does not, however, seem to be the cause, for in cases of absence of the succedaneous tooth the process of absorption of the root of the temporary tooth occurs as usual.

The permanent teeth follow the temporary successively as the latter are lost. As the jaw gradually increases in length there is a second permanent molar added at the twelfth to the fourteenth year and a third one at the eighteenth to the twenty-fifth year.

The permanent teeth erupt in the same manner as the temporary organs; that is, by the absorption of the bone from the crown portion. As this process of absorption occurs during the eruption of both sets the jaws would become thinner from above downward; to offset this nature adds below more than is absorbed above so that the dimension from above downward increases up to the prime of life. As the second set is gradually lost bone is not replaced as rapidly as lost so that in an old jaw the alveolar processes are lost (showing the absorption from above downward) and the vertical dimension decreases.

According to Rose the teeth erupt earlier in the male than in the female and earlier in those children of the cities and of the well-to-do. On the other hand Bean and Boas found that they erupt earlier in the female. The lower teeth erupt usually before the corresponding upper with the exception of the premolar teeth.

Connected with the permanent tooth is a structure, the gubernaculum dentis, that seems to be of importance. It is a fibrous, cord-like structure attached to the apex of the tooth-sac and ends at the epithelium of the gum. It seems to direct the follicle by its tension and also to indicate the direction of eruption, and to maintain the tooth in position.

In regard to malformation of the teeth, both sets may fail to appear, or the succedaneous teeth alone may not develop; again individual teeth may be absent, or a third set may appear after the second has been lost. What is more common than the latter is a duplication of some of the permanent teeth forming a row within the
normal set; a fourth molar may appear if the jaw is long enough to accommodate it. Wisdom teeth are frequently absent. Malformations of the root may be in the form of an additional root or the fusion of several to form one massive root. Again, the teeth may be united by fusion (if before birth) or concrescence (if after birth). If two teeth are found in a single sac the condition is known as *geminous teeth*. 
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