THE

MINUTE ANATOMY OF THE TEETH

IN THE LIGHT OF THE

BIOPLASSON THEORY.

BY

CARL HEITZMANN, M.D.,

—AND—

THE MINUTE ANATOMY,

PHYSIOLOGY, PATHOLOGY, AND THERAPEUTICS

OF THE

DENTAL PULP.

BY

C. F. W. BÖDECKER, D.D.S., M.D.S.

[*REPRINTED FROM THE DENTAL COSMOS.*]

PHILADELPHIA:
PRESS OF PATTERSON & WHITE.
1882.

THE MINUTE ANATOMY OF THE TEETH

IN THE LIGHT OF THE

BIOPLASSON THEORY.

BY C. HEITZMANN, NEW YORK.

(Address before the New York Odontological Society, February, 1882.)

MR. PRESIDENT—Gentlemen of the Society: It was with great pleasure that I accepted the invitation to bring before you a subject which, it seems, gains more interest from year to year. It is my purpose to say a few words about the general bearing of the new doctrine which I had the honor to promulgate about ten years ago. It was your profession (thanks to noble-hearted men such as Dr. Atkinson) which first gave cordial recognition to my work. My laboratory was favored especially by dentists, and, without boasting, I can say that most of the work in the investigation of the anatomy of the teeth which has been done in the last few years, has emanated from thence.

You all know, Gentlemen, what the cell theory meant. I don't wish to say much about it. You all have learned what the cell was thought to be. Gradually, however, all the assertions concerning the nature of the cell were found not to be in accordance with the facts observable under the microscope; so much so that about ten years ago Drysdale, of London, said, "A cell is like a gun-barrel without a gun and a lock." It was denied that its contents are liquid, then it was denied that a nucleus was essential, and then everything was denied; still, one thing was kept—that was the name. It seems that later observers, and particularly Germans, thought it a necessity to adhere to that word, to which no meaning could be attached, for twenty years.

I wish to commence with the statement made at the beginning of the seventh decade of our century,—by Beale, of England, and Max Schultze, in Germany. Lionel Beale in 1860 offered a very plausible theory concerning the structure of the tissues. Unfortunately, however, his microscope, although enlarging very much, showed him very little. In his publications, for instance, an amœba was depicted of the diameter of a thumb-nail; there was a central nucleus, and all the rest of the amœba was structureless. A year later Max Schultze issued the protoplasm theory; he claimed that the real living part of the cell is not a liquid, but a jelly-like mass—for which he proposed the term *protoplasm*—endowed with a nucleus and exhibiting granules. In his idea the constituent elements of the cell were a semi-fluid mass holding a central nucleus and a certain number of granules.

In the same year a critical mind (E. Brücke) said that we have no right to maintain that a nucleus is an essential part of the cell, inasmuch as all of us know that there are a great many so-called cells that are destitute of a nucleus. The idea developed, especially with Stricker, that even the granules were not essential; perhaps these were secondary productions, perhaps they were taken into the protoplasma from outside; everything that was left was the jelly endowed with life.

All these gentlemen, of course, knew that a body devoid of structure could not exist; and if they said structureless, they meant, in all probability, that the structure was not perceptible. Such was the condition of things when, in 1872, I took up the study, and, as you perhaps all know, started with the most elementary formation of life—with amœbæ.

I discovered a delicate reticulum pervading the whole mass called at that time protoplasm—a reticulum which, whenever the nucleus was present, was in direct union with it and produced an investing thin layer around the amœba. This layer is by no means identical with the membrane of the cell, inasmuch as it admits of a great degree of stretching. When I saw this reticulum, with its points of intersection, changing its shape, growing, in certain conditions, I said, "Here is a formation in the protoplasm which is possessed of all the properties that are necessary for the condition of living matter, viz.: *motion, change of shape*, and *growth;*" and I concluded that the solid nucleus, the threads emanating from the nucleus, the granules serving as points of intersection, and the investing layer are the *real* formations of living matter, while the liquid contained in the meshes is destitute of life.

The mass of the amœba, as you know, changes its shape by protruding offshoots, and creeps through the field of the microscope.

I concluded there was *contraction* of the reticulum from the fact that the granules grew larger at a certain part of the amœba, the meshes became narrower, and the liquid was driven to another portion of the amœba, which is inclosed by a continuous layer of living matter. The liquid driven to the opposite portion produced a stretching of the reticulum, which I termed *extension.*

All this seemed to me a settled fact, and was published as such, but no attention was paid to it, although some observers had seen the reticular structure before me, and in different objects. This was true of Nasmyth. I was astonished to see his figures, published in 1839, showing this reticulum in the formation which covers the crown of the tooth. In 1868 Frommann demonstrated the reticulum in the so-called ganglion-cells of the brain, as did others in different places, but none of these observers understood its significance. I was the first to maintain that all that which was formerly termed protoplasm was endowed with reticular structure.

When, at the close of the year 1874, I left Europe in disgust and despair and came to this country, I found here the heartiest support and encouragement. The first proof of the existence of the reticulum was given by J. J. Woodward, who, without knowing anything about its presence, made micro-photographs, and these plainly exhibit the structure. Dr. Louis Elsberg early expressed concurrence in this view, based upon studies in my laboratory; he first proposed a new name for the designation of this theory, and that is "The *Bioplasson* Theory," in contradistinction to *proto*plasma, which means something formed, while *bio*plasson means the forming or living matter.

The word *cell* after this discovery, of course, became worthless, and it was Elsberg who proposed for the word cell the word *plastid*, or *bioplast*. I give preference to the term *plastid;* the word, however, does not matter if we only know what is meant by it. To-day there are two dozen of the very ablest microscopists, both abroad and in this country, who have seen the reticulum, and who fully agree with me and give me the credit for its discovery, as being the general rule in any bioplasson formation. Strange to say, however, from certain parties some little opposition is made.

A microscopist of this city publicly announced that he had never seen the reticulum, kindly adding that very probably his microscopes were not good enough to enable him to do so. Lately Dr. Lester Curtis published an article on this subject, and stated that he did not see the reticulum. This is a very modest way to announce that one cannot see what another can. If a person publicly confesses that he cannot play on the piano a master-piece of Liszt's, we are all willing to believe it; but does it follow that others cannot play the piece either? What is gained by such a confession? Dr. Curtis gives illustratons of what Elsberg and I have said and seen, and of what he could *not* see. I mention this because you are all prepared to understand that delicate observations of this nature are not easily made by every one. A great many look in the microscope, but very few can *see*. If one of you who had never played the violin were handed a good violin and told to play a tune, he would say, "I can't." Let him practice for a few years, and learn to play a tune. It is very much the same with the microscope. If you look in for but a short time, you cannot see. It required more than fifteen years' application to enable me to see what can readily be seen, and if a tyro comes and declares that he cannot see, I do not think such assertions should be taken as proofs against facts corroborated by others more experienced.

According to the new views, the structure of the plastid is a very complicated one. Indeed, we are astonished to see that every particle of a plastid—its smallest portions, for instance granules thrown off—floating about in a liquid, is endowed with all the properties that formerly were attributed to plastids; that is, motion and growth. We become convinced that it is not the plastid which is the elementary organism, but the granule of living matter; and this is considered as elementary only for the reason that our microscopes do not show more. If in time to come our lenses shall be constructed of better refracting media than glass (of diamond, for instance), perhaps we may discover more than we know at present.

These are the essentials of the new doctrine concerning the structure of "protoplasm." New views were also obtained concerning the structure of organisms ever so highly developed. It has been demonstrated that the body is by no means composed of isolated elements, so-called cells, as it was formerly thought to be. The best observers have held that the body was composed of a great number of individual cells, much in the way that a house is constructed of bricks—put together by cement. The bioplasson theory suggests that in the tissues of the body there is no such thing as an isolated cell, but that the tissues from the crown to the heel are one continuous mass of living matter, mainly in a reticular arrangement. Only the closed cavities of the body, the lymph- and blood-vessels, contain in a fluid isolated bodies in the shape of lymph- and blood-corpuscles, etc. In this view, therefore, the body is constructed like an engine in which all parts, though independent to a certain degree, are connected with one another so as to build up a continuity and render even the organism of man a grown complex amœba.

In this complex body there are portions of the living matter serving in the nerve action; portions in the building up of the lungs; other portions serving for motion. There are portions for the support of the body, such as the bones; others serving as tools, such as the teeth.

The new bioplasson view has thrown light upon the mode of development of the organism. Gradually the fact has been acknowledged that there are at first three layers or leaves from which all tissues arise, the name epiblast designating the upper layer, mesoblast the middle, and hypoblast the lower layer. Our best modern embryologists have asserted that the nervous system, of which the first trace is visible close below the epiblast, is a festooning of the epiblast. In this view the outer covering of the body would give rise to the nervous tissue, the most active tissue of the body—the brain and spinal cord.

In the bioplasson view the impregnated germ is nothing but an amœba flattened out, as it were. We have an upper investment of the amœba representing the epiblast, and a lower investment, the hypoblast, while the main mass of the body represents the mesoblast.

In the amœba a so-called vacuole may appear temporarily, which is again inclosed by a thin layer of living matter, and we observe a closed space in the mesoblast—the first trace of the future heart. As in the amœba, the vacuole contains a number of isolated granules,—the first-formed blood-vessels, containing the blood-corpuscles. It is the mesoblast only which holds blood-vessels; the epiblast and hypoblast and their derivations will never show blood-vessels. In this view, therefore, the entire body is constructed of only four kinds of tissues, three of which, viz.: the connective tissue, the muscles, and nerves, arise from the mesoblast.

The connective tissue, among other functions, gives support to the whole body in the shape of the skeleton, and serves in the process of mastication in the shape of teeth.

The elements of the epiblast and hypoblast are called epithelia, investing the outside of the body and the cavities which are in direct or indirect communication with the outer world.

If you compare, Gentlemen, the bioplasson doctrine and its developments with what Beale has said, you will at once see the difference.

Beale claims that in the fully-developed organism the greater part, or, at least, a very large part, of the body is destitute of life. He asserts that the living matter is represented mainly by the nucleus, whereas the tissues are formed material, and not alive. He claims that the most active tissues of the body, such as muscles and nerves, are formed material. This is the very objection that Bastian has raised against the teachings of Beale. In my view, every tissue is alive except the horny material, epidermis, nails, and hairs. We cannot conceive of a part of a living body destitute of life. Even in the comparatively inert tissues of the body, in the connective tissues, the bone, and cartilage,—the whole is pervaded by a reticulum of living matter.

The new bioplasson theory suggests that there is the greatest amount of living matter contained in this mass. We readily understand by examining the muscle the reason why it moves; it is essentially upon the plan on which the amœba moves. The nerve-tissue, Beale suggests, is formed material. We say it is living material of a very concentrated form, and thus we understand and get an insight into nervous activity, which is based entirely upon the motion of this delicate reticulum. The new doctrine suggests a number of facts, so far in full harmony with all our observations. The connective tissue is characterized by the presence of what is formed, or the glue-yielding substance. Not every variety is glue-yielding. Some of these substances seem like glue, and others, upon being boiled, give a gelatinous liquid, but not sticky; these are only special varieties of one and the same substance.

The new theory suggests that the inert basis-substance arises from the liquid present in the meshes of the bioplasson reticulum, which, although concealed in the basis-substance, remains unaltered.

The four varieties of connective tissue are the jelly-like myxomatous, the fibrous, the cartilaginous, and the bony. All these varieties have their representatives in the tissues constituting the tooth, and in the tissues attached thereto. The myxomatous tissue, the best representative of which is the umbilical cord, is present in the pulp of the tooth. The fibrous connective tissue, the best representative of which is tendon, being dense, firm and striated, we find about the tooth in the pericementum and periosteum. The cartilaginous tissue is not directly involved in the formation of the tooth, but it gives rise to the jaw-bone, and plays an important part in the formation of the jaws; while the bony tissue is of the greatest importance, inasmuch as it furnishes the sample of the structure which, with some variations, is found in the formation of the tooth.

In 1873 I first asserted that all the various connective tissues are provided with living matter. So great was the surprise of the learned world at these assertions that several years afterward Frey, of Zürich, who wrote a book, tried to ridicule the whole thing and to kill me off by placing me in a foot-note in his book. Of course, it is easy enough to ridicule assertions so long as we are not satisfied that they are correct, but if they prove to be correct such practice becomes very dangerous.

Stricker, of Vienna, in whose laboratory I executed much of my work in 1873, saw most of my specimens, although I did not care much for his opinion. He was slow in accepting my assertions, but four or five years ago he published an article claiming that the reticulum was present in the nucleus. Last year he surprised me with a copy of his latest publication at that time, wherein he corroborated the presence of the reticulum in salivary corpuscles; more than that, he asserts that the reticulum is present in the cornea of the eye, and that where at one moment is protoplasm, after a while basis-substance will be seen, and, in the place of basis-substance, after a while will be seen protoplasm.

In Stricker's laboratory Spina, two years ago, made the wonderful discovery that this reticulum existed in the cartilage,—some thing that I published in 1872 and 1873. He discovered a new method for its demonstration,—namely, treatment with *alcohol*, a method so simple that to-day even a child can see the reticulum in cartilage.

Meantime, I have not been idle. In the past seven years I have demonstrated all that to hundreds who were desirous to learn something about the new theory. It seems to me that what we have done in the past seven years in this country carries us quite ahead of the old world; we have become the leaders in this line of investigation.

As regards the bone-tissue, the idea was prevalent for a number of years that there were in it spaces filled with liquid, but nothing was known about the seat of life in the bone, for this reason: that a discrimination between the living and dead (necrotic) bone was impossible.

Virchow thought that the cells, which at that time were identical with the lacunæ, were the seat of life, although in his view the cells contained a liquid. With our modern views, it is hardly necessary to say that a liquid is never endowed with life. In 1870, in Stricker's laboratory, it was first found that the lacunæ of the bone-tissue held protoplasm. In our present views the bone is not only supplied with living matter, with plastids in the lacunæ, but also the offshoots of the lacunæ,—the canaliculi,—contain delicate filaments of living matter connecting the plastids; thus the bone-tissue is rendered an uninterrupted reticulum of living matter just as is any other tissue.

And now a few words concerning the minute anatomy of the teeth.

The manner of examining the tissues of the teeth in former times was like this: the tooth was allowed to dry; it was then split into thin laminæ by means of a saw; these were then ground down by means of a stone. In specimens thus obtained the lacunæ of the cement, the canaliculi of the dentine, necessarily looked black, owing to the presence of a little air and some extraneous matter, but not the least idea could be obtained in this way as to the contents and the formations of living matter which enter largely into the construction of the tissues of the teeth. The first necessity, therefore, of research in the new direction was to devise a new method of preparing specimens for investigation, and this was found in the use of chromic acid for softening the teeth. This proved to be a powerful reagent for extracting the lime-salts of the tooth and for preserving, at the same time, its soft parts. It was introduced by H. Müller, in 1868, for preparing bone. All previous observers were satisfied to examine dry bone as well as dry teeth, forgetting that such dried material could not be useful for study, as it merely showed the frame of the former tissues, and not the tissues themselves. If, on the contrary, the soft parts be preserved and retained so as to be visible with high amplifications, they are in the best possible condition for the observation of new facts concerning their structure, which is the case with the specimens prepared by the use of chromic acid. Enamel, however, never could be softened by this means. For the study of enamel we took a freshly-drawn tooth, and, keeping it moist in order to preserve the soft parts, ground it thin by means of the way formerly adopted. The new facts obtained by this simple way are to-day well established.

All sensible dentists must have been aware of life in the tooth; the simple fact that eating a sour apple would produce a certain effect upon the teeth—"setting them on edge"—has occupied the attention of thoughtful men for a long time. Some have spoken of the chemical action of the acid on the enamel, others of the conduction of the acid down to the pulp-chamber; but all that was unsatisfactory. Certainly every dentist must have observed that the living dentine is endowed with a high degree of sensibility, especially in certain places; for instance, at the boundary line between the dentine and enamel at the neck of the tooth. Many other facts, the reaction upon filling, the so-called solidification around a filling, could not be explained by the former view. Tooth was considered to be cartilage with infiltrated lime-salts in which there were canaliculi, holding central fibers, the nature of which was not known. The enamel, even in the eyes of the best observers, was thought to be a crystal, a calcareous mass epithelial in its origin. The later researches show that the tooth is pervaded by a bioplasson reticulum in the same way as an amœba. It does not creep out of the mouth like an amœba, on account of the infiltration with lime-salts in the lifeless portion of the tooth, *i.e.*, the original liquid, which has become a solid basis-substance, while the reticulum remains unchanged, not only throughout the dentine, but also through the enamel.

We have learned, through the researches of Bödecker, that the fibers present in the canaliculi are living matter. These first had been depicted in Richard Owen's celebrated work by the draughtsman employed by him. In the picture we see the fibers, while no mention is made of them in the text. Tomes was the first to describe the fibers, and he thought they were probably nerves. This approaches our views, for we can prove living matter proper and nerve-tissue to be one and the same thing; and we can trace the ultimate fibrils of nerves to direct or indirect connection with the dental fibers. Any irritation of the dentinal fibrils is transmitted to the nerves which are present in the pulp-tissue.

It has been demonstrated that the so-called cartilaginous basis-substance is pervaded by a delicate reticulum, and, although this cannot be directly seen, we have to assume its presence from facts obtained in the study of embryology, and in the study of the different appearances of the teeth in caries, as shown by Frank Abbott.

The enamel proves to be a live tissue, and supplied with a certain amount of living matter,—scanty, it is true, but in structure akin to dentine. Although its first stage is epithelial in nature, Bödecker's studies have shown that this epithelium is in turn changed into medullary tissue, which gives rise to the enamel—a complicated course which, however, is known to occur in the thyroid body.

The enamel-rods interlace in different directions, have interstices between them, and here is found living matter, which, as a reticulum, pervades the whole enamel. In the earliest formation of the tooth in the fetus, when the structure of the enamel is identical with that of the dentine, we can see the fibrils with great distinctness.

We have obtained an idea about the life of the enamel and the dentine, and, of course, the cementum ranks among the living tissues, as does bone.

The last question to be settled in this study was the nature of the pulp-tissue, and I dare say that to-day the character of this tissue is plain, both physiologically and pathologically. Dr. Bödecker's specimens have enabled me to say so.

In the light of the new views, Dr. Frank Abbott has studied the process of caries, and has shown that it is an inflammatory process which, owing to the scanty supply of living matter, is limited in its effect. While all tissues supplied with blood-vessels, if inflamed, produce something new, an outgrowth of new tissue, caused by increase of the inflammatory corpuscles (which are essentially the same as embryonal) in tissues destitute of blood-vessels, such as cartilage, the inflammation stops at a certain point, mere dissolution of the basis-substance takes place, the living matter reappears, but no outgrowth from that matter will occur. It has been proved that this process takes place in caries of the teeth. The first step in the process is that the lime-salts present in the meshes of the reticulum are melted out, the glue-yielding basis-substance is liquefied by means which we do not yet fully understand, and then the reticulum is re-established. The whole decalcified mass, still endowed with life to a certain extent, at last divides into medullary elements. Here is a stand-still, and new formation of living matter does not take place. The soft material becomes the seat of growth of leptothrix, and represents a decayed mass, which, constantly irritating, leads to a continuance of the caries.

The next important fact, theoretically at least, is the inflammation of dentine in its middle and inner portions, inducing secondary dentine, which Dr. Bödecker has shown to be of regular occurrence with advancing age or whenever irritation takes place. He found that this irritation, proceeding from the periphery to the center, led to a new formation of the tissue, which was proved to be secondary dentine in its three main varieties: with irregular canaliculi, with laminated structure, and structure kindred to bone.

Our specimens demonstrate that the secondary, like the primary, dentine is permeated by living matter, which, by a process of inflammation starting in the pulp-tissue, breaks down into medullary elements in globular fields or territories.

A subject which has been studied for two years in my laboratory by Frank Abbott, but which is not yet fully ripe for publication, is that of the melting of the enamel, caused by the same process which melts down the cementum and the dentine in deciduous teeth. There is in Tomes's book an illustration which shows that such a melting of enamel does take place, but, as we trust only to our own observations, we must postpone everything concerning this branch of the subject until we have trustworthy specimens. What we have seen is that a process of melting occurs on the plan of a slow inflammation; first, a liquefaction takes place in the basis-substance; afterward, decalcification, and then dissolution of the glue-yielding basis-substance. Thus the living matter becomes freed. Abbott found peculiar excavations, which are the territories of the tissue of the cementum. Kölliker, in 1874, first drew attention to such excavations on the surface of growing bone. At that time nothing was known as to the presence of living matter in cementum, and we should not be surprised that he was of opinion that these excavations and the bodies seen in them were something penetrating from the outside. So great was his respect for these bodies that he gave them the name of "bone-breakers." Reference was made by him to the melting process in temporary teeth. What we have seen does not confirm this bone-breaker theory at all. We say that the lacteal tooth, so long as it is connected with the soft surrounding tissue, must be endowed with life; therefore, the appearance of excavations filled with bioplasson is nothing but the reappearance of the original embryonal condition. The more surprising fact is that from this newly appearing tissue filling the excavations of lacteal teeth regular bone may arise.

This is only an outline of what has been done so far. I am about to publish the results of ten years' labor in the shape of a book. I have endeavored to reproduce all the work done in my laboratory by a number of gentlemen during the past seven years, in order to show what has been performed in America. My idea just now has been to give a mere sketch of the bioplasson doctrine, for two reasons: first, to render the future papers of Dr. Bödecker (and, I hope, also those of Dr. Abbott) clear and acceptable to you; and, secondly, to caution you against rough treatment of the teeth. Some of you have been accustomed to work upon the enamel as if it were worthless stuff,—calcareous matter void of sensibility. My studies, although theoretical, I think, have some value to the dental practitioner, in having demonstrated that all dental tissues are alive, and I cannot believe that the removal of any part of these tissues can be done with impunity. The punishment will come, sooner or later, if you deprive the tooth of its best protector,—the hard, solid enamel.

Dentine, apparently an inert tissue, reacts upon everything we do with it; a perfect revolution takes place in the dentine if you fill a tooth with any material. You have to regard the conditions surrounding the filling and the reaction which will follow upon its introduction, and much depends upon how you do your work and the material which you use as to what this reaction will be—whether beneficial or the source of new suffering to the patient.

I announced a year ago that, from my theoretical stand-point, I should not insist upon filling temporary teeth with gold. I was misunderstood at the time. I did not mean that gold would do harm, but meant that it was unnecessary; in the lacteal teeth, so poorly provided with lime-salts, a slight protective filling does all the work one may expect.

A great many other points are attached to these new views. We know that all scientific research is at first of little practical value, but such an application of the theoretical knowledge must come without question. A great many practical questions are involved in the study of the anatomy of the teeth generally. I often say that a dozen dentists could be kept busy for a dozen years in finding out new facts based upon the revelations of the bioplasson theory. The interest in the subject will gradually increase, especially if the right kind of practitioners will continue to assist me as they have so successfully done hitherto.

THE MINUTE ANATOMY, PHYSIOLOGY, PATHOLOGY, AND THERAPEUTICS OF THE DENTAL PULP.

BY C. F. W. BÖDECKER, D.D.S., M.D.S., NEW YORK, N. Y.

Methods of Preparing Specimens.

The best method of preparing pulp-tissue for examination is, immediately after the removal of the tooth from the mouth, to place it in an aqueous solution of chromic acid of one-half to one per cent. in strength. To this mixture may be added, every third or fourth day, to hasten the process of decalcification, one or two drops of dilute hydrochloric acid. It is important to use a large quantity of the liquid—not less than a quart for one or a few teeth—and to renew the same at least every six or eight days. After the teeth have been in the chromic acid solution a few weeks, the peripheral portion of the dentine will become sufficiently soft to be cut by a razor. When the hard portions of the dentine are reached by the cutting-instrument, the extraction of the lime-salts must again be continued in the manner described above until the pulp-cavity is reached.

Another method is to split the tooth as soon as possible after its extraction from the mouth with a strong pair of excising-forceps. The teeth best adapted for this method are the incisors, canines, and bicuspids. By an experienced manipulator the pulps of molars can be extricated from their inclosing walls, but with less success than in the teeth before mentioned. In splitting, put the cutting-edges of a sharp pair of excising-forceps in the longitudinal direction near the apex of a single-rooted tooth, then make a sharp and quick pressure, when, as a rule, the tooth will split into halves with the pulp-cavity exposed. Immediately moisten the pulp with a solution of chloride of sodium in water, of the strength of about one-half per cent., and then remove the pulp. The greatest care must be taken, in removing the fragments of the tooth from the pulp-tissue, to avoid tearing the organ, which greatly alters the microscopical aspect of nerve-tissue. If the pulp is to be stained with carmine, hæmatoxylon, fuchsine, hyperosmic acid, picro-indigo, or chloride of gold, etc., place it in the staining-fluid immediately after its removal from the hard parts of the tooth.

Among the reagents mentioned I have found but one of considerable value, viz.: the solution of chloride of gold of the strength of one-half per cent. This reagent can be applied to fresh pulps as well as to very thin sections obtained after hardening in chromic acid. These specimens, however, must, as a matter of course, be carefully washed with distilled water before adding the chloride of gold solution. This reagent may be allowed to remain in contact with the specimens for from twenty to thirty minutes, when they should again be washed in distilled water and exposed to daylight. In a few days fresh specimens will assume a bright violet color, while sections which have previously been in a chromic acid solution become brownish-violet. Osmic acid, in solution of one per cent. in strength, renders the contours of the constituent tissues, and especially those of the medullated nerve-fibers, more distinct, as it stains the nerve-fat dark green. Both fresh and chromic acid specimens may be treated with osmic acid. Thin sections do not require more than an hour's exposure to this reagent, while whole fresh pulps may be left in it for two or three hours. Except the ammoniacal solution of carmine, which is known to be excellent for staining certain parts of the tissue, I would not lay stress upon applying any of the other reagents mentioned.

If we wish to examine the pulp, together with the inclosing dentine, or a pulp-stone, the specimen previously softened by chromic acid must be imbedded in a mixture of paraffine and wax, which is best done in the following manner: place the softened tooth in absolute alcohol for about twenty-four hours; then prepare a box made of rather thick paper, somewhat larger than the specimen; warm the imbedding mixture, which consists of about eight parts of paraffine and one of white wax, until it is barely liquid; pour enough of it into the paper box to about half fill it; then take the specimen out of the alcohol, and as soon as it begins to dry place it in the paper box and pour over it some more of the paraffine and wax, so as to cover it completely. But care must be taken not to have the imbedding mixture too hot, as it may injure the living matter. The specimen then, after the mixture has become sufficiently hard, is ready for cutting, when very thin sections can easily be obtained.

If a fresh pulp is thin enough it may, immediately after its removal from the split tooth, be transferred to the slide, with the addition of an indifferent fluid, such as the solution of chloride of sodium, etc. But a slight and careful pressure upon the cover is necessary in order to spread fresh specimens. The fresh pulps of lower incisors, being the thinnest, are the best adapted for examining the system of blood-vessels. In a short time, however, these blood-vessels fade away, and the specimen becomes unfit for preservation. Isolated pulps may be placed between two plates of velvet-cork, and thus cut into thin sections with the razor. I would recommend dilute glycerin as the best preserving-fluid for pulp-specimens.

The Minute Structure of Normal Pulp-Tissue.

If we examine a thin longitudinal or transverse section of the pulp with low powers of the microscope (200 diameters), we recognize a large number of blood-vessels and bundles of medullated nerve-fibers. The majority of these blood-vessels are capillaries; the veins are less numerous, and arteries are scarce. In many pulps we find no arteries at all, in others a limited number, very often in the midst of the medullated nerve-bundles. The medullated nerve-bundles mostly run in a longitudinal direction, but not infrequently we observe smaller bundles, or single medullated nerve-fibers, diverge from the longitudinal direction, running obliquely through the pulp-tissue.

In transverse sections of the pulp we meet with arteries, veins, and capillaries, the first cut across, the others distributed in all directions. The bundles of medullated nerve-fibers are seen most distinctly in transverse sections. They often hold in their interstitial tissue capillary vessels and arterioles, which also appear in transverse sections. In very thin sections it often happens that the nerve-fibers fall out, and then we see a roundish empty space bounded by the sharply defined external perineurium. The absence of an endothelial coat renders such spaces easily recognizable in distinction from blood-vessels.

The main mass of the pulp, as seen with low powers, is composed of a delicate fibrous reticulum, containing a large number of bright shining corpuscles. Longitudinal sections in many instances exhibit delicate fibrous bundles scattered throughout the reticular structure of the pulp, mostly in the neighborhood of large blood-vessels and nerve-bundles. Pulps composed of a fibrous connective tissue only are rather exceptional, and, as it seems, are without any relation to the age of the person. They are probably the result of morbid processes. Toward the outer surface of the pulp the reticular structure is, as a rule, denser than in the middle portions. This peripheral part is surrounded by a wreath of elongated formations arranged in a radiating manner all around the pulp—the so-called "odontoblast layer."

Higher powers of the microscope (500 to 600 diameters) reveal a minute reticular structure, consisting of delicate fibers or anastomosing bioplasson cords, with very small oblong nuclei at their points of intersection. The mesh-spaces inclosed by this reticulum either look pale and finely granular throughout, or there is, besides the pale granular substance, a bright yellowish body, either homogeneous or granular, of the size and aspect of a nucleus. The number of the latter formations varies greatly in different pulps. Where bundles of a fibrous tissue traverse the reticulum, there the latter blend with the former. In the fibrous bundles, besides the delicate fibrillæ, we see scanty and small oblong nuclei.

Fig. 1.

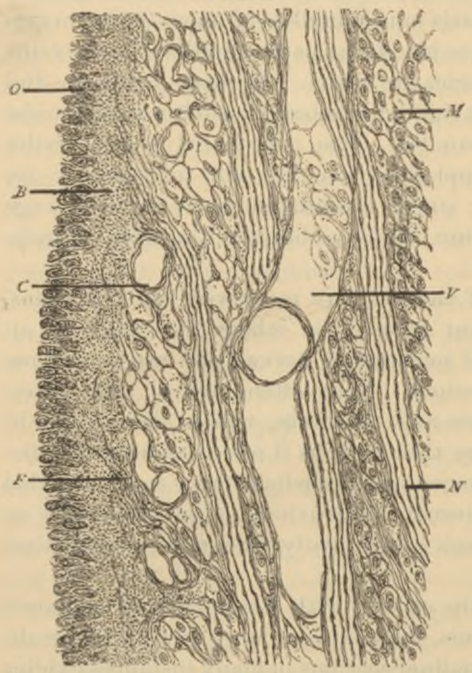


Fig. 1.—Segment of the pulp of a first molar tooth. Longitudinal section.

M, myxomatous connective tissue; *V*, vein; *C*, capillary blood-vessel; *N*, bundle of medullated nerve-fibers; *F*, terminal non-medullated nerve-fibers; *B*, bioplasson layer, containing the terminations of the nerves; *O*, layer of medullary corpuscles, termed odontoblasts. Magnified 200 diameters.

As mentioned before, the fibrous connective tissue prevails at the periphery of the larger blood-vessels and nerve-bundles. In transverse sections these nerve-bundles invariably exhibit a distinct fibrous sheath containing oblong nuclei — the so-called external perineurium. The nuclei imbedded in the sheath do not project above the level of the sheath, as is plainly observable on empty ones where the fibers have fallen out, while the endothelia of blood-vessels of any description invariably protrude toward the inclosed space, thus affording an excellent means of distinction between blood-vessels and empty nerve-sheaths.

The arteries are characterized by the presence of a layer of smooth muscles, outside of which is seen a slight fibrous coat. The layer of smooth muscles necessarily thickens the walls of the blood-vessels, thus rendering them easily recognizable in transverse sections. The veins are marked by their large caliber and a fibrous coat, being at the same time filled with blood-corpuscles. The capillaries are composed of a single endothelial layer, which is separated from the adjacent reticulum by an extremely delicate light rim. They are either found empty or containing a few blood-corpuscles.

In longitudinal sections the medullated nerve-fibers show the well-known fluted double contour of considerable refraction (the sheath of Schwann). Inside of this is the myolin (nerve-fat) concealing the central axis-cylinder. Schwann's sheath exhibits delicate oblong or spindle-shaped nuclei, and external to this we observe a very delicate layer of fibrous connective tissue—"the internal perineurium." In cross-sections of the nerve-bundles a more or less circular group of medullated nerve-fibers is seen, each of which in its center exhibits the axis-cylinder in the shape of a roundish, glistening dot, the single nerve-fibers being separated from one another by the delicate internal perineurium. Not infrequently capillary and arterial blood-vessels are met with between the nerve-fibers which, at the periphery of the bundles, blend with the nucleated sheath of the external perineurium.

As to lymphatics of the pulp, I can say that in some specimens I have seen branches of vessels of the size of veins without an adventitial coat, being composed of large, flat, slightly-protruding endothelia. These vessels I believe to be lymphatics, as they contained a finely-granular coagulated albumen, scanty granular corpuscles, and a very limited number of blood-corpuscles. As to the distribution of lymphatics, I must abstain from positive statements.

At the periphery of the pulp the delicate reticulum constituting the pulp-tissue is very dense, and its small meshes are supplied with numerous corpuscles looking like nuclei. In this layer we meet with only very narrow capillary blood-vessels. The outer surface of this layer is bounded by radiating rows of shining corpuscles of the size and appearance of nuclei. These rows are separated from one another in a longitudinal direction by light rims in which delicate fibrillæ can be frequently observed.

In chromic acid specimens stained with carmine, or, still better, in those treated with chloride of gold, high powers (1000 to 1200 diameters) reveal an extremely minute reticular structure pervading all formations of the pulp-tissue. It is this structure, that of bioplasson as well as basis-substance, that C. Heitzmann discovered in 1873. ("Untersuchungen über das Protoplasma, Sitzungs-Berichte der Kaiserlichen Academie in Wien.") Starting from the center of a mesh-space, we see a body like a nucleus, either homogeneous and apparently destitute of structure, or with the appearance of a vesicle with a distinct, bright wall. Inside the hollow nucleus we see a varying number of bright granules, interconnected with one another as well as with the inclosing wall by means of delicate filaments. Around the nucleus a minute light rim is seen, which again is traversed by radiating filaments connecting the nucleus with the extremely delicate, grayish reticulum pervading the light basis-substance contained in the mesh-spaces of the fibrous net-work. The delicate reticulum in the basis-substance is recognizable, even though the central nucleus be absent. The fibrous or bioplasson net-work which incloses the mesh-spaces also shows a delicate reticulum in connection with the nuclei at the points of intersection. Thus, all coarser reticular structures, as well as the fields of basis-substance, are traversed by an extremely delicate reticulum, which C. Heitzmann claims to be living matter proper. In this view I fully concur, and, so far as my experience goes, I would mention that inflammation in general, as well as that of the dental pulp, cannot be understood unless the presence of living matter throughout all formations of bioplasson as well as basis-substance is admitted. It is this matter which grows and leads to a new formation, so strikingly shown in inflammation. I may add that fibrillæ of living matter are directly connected with the blood-vessels by means of delicate offshoots penetrating the light rim around the blood-vessels called the "perivascular space."

The formations at the periphery of the dental pulp termed "odontoblasts" by J. Tomes, and which by some observers have been considered as epithelial-like formations, under high amplifications exhibit the following:

Longitudinal fields, somewhat resembling epithelia, border the pulp in a radiatory direction. Such a field may appear in the shape of a finely-granular bioplasson or basis-substance in which there are imbedded oblong nuclei in varying numbers. The nuclei exhibit coarse granules and a dense reticulum of living matter, while the elongated fields inclosing the nuclei exhibit pale granules and a delicate bioplasson reticulum. Between these latter formations a delicate light rim is seen, wherein we observe sometimes broad, sometimes delicate, fibrillæ in connection with the reticulum of neighboring formations, accompanied by delicate conical offshoots, which penetrate the surrounding rims at right angles. In many instances these formations between the odontoblasts can be followed into the dentinal fibers, lodging in the midst of the dentinal canaliculi.

It is obvious, from what I have seen, that the odontoblasts furnish the matrix for the basis-substance of the dentine, whereas the dentinal fibers, being formations of living matter, originate *between* the odontoblasts. When studying secondary dentine I described and depicted a specimen corroborating this assertion (DENTAL COSMOS, Vol. XXI., p. 412).

The manner in which the bioplasson of the odontoblasts is transformed can be understood only on the basis provided by the researches of C. Heitzmann (*loc. cit.*), who claims that the liquid held in the meshes of the reticulum of living matter by a chemical process is rendered solid and glue-yielding, while the living reticulum itself remains unchanged, and merely becomes invisible because it has nearly the same refracting power as the basis-substance. Where the refracting power varies enough, the formations of living matter remain distinctly perceptible. Such is the case with the dentinal fibers and their transverse conical offshoots within the dentinal canaliculi.

In sufficiently stained chloride of gold specimens of a nine-months' fœtal pulp I have observed that the medullated nerve-fibers upon approaching the periphery of the pulp are destitute of their myolin sheath, and now, being bare, axis-cylinders split into numerous extremely delicate beaded fibrillæ—the "axis fibrillæ." They are marked by a dark-violet color, and run in the light rims between the rows of the odontoblasts near the pulp-tissue proper, and are connected with the odontoblasts by means of delicate conical offshoots. In some instances I have observed that these axis fibrillæ terminated in knob-like extremities. But whether the nerve-fibers directly anastomose with the dentinal fibers I am unable to say. That an indirect connection of the two is established by the intervening reticulum of living matter I positively assert.

FIG. 2.

Fig. 2.—Segment of the pulp of a temporary tooth, stained with chloride of gold.

M, myxomatous connective tissue; *N*, terminal non-medullated nerve-fibers, in a uniformly granular bioplasson layer; *O*, rows of medullary corpuscles, termed odontoblasts; *F*, dentinal fibers between the odontoblasts; *D*, dentine. Magnified 1200 diameters.

The results of my researches of the normal pulp are as follows:

I. The dental pulp is a variety of connective tissue termed myxomatous, representing an embryonal form of it. Pulp-tissue, therefore, is a remnant of embryonal tissue, lasting, in some instances, throughout life, and kindred to those formations termed "adenoid tissue."

II. The myxomatous tissue of the pulp is intermixed with a delicate fibrous connective tissue in varying amounts. Pulps entirely or nearly built up by fibrous connective tissue probably are not to be considered physiological.

III. The pulp-tissue is traversed by a close system of blood-vessels, viz., arteries, veins, and capillaries. Arteries are not invariably found in the pulp, but they are by no means of exceptional occurrence. Lymphatics in small numbers are also present.

IV. The pulp-tissue is richly supplied with nerves, which, in the shape of bundles of medullated nerve-fibers, traverse the myxomatous tissue. Toward the periphery of the pulp they lose their myolin sheaths, become non-medullated, and, in the shape of minute beaded fibrillæ, branch between the odontoblasts.

V. The odontoblasts at the periphery of the pulp are elongated bioplasson formations with rows of nuclei. They are medullary corpuscles such as we see wherever a new tissue arises from a former one. They build up the basis-substance of the dentine by solidification (transformation into glue, and infiltration with lime-salts). The reticulum of living matter traversing the odontoblasts remains unchanged in the basis-substance of the dentine.

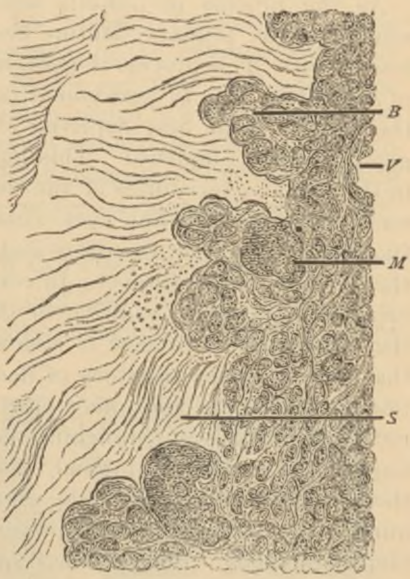
VI. The dentinal fibers originate between the odontoblasts. Being formations of living matter, they are in direct connection with the reticulum of living matter—first of the odontoblasts and afterwards of the basis-substance of the dentine. The connection between the ultimate nerve-fibrillæ and dentinal fibers is very probably an indirect one by means of the intervening reticulum of living matter.

The Pathological Conditions of the Pulp.

Pulpitis.—I have examined a large number of specimens of pulpitis, but have not met with this process except in pulp-chambers more or less reduced in their caliber by a new formation of secondary dentine. I do not want to say that pulpitis never occurs without this preceding formation, but to me it seems quite probable. In caries of dentine, or in mechanical or chemical abrasion, long before the pulp-cavity is approached, we have known, since the time of John Hunter, that, corresponding to the lost portion on the outer surface of the tooth, secondary dentine is deposited in the corresponding direction within the pulp-chamber. Evidently in pulpitis caused by a sudden and severe irritation the production of secondary dentine is induced before the irritation becomes sufficiently high to develop inflammation. If pulpitis does occur without the previous formation of secondary dentine, it must be a rarity. Where primary dentine is invaded by the inflammatory process, traces of secondary dentine scattered along the pulp-chamber are visible, and the probability is that the secondary dentine to a great extent has been destroyed by the inflammation before the primary dentine was reached.

As I have published in the Dental Cosmos, Vols. XXI. and XXII., my researches on the formation of secondary dentine and pericementum, and on pericementitis, in the light of recent investigations on inflammation, etc., I shall have to say but little on pulpitis. The main characteristic of this process is the appearance of a large number of inflammatory or medullary corpuscles in the pulp-tissue. These corpuscles, the same as in pericementitis, arise from the living matter present in the bioplasson formations as well as from that hidden in the basis-substance.

Fig. 3.



Pulpitis.—*S*, secondary dentine; *B*, bay-like excavations filled with medullary or inflammatory corpuscles; *V*, transverse section of a blood-vessel; *M*, multinuclear body. Magnified 300 diameters.

Where before a fibrous reticulum was visible, containing in its mesh-spaces basis-substance with central nuclei, in the earliest stages of inflammation numerous bioplasson bodies are seen, either closely packed together in heaps or separated from one another by layers of a granular bioplasson. The process of inflammation in many instances does not invade the whole of the pulp at the same time. I have specimens where only a portion of the pulp or several independent portions have been invaded by the inflammatory process, while a varying amount of the pulp-tissue is left unchanged. The manner in which the inflammatory corpuscles make their appearance is as follows: Portions of living matter, of either the myxomatous reticulum and its nuclei or of the basis-substance (evidently after its liquefaction), grow into a shining homogeneous lump, from which a nucleated mass of bioplasson will arise by a differentiation of the living matter into a reticulum. The living matter of the nerve-fibers furnishes material for the formation of inflammatory corpuscles, which in lower degrees of this process are traceable in the shape of longitudinal rows of inflammatory corpuscles, with but scanty remnants of nerve-fibers recognizable as such. In higher degrees even this trace of former nerve-bundles is lost. The blood-vessels rapidly disappear. Even in the early stages of pulpitis we have difficulty in tracing out blood-vessels, as most of them are either compressed or made impermeable by a process of solidification and splitting into inflammatory corpuscles. Where blood-vessels are seen unbroken, they appear considerably dilated and engorged with blood-corpuscles. The arteries resist the destruction for the longest period of time. Even in considerably inflamed pulps we meet with arteries which have retained their essential features. An artery in one of my specimens, cut transversely, shows the concentric layer of smooth muscles split up into small lumps of living matter, and in its inclosed space a large number of inflammatory corpuscles, evidently sprung from proliferation of the endothelial coat.

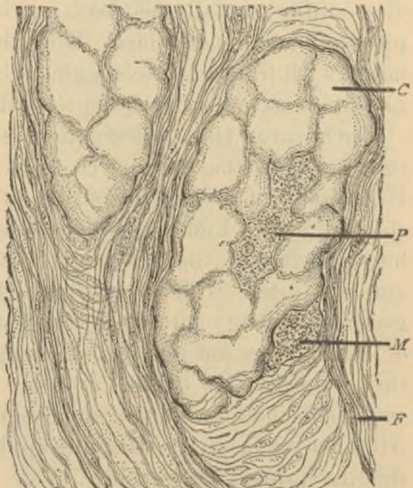
As the process of pulpitis advances, first the secondary and afterward the primary dentine becomes destroyed to a greater or less extent. The process is essentially the same as the destruction of cementum due to pericementitis. The solid basis-substance of the dentine is at first deprived of its lime-salts, after which the gluey portion is liquefied. This liquefaction invariably takes place in the globular territories of the dentine, and by the coalescence of such territories bay-like excavations are seen penetrating the dentine, at first with faint outlines and afterward sharply defined from the calcified basis-substance. In consequence of this liquefaction the original bioplasson condition of the dentine is re-established. If the inflammatory process is a slow one (chronic), it may happen that from a former territory of dentine, by a process of recalcification, a territory of bone may originate, in the center of which we recognize an oblong, branching bone-corpuscle. This formation, however, is rather exceptional. The rule, on the contrary, is that the bioplasson filling a bay-like excavation becomes supplied with a number of new nuclei, thus representing the stage of a multinuclear bioplasson body. Such a mass splits up into a large number of inflammatory corpuscles, which, in the bay-like excavations as well as in the pulp-tissue proper, establish a condition termed "inflammatory infiltration."

In milder forms of inflammation the pulp-tissue, although considerably changed, still remains a tissue as long as the delicate filaments of living matter interconnecting the single inflammatory corpuscles with one another and with the periphery of the pulp are unbroken. At this stage, should the inflammatory process abate, the tissue may advance into the original condition of a basis-substance. As is known, every variety of connective tissue, once inflamed, becomes a fibrous or cicatricial tissue. It is quite possible, therefore, that the few pulps I have met with exhibiting the structure of fibrous connective tissue and scantily supplied with blood-vessels are the products of a former inflammation. It is also probable that further advance into other tissues found in the pulp, such as dentine and bone, are the results of a slight inflammatory condition which did not extend to the stage of hyperplasia or hypertrophy. In a few specimens, mostly of fibrous structure, I have seen the bundles of medullated nerve-fibers transformed into rows of fat-globules. Evidently here the nutrition of the nerve-fibers has been interfered with to such an extent as to allow the formation of fat from the nerve-tissue proper. Should the inflammation reach a high degree, the inflammatory corpuscles will become separated from one another —torn apart—and the result is the formation of pus, which, as a matter of course, is no subject for microscopical research, except the discoloration of the dentine of the tooth. Of this, for the present, I have nothing to say. An intense inflammatory process may very soon lead to an engorgement of the afferent vessels and their strangulation by pressure. In this instance death and putrefaction of the inflamed pulp will ensue, which is known clinically as "gangrene." Some reliable observers claim that gases of putrefaction in gangrene may be developed in quantities sufficient to crack the tooth. In my practice I have never encountered such an accident.

Calcification and Waxy Degeneration.

Deposition of lime-salts in the pulp-tissue is very common. It presents itself in the shape of globular, elongated, or irregular formations, having under the microscope a more or less lobulated surface and a high degree of refracting power. The age of the person apparently has nothing to do with the calcification of the pulp. Some very good observers have described it as the result principally of caries or loss of substance of the tooth by mechanical means. I have a great many specimens of pulps prepared from bicuspids and first and third molars of young persons, which had to be extracted on account of irregularity or want of room, and most of them are externally perfectly sound. Some of the wisdom-teeth were removed when only one or two of their cusps had pierced the gum, but with only one exception all of these pulps exhibit greater or less quantities of calcific deposits as well as eburnifications. The

Fig. 4.



Calcification.—Pulp of a first lower molar of a healthy young man 18 years of age, extracted on account of irregularity.

C, calcified masses composed of irregular lumps, probably former medullary corpuscles; *M*, medullary corpuscle unchanged; *P*, central plastid free from infiltration; *F*, capsule of fibrous connective tissue. Magnified 300 diameters.

same conditions I have observed in pulps derived from the teeth of old persons.

Pulps containing a larger number of calcified spicula, as a rule, exhibit more fibrous connective tissue than myxomatous. Invariably around the calcified masses a dense layer of fibrous connective tissue has formed, ensheathing the calcified masses. Where these masses have fallen out an empty fibrous sac is left behind, in which there are neither endothelia, so characteristic of blood-vessels, nor oblong nuclei, which we see in the external perineurium of the bundles of medullated nerve-fibers. The presence of this envelope may convey the idea (especially if the calcified masses are elongated and appear like small lobulated sausages) that an obliteration has first occurred in the blood-vessel by a process which in other vascular systems, mainly that of the lungs, is known as "fatty embolism." The application of different reagents, especially osmic acid, has, however, convinced me that neither of these formations is a fat embolism, and I am unable to observe any positive connection between the blood-vessels and the calcified masses. Sometimes it looks as if a capillary blood-vessel were attached to the space containing the calcified mass, or it may occur that a capillary vessel is suddenly dilated like a small aneurism, and in this widened portion we notice pieces of a calcified mass. The idea that the plasma of the blood laden with lime-salts accumulates in the capillaries of the pulp, and, unable to escape behind, deposits its lime-salts, I do not accept.

Much rarer than calcification is a peculiar change of the pulp-tissue which I have observed, both with and without calcifications. It consists of a transformation of the myxomatous tissue into a shining, nearly homogeneous mass, devoid of a distinct demarkation between it and the unchanged tissue of the pulp. In this homogeneous mass, which may greatly vary in extent, we recognize granular, stringy formations, and not infrequently smaller bundles of nerve-fibers not noticeably changed in their structure, traversing the homogeneous fields. In some instances the nerve-fibers within such fields look dark and coarsely granular, as if composed of crumbs. All I can say as to the reagents applied is that the homogeneous mass readily stains with carmine.

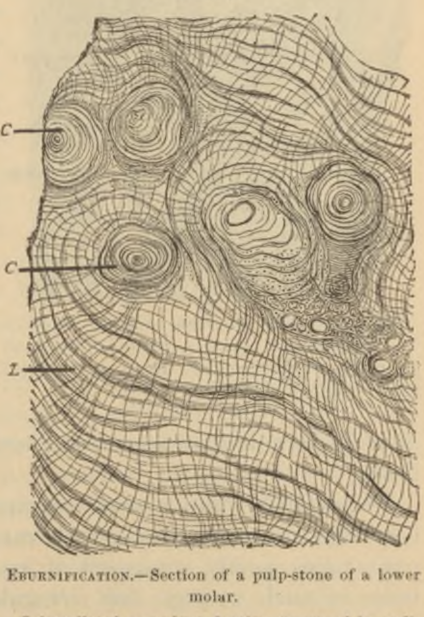
Changes of tissue of this character are very common in different organs, especially in the spleen, the liver, and the kidneys. They always indicate a low degree of nutrition, and are said to be generally caused by syphilis. This change bears the name of "amyloid or waxy degeneration." Its nature, however, is yet far from being known.

Dentinification, Eburnification, and Ossification.

It was necessary to make a new word for the designation of a process which, although known for many years, has never been fully understood. I refer to the new formations of dentine in the midst of the pulp-tissue independent of the dentine composing the walls of the pulp-chamber. It is the formation of the so-called "pulp-stones" which by some observers are announced as the result of a process of calcification, but by John Tomes, Ulrich, Hohl, Bruck, Baume, and Witzel, have been described as formations of a variety of secondary dentine. So-called pulp-stones, as is well known, may be found either connected with the dentine proper by means of a peduncule, or loosely imbedded in the connective tissue of the pulps. Most of these formations are composed of dentinal tissue in the form termed secondary dentine. Rarer occurrences are those constructed exclusively of a laminated bone-tissue. Somewhat rarer are combinations of both dentine and bone-tissue. The rarest are new formations of dentine strictly identical with primary dentine.

1. So-called "pulp-stones" of the character of secondary dentine. The most marked characteristic of these specimens is the presence of dentinal canaliculi irregularly scattered throughout the calcified basis-substance. Sometimes the canaliculi assume a tolerably well marked radiation; at others large masses of calcified basis-substance are destitute of canaliculi, which, in scanty bundles, are found toward the periphery of the pulp-stone. All the three varieties of secondary dentine which I have described in the DENTAL COSMOS, Vol. XXI., are found in these formations. Portions of the basis-substance, especially toward the periphery, may exhibit delicate concentric laminations. In the midst of an apparently homogeneous basis-substance small laminated territories may occur, containing a central corpuscle with branching offshoots, somewhat resembling a bone-corpuscle.

FIG. 5.



EBURNIFICATION.—Section of a pulp-stone of a lower molar.

L, lamellated secondary dentine, traversed by radiating dentinal canaliculi; *C*, *C*, globular masses, exhibiting a concentric striation. Magnified 300 diameters.

In sections of one pulp-stone I have found numerous concentrically laminated territories, more or less distinct, and either one or two protoplasmic formations in their centers. The tissue between the territories was partly granular and composed partly of a tissue like secondary dentine with irregular canaliculi. Here and there medullary spaces were seen traversing the tissue from which evidently the new formation of the territories had started. This variety is the regular osteo-dentine.

2. So-called "pulp-stones" composed of regularly developed laminated bone. I have, as mentioned before, pulps composed almost exclusively of a dense fibrous connective tissue, the bundles of which are interlaced in all directions so as to establish a regular cicatricial connective tissue. Scanty nerve-bundles and blood-vessels traverse the dense connective tissue, which in some places appears to be more or less crowded with medullary or inflammatory corpuscles. In such fibrous pulps I have seen smaller or larger masses of fully developed bone-tissue, composed of more or less regular lamellæ, or of calcified fibrous lamellæ. In these a large number of irregular branching bone-corpuscles are seen, arranged in rows or chains, where the basis-substance shows a more fibrous character. Sometimes the bone-tissue appears in lamellated islands, sharply marked from the surrounding fibrous tissue. No formations of secondary dentine were combined in these cases with the bone-tissue.

Fig. 6.

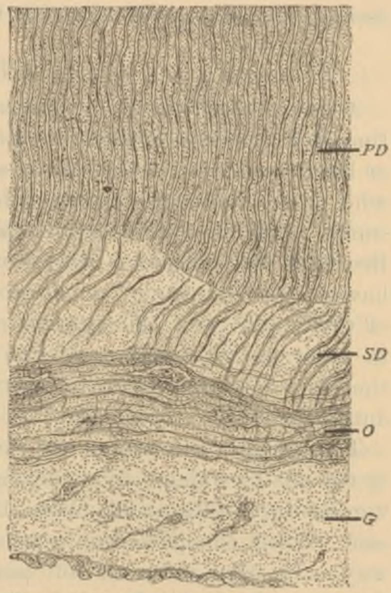
Ossification.—Section of pulp of upper lateral. *L*, longitudinal, *T*, transverse, bundles of cicatricial fibrous connective tissue; *B*, spicula of lamellated bone. Magnified 500 diameters.

3. So-called "pulp-stones" composed of a mixture of regular bone and dentinal tissue. In rare instances I have met with pulp-stones partly composed of secondary dentine and lamellated bone in such a way that irregularly bounded masses of bone contained a few large bone-corpuscles, alternately surrounded by a basis-substance, which contained only irregular, wavy, dentinal canaliculi.

4. So-called "pulp-stones" composed of dentine with the features of primary dentine. I have examined a large number of pulp-stones;

one of them, a mass about the size of a pea, was built up of dentine. The canaliculi of this dentine are perfectly parallel, and between these a finely reticular basis-substance, arranged in the same way as we see in the primary dentine of temporary teeth of children, which teeth are generally poorly supplied with lime-salts. In this specimen, too, the dentinal canaliculi are very wide, the basis-substance between them, on the contrary, narrow. The dentinal fibers are relatively bulky beaded formations with numerous large conical spokes penetrating the peripheral space of the canaliculi. This regular dentine toward the periphery of the pulp-stone is bounded by a slightly fluted contour, a narrow zone which exhibits the structure of canaliculated secondary dentine. This zone blends with a still narrower one, which is composed of an indistinctly lamellated bone-tissue, wherein bone-corpuscles, large in size but few in number, are imbedded. This layer is followed by the bounding layer of the specimen, exhibiting a granular appearance containing a few angular or spindle-shaped protoplasmic bodies and a few dentinal canaliculi.

Fig. 7.



DENTINIFICATION.—Section of pulp-stone of upper molar.

PD, primary dentine; *SD*, secondary dentine; *O*, irregularly lamellated bone-tissue; *G*, granular layer toward the pulp-tissue. Magnified 500 diameters.

As to the development of dentine and bone in the midst of pulp-tissue, I have to say only a few words. Carl Wedl thinks that these formations arise from an invasion of the odontoblasts into the midst of the pulp-tissue, he assuming that dentinal canaliculi can only be formed by that layer. My own observations demonstrate that the odontoblasts are nothing but medullary corpuscles arranged in rows. In the present stage of our knowledge we have no reason to assume that the medullary corpuscles of the periphery of the pulp are specifically destined for the formation of dentine. It is just as reasonable to assume that the blood-vessels in the pulp furnish a certain variety of pabulum to the medullary corpuscles termed odontoblasts, under the influence of which nourishing material they are transformed into the tissue of bone.

Should medullary corpuscles, in consequence of a slight irritation or an augmented afflux of nourishing material, arise in the midst of the pulp, they may just as well produce dentine as bone. The laws which control the new formation of tissue are as yet far from being understood, and it seems to me that very little can be gained by the assumption of a specific function for the medullary corpuscles.

II.—History.

A great deal has been written on the dental pulp. From the time of Prochaska (1780) to the present many essays have appeared, or have been read before dental societies, but the number of those who have advanced scientific knowledge in this direction is very small. J. Tomes, E. Albrecht, Heider, C. Wedl, R. Hohl, Boll, J. Bruck, R. Baume, and A. Witzel ought to be especially mentioned as having contributed very much valuable information to our knowledge of the dental pulp. The literature of the subject is too voluminous to allow me to mention all who have written upon it, and I will therefore only make short extracts from a few of the most prominent authors.

The earliest treatise on the dental pulp which I have been able to trace is by Galen ("Systemisches Handbuch der Zahnheilkunde," von Georg von Carabelli; Wien, 1844), who was born A.D. 131. He said, "I felt the pulsation in a tooth that was aching in the same way as in other inflamed soft parts. I wonder that a tooth can be inflamed. But when I again suffered from toothache I distinctly felt that this was not caused by the tooth, but the inflamed gum. By having had both kinds of pain, I positively know that the seat of the one pain was in the gum, but the other was in the tooth." He was also the first to observe that the teeth are provided with soft nerves.

John Hunter says, "A tooth very often wears down so low that its cavity would be exposed if no other alteration were produced in it. To prevent this, nature has taken care that the bottom part of the cavity should be filled up by new matter, in proportion as the surface of the tooth is worn down."

Georgii Prochaska ("Operum Minorum Anat. Physiol. et Path. Argumenti," Pars II.; Viennæ, 1800) also called attention to the fact that when by attrition the teeth on their upper surfaces are worn there is produced within the pulp-chamber just as much new material as is worn away on the outer surface.

Rousseau ("Anat. Comp. du Syst. Dent. Chez l'Homme et Chez les Princip. Anim.;" Paris, 1827) found "osteoids" and bony growths in the pulp-cavity, but states that Bertin had known this before him.

Bertin ("Über Neubildungen der Zahnpulpa von Rudolph Hohl;" Halle, 1868) says, "The teeth are not empty, but filled with a soft mass, which originated from a lymphatic fluid. This fluid thickens by evaporation without obtaining the consistence of bone, although sometimes this substance does form hard masses, not in connection with the other tissues originally, which, however, later are united with the dentine."

Thomas Bell ("The Anatomy, Physiology, and Diseases of the Teeth;" Philadelphia, 1830), in speaking about mechanical abrasion, says, "We find that, instead of these teeth being the subject of absorption, a new deposition of bony matter is, in fact, going on to fill the cavities, which would otherwise be exposed. It is first deposited in that part of the cavity toward the worn surface, and becomes gradually more and more filled as the tooth becomes abraded."

Raschkow ("Meletemata Circa Mammalium Dentinum Evolutionem;" Warschau, 1835) found stony masses in the molars of deer, hares, and pigs.

A. Nasmyth ("Researches on the Development, Structure, and Diseases of the Teeth," 1849) says, "Much diversity of opinion has already existed respecting the connection of the pulp with the ivory of the tooth, and as to whether the ivory be simply a product of the pulp or a transformation of its substance. The formative surface of the pulp displays a regular cellular arrangement. The radiating rows of cells are surrounded by a well-defined scolloped border, from which occasionally processes are observed to project at regular intervals." This author also, on page 226, plate vi., describes and nicely depicts several cases of ossification of the pulp.

R. Owen ("Odontography," vol. ii.) illustrates a new formation of osteo-dentine from a bicuspid tooth developed with hair in a cyst of the human ovarium.

F. Ulrich ("Zeitschr. der Kk. Gesel. der Ærzte zu;" Wien, 1852) noticed new formations of the dental pulp, of which he described three varieties, viz., the dentinoid, the osteoid, and a mixture of the two tissues in one.

P. B. Goddard ("The Anatomy, Physiology, and Pathology of the Teeth;" New York, 1854) described the dental pulp as composed of granular matter invested by a delicate membrane or epithelium.

Kölliker ("Gewebelehre;" Aufl IV.) noticed new formations of dentine and cement on the walls of the pulp-cavities of teeth.

From L. S. Beale ("On the Structure and Growth of the Tissues, and on Life," 1865) I abstract as follows: "The tissue of the pulp, it must be distinctly borne in mind, is not converted into dentine; neither does dentine, nor the tissue from which it is formed, exhibit any characters which justify our classifying it with the connective tissues. * * * No dentine was ever produced except by the agency of the so-called 'cells.' I agree with Kölliker and Lent, that the dentinal cells are the only active agents concerned in the formation of the dentine, but cannot regard the canals as direct processes of the whole dentinal cells, nor admit that the matrix is an intercellular substance. The mass of the pulp is composed of a simple form of connective tissue, with numerous oval and triangular corpuscles (germinal matter) not unlike that of which the mucous tissue of the umbilical cord consists."

R. T. Hulme ("On Calcifications of the Dental Pulp," Transactions of the College of Dentists of England, 1861) gives a good description of the new formations in the pulp-cavity. He names four varieties, viz., secondary dentine, dentine of repair, osteo-dentine, and nodular dentine, but he is of the opinion that the term "secondary dentine" would suffice for all varieties. He beautifully illustrates in two plates ten cases of new formations, one of which is copied from Salter, "Guy's Hospital Reports" of 1853.

From John Tomes ("System of Dental Surgery;" London, 1873) I quote, "The opinion held by Waldeyer, Boll, Beale, and many others, that every part of the dentine is a direct product of the conversion of the odontoblasts. This view is probably the true one. * * * The odontoblasts close up to the dentine are in actual contact with one another, and there is no room for an intercellular substance. * * * The most external portions of the odontoblasts undergo a metamorphosis into a gelatigenous matrix, which is the seat of calcification, while their most central portions remain soft and unaltered as the fibrils. According to this view, the fibril, the sheath, and the matrix are but three stages in the development of the same tissue. * * * Some pulps will be found to contain numerous nodules of dentine; in others the greater part of the pulp will be found converted into secondary dentine. Or the calcification of the pulp may be limited to the production of a patch of dentine added to the wall of the pulp-cavity. Small isolated calcareous globules are to be found in perfectly healthy developing teeth."

From E. Albrecht ("Die Krankheiten der Zahnpulpa;" Berlin, 1858) I copy, as follows: "The principal change of the teeth caused by the pulp is the phenomenon of calcific deposits, which are found partly on the walls of the pulp-cavity and partly within the pulp-tissue. * * * The globular masses in older teeth are not to be regarded as normal but anomalous formations, although sometimes the canaliculi of the dentine have grown through them. The globular masses show some striped formations with a radiatory arrangement, the center of which is occupied by a dark-colored empty space of irregular shape, and provided with several offshoots, looking like a bone-corpuscle, in which sometimes roundish cell-like formations, with nucleus-like contents and offshoots, are seen. * * * By the formation of pus in a small place near these globular masses, on the wall of the pulp-cavity, it may occur that some of this substance is destroyed and a cavity formed, which later on, by a less normal formation of dentine of repair, is separated from the pulp-cavity and filled with pus, thus representing an abscess in the dentine."

From R. Hohl ("Ueber Neubildungen der Zahnpulpe;" Halle, 1868) I cite, as follows: "New formations of the dentine are found within the soft tissue of the pulp as well as on its periphery in connection with the primary dentine. The former are present in the shape of small hemp-seeds; the latter from their origin are connected with the walls of the primary dentine, and always grow where, on the corresponding outer surface of the tooth, loss of substance has occurred. * * * This formation has been called 'dentine of repair,' and protects the pulp-cavity from exposure. The other formations, however, being found loose in the pulp, are not designed for any purpose of repair. * * * The free odontomes are easily distinguishable by the naked eye; they may, however, be mistaken for calcifications, which, in their form, are identical with odontomes. * * * The microscopical structure of these formations presents the following deviations from normal dentine: their canaliculi run in all directions, especially in those formations found loosely imbedded in the pulp-tissue. Now and then the dentinal canaliculi enlarge like a sack, or terminate in large holes, which, however, ought not to be regarded as bone-corpuscles. * * * Osteo-odontomes are mixed formations, and show dentine in one and cement in another place. * * * Osteomata are found both free and adhering to the walls of the pulp-cavity. The bone-corpuscles are found sometimes analogous to those of the cementum; at others they are seen as rudimentary formations only. * * * The contents of the bone-cells I positively believe to be a clear liquid, although in some places it looks granular. In no instance was it possible for me to see a nucleus in the cells, and their contents, as mentioned before, are perfectly homogeneous and clear." This work is illustrated by two very nicely executed plates.

Franz Boll ("*Archiv für Microskopische Anatomie*," vol. iv.; Bonn, 1868) says, "An examination of a specimen of pulp-tissue by five hundred diameters will exhibit, besides the numerous medullated nerve-fibers, an enormous quantity of very fine, peculiar, silk-like, and shining fibrillæ, which, upon the first glance, may be mistaken for very fine fibers of elastic tissue. Upon closer examination, however, they prove to be minute non-medullated nerve-fibers. The transition of the medullated into the non-medullated nerve-fibers goes on quite gradually. At first the axis-cylinder is surrounded by its comparatively thick myelin sheath, exhibiting its characteristic double contour. Soon, however, this myelin sheath decreases in thickness, and afterward is seen only in some places, where it forms the characteristic varicosities. They yet exhibit the double contour, but the very thin layer of myelin surrounding the axis-cylinder shows only a single contour. At first these intervals are small and the varicosities appear in regular succession, but soon the former become larger and the latter scarcer, until they are altogether absent. The fibers in this place are quite delicate, yet exhibit alternate expansions and constrictions in their diameters. But soon they lose this characteristic feature, and appear as naked, homogeneous axis-cylinders. As mentioned before, these nerve-fibrillæ look somewhat like fibers of elastic tissue, but their great delicacy and little resistance for reagents are proofs that they are nerves. * * * In the investigation of the terminations of these minute non-medullated nerve-fibers we meet with great obstacles. By the usual way of splitting a tooth in a vise and removing the pulp by a pair of fine tweezers, we do not obtain the whole of the pulp. The peripheral portion of the pulp forming the boundary toward the dentine is composed of a continuous layer of elongated cells, which, by long processes extending into the dentinal canaliculi, adhere to the dentine. However carefully the pulp is removed from the split tooth, we will hardly ever be able to find traces of this peculiar peripheral layer upon the pulp. The outer layer of cells, by their long processes, which extend into the dentinal canaliculi, are held firmly to the inner surface of the dentine, appearing, to the naked eye, as a thin mucus-like film. If this film is carefully scraped off with a knife and brought under the microscope, we observe that, besides the peripheral cells, it contains some of the inner parts of the pulp-tissue. To be able to obtain the whole of the pulp untorn, I proceed in the following way: I split a fresh tooth once in a vise and place the pulp and tooth in a very weak solution of chromic acid, of the strength of one-thirty-second of one per cent. After one hour I carefully remove the loose fragments of the tooth, and then, with a thin and sharp knife, go between the pulp and the dentine close to the walls of the pulp-cavity. Thus, with a little practice and some good luck, I am often successful in obtaining the outermost portions, with the whole of the pulp in position. The peripheral processes of the outer layer of cells, which extend into the dentinal canaliculi, are generally torn off close to the body of the cells. Sometimes it happens that by the pull of the knife these fibers come out of the dentinal canaliculi in considerable length. * * * On specimens obtained in this way enormous numbers of non-medullated nerve-fibers (which by their division are greatly augmented) are seen toward the periphery of the pulp. By tearing such pulps apart with very fine needles we will obtain hardly a specimen which does not contain some of these minute nerve-fibrillæ. A very close net-work of these fibrillæ is seen on the boundary between the proper tissue of the pulp rich in vessels, and the peripheral cells, which, when removed in the ordinary way, generally adheres to the wall of the pulp-chamber. Some of these delicate nerve-fibers we see coming out of the layer below the peripheral cells, making their way between the latter, which are closely packed together, and extending above them, where they end. * * * We have now to consider the question, do the extremities of these minute free nerves extend into the dentinal canaliculi or not? I have spent a great deal of time to prove this, but have not been successful. Although I can furnish no direct proof, yet I regard the prolongation of the nerve-fibers into the dentinal canaliculi as certain. The outer surface of the peripheral portion of the pulp and the walls of the pulp-chamber are in absolute contact, so much so that there would be no room for the extremities of these protruding nerves. The direction of the ends of these nerves being parallel with the dentinal canaliculi, leaves us to think of no other way but that they, as well as the processes of the peripheral cells of the pulp have been lifted out of the dentinal canaliculi. We have, therefore, to assume two varieties of canaliculi in the dentine near the pulp: those containing the processes of the peripheral cells of the pulp, and others which receive the minute nerve-fibers emanating from between these cells."

J. H. McQuillen (DENTAL COSMOS, vol. x.) says, "A very valuable specimen was forwarded recently by Dr. C. B. Rising, of West Rockford, Ill., illustrative of that interesting but painful affection known as calcification of the pulp, in which the pulp-cavity is either occupied by a number of nodules or almost obliterated by the formation of a structure which, under the microscope, presents a peculiar appearance named secondary dentine."

S. J. A. Salter ("Dental Pathology and Surgery;" New York 1875) says, "The pulp is a soft mass which exactly fills the chamber in the fang and crown of the tooth. * * * There appear to be no lymphatics in the tooth-pulp. * * * A very pale, ill-defined areolar tissue, pervaded by numerous round and oval cells or nuclei, occupies the spaces between the vessels and nerves. The cellular bodies toward the surface are enlarged, and assume the form of columnar epithelium. From the extremities of these project minute tubular prolongations, which constitute the animal basis of the dentinal tube-wall. * * * Calcification of the pulp must be looked upon as morbid in the lowest degree, being to a great extent reparative and the result of trivial causes, though I believe it never occurs unless the tooth has been in some way the subject of injury or irritation. * * * The pathological change consists in the impregnation of the various tissues of the pulp with calcareous matter, involving more and more of the structure of the pulp, and its ultimate conversion, under favorable circumstances, into osteo-dentine. * * * The process of lime-impregnation is different from that which occurs in the formation of normal dentine and 'dentine of repair.' In these calcification is superficial, and only involves those elements which constitute the animal basis of dentine, namely, the tubular prolongations from the peripheral cells and the hyaline intertubular substance. Their calcification, moreover, is 'globular,' as already mentioned. * * * The relation of these calcified masses to the tissues among which they are found is very remarkable. The whole of the tissues, cells, nuclei, connective tissue, blood-vessels, and multitudes of nerves are swallowed up and obliterated by the calcification process."

From J. Bruck, Jr. ("Beitraege zur Histol. und Path. der Zahnpulpa;" Breslau, 1871) I copy the following: "The structure of dentinal new formations is identical with that of normal dentine, with the difference that in the former the dentinal canaliculi assume a radiating arrangement and their course is wavy. These new formations are seen not only in carious, but frequently in healthy temporary and permanent teeth. Very often these dentinal formations are met with in teeth the crowns of which have been worn by attrition, and in chronic cases of caries. * * * Calcification of the blood-vessels and nerve-fibers may occur; but I do not believe that calcified masses are found without being in connection with blood-vessels or nerve-fibers. In all my researches I have never found a calcified mass loosely imbedded in the tissue of the pulp, but always was enabled to observe either a dentinal or an osteo-dentinal structure in it. I would therefore like to state that all formations which previously have been described as depositions of lime-salts within the pulp are nothing else than new formations of dentine. * * * It is not without interest that I have shown that dentinal tissue may be developed not only from the odontoblasts (ivory cells), but from any cell of the tissue of the pulp. Thus bone-tissue is brought one step nearer to dentine, and, as dentinal canaliculi have been found in the bone of fishes, this may throw additional light upon the subject." This pamphlet is illustrated by sixteen engravings upon two plates, which are executed in the most natural manner, and are the best on this subject that I have ever met with.

According to Waldeyer ("A Manual of Histology," by Professor S. Stricker; New York, 1872), "The external layer of the pulp is formed by a layer of large cells, of elongated form, and provided with numerous processes called 'odontoblasts,' which are arranged so as to form a kind of columnar epithelium. Three kinds of processes may be distinguished in these cells: the dentinal process, the pulp process, and the lateral processes. The dentinal processes constitute the dentinal fibers; odontoblasts with several dentinal processes are broad at the end, but as the processes pass on they gradually diminish, to form the dentinal fibers. The odontoblasts are intimately connected with one another by means of fine, short teeth, which the lateral processes of all the dentinal cells form."

From Carl Wedl ("The Pathology of the Teeth;" Philadelphia, 1872) I cite: "The outer surface of the pulp is covered with conical cells (odontoblasts), from the broad faces of which, directed outward, comparatively thick processes extend. The dentinal processes enter the continuous dentinal canals, and, like the latter, divide into branches and numerous ramifications. * * * The basis-tissue of the pulp consists of a loose connective tissue. Bundles of wavy connective tissue serve to give it firmness. In aged persons the pulp is more dense, tenacious, and contains also a larger quantity of fibrillated connective tissue. * * * A new formation of dentine, which has arisen subsequent to the abrasion of the crown, is perceptible upon the abraded surface as a central spot surrounded by polished dentine. In these cases there occurs a continued development of dentine within certain limits, determined by an irritation, and the new layers are deposited in immediate contiguity with the old, and in parts are intimately and organically united with the latter. Dentine of this description, which serves as a protecting covering of the pulp, is called 'dentine of repair,'—secondary dentine. * * * Thin cross-sections of these new formations present a central basis-substance, composed, in many cases at least, of transparent, diskoid, homogeneous, structureless, nucleus-like masses, around which concentric layers are disposed in a manner similar to those around the Haversian canals in bone. * * * I have met with a few cases only of true new formation of osseous substance within the parenchyma of the pulp. They occurred in the pulps of milk-teeth which were undergoing resorption. * * * The greater portion of the very common osteo-dentinal formations is composed of dentine; the bony substance occurs in very small quantity, and may consist merely of a group of a few bone-corpuscles. * * * With regard to the development of these isolated encysted new formations, Heider and I have maintained the view of the occurrence of an inversion of the layer of dentinal cells, upon the following grounds: the dentinal canals pursue a centripetal course; therefore, the dentinal cells, which enter into the formation of the latter, and the development of which proceeds from the periphery of the inverted portion toward the center, must have assumed an adequate arrangement. * * * The calcareous grains are true concrements, and occur also as accessory products in connection with hard new formations, but never enter into organic union with the original dentine. They are located within the parenchyma of the pulp, and are calcifications in the connective tissue."

In the "Atlas to the Pathology of the Teeth," arranged and explained by the late Prof. Dr. M. Heider and Prof. Dr. C. Wedl, the following figures illustrate new formations in the pulp: Nos. 46, 48, 49, 51, 52, 53, 54, 55, 56, 57, 58, 60, 61, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 76, 77, 78, 80, 97.

C. S. Tomes ("Manual of Dental Anatomy;" Philadelphia, 1876) says, "The pulp may be described as being made up of a mucoid, gelatinous matrix, containing cells in abundance, which are especially numerous near to its periphery. In it some fibrous connective tissue is discoverable. * * * The odontoblast layer sometimes is called the 'membrana eboris.' They (the odontoblasts) are furnished with three sets of processes: the dentinal process (which is equivalent to the dentinal fiber); by means of lateral processes the cells communicate with those on either side of them, and, by means of their pulp processes, with cells lying more deeply. The membrana eboris covers the surface of the pulp like an epithelium. * * * No lymphatics are known to occur in the tooth-pulp. * * * The exact nature of the terminations of the nerve-fibers in the pulp is not with certainty known; the primitive fibrils often form meshes, but this does not appear to be their real termination."

Robert Baume (in "*Deutsche Vierteljahrsschrift für Zahnheilkunde,*" 1874) describes new formations of dentine in human pulps, as well as in those of the ox, elephant, and hippopotamus, to which he applies the term "interstitial dentikels."

(I am sorry to state that I have not been able to obtain Dr. Baume's "Lehrbuch der Zahnheilkunde" in time for this publication.)

M. Schlenker (in "*Deutsche Vierteljahrsschrift für Zahnheilkunde,*" 1875) describes two cases of new formations of dentine and bony masses in human pulps, but says little of their minute structure.

Adolph Witzel, in his work, "Die Antiseptische Behandlung der Pulpakrankheiten;" Berlin, 1879, says, "The odontoblasts at their free extremities exhibit thick prolongations, which have been torn out of the dentine; and in their finely-granular protoplasm contain one or two nuclei. * * * The new formations of dentine, considered histologically, are composed of a finely-granular or lamellated basis-substance, in which more or less dentinal canaliculi are present. The basis-substance, as will be observed in these new formations, everywhere is largely prevailing. The course of the dentinal canaliculi is very different. In some of the small globular new formations the dentinal canaliculi divide, and are distributed within the basis-substance in a radiatory arrangement. * * * The development of the free new formations of dentine is, as Heider and Wedl announce it, accomplished by an invasion of the odontoblast layer. I, according to my own observations, cannot conform with this view, but have to support the assertions of Hohl, who, with right, claims that if the loose new formations of dentine arise by an invasion of the odontoblasts, they ought to be traceable, which Hohl, as well as myself, has never been able to do. * * * The development of the free dentikels, according to my researches, is accomplished in the way, that, first, the connective-tissue corpuscles in the midst of the pulp-tissue are sprouting fine offshoots; or they proliferate and form anastomoses; the connective tissue then begins to calcify, and, as calcification (dentinification) advances, the connective-tissue corpuscle itself becomes constricted, and gradually is transformed into a dentinal canaliculus."

III.—Therapeutics.

In the September number of the *Dental Cosmos* for 1876 there was published a paper, by Junius E. Cravens, D.D.S., of Indianapolis, Indiana, entitled "Lacto-Phosphate of Lime, Pathology and Treatment of Exposed Dental Pulps and Sensitive Dentine," in which attention was called to the injurious effects of pure carbolic acid and creasote in the treatment of exposed pulps. This article seems to have awakened the interest of several thinking minds. At the meeting of the New York State Dental Society, a few months later, Dr. W. C. Barrett, of Buffalo, read a paper on "The Use of Creasote in Treating Simple Exposures of the Dental Pulp. Is it Correct Practice?" This again directed my attention to the subject. Before that time I had usually capped exposed pulps with either a solution of gutta-percha in chloroform, or with zinc oxide mixed with creasote, filling the rest of the cavity with oxychloride of zinc, from which I had had to record quite a number of failures. I tried to save every pulp as long as there appeared to be life. Arsenious acid, which, before I became acquainted with Dr. Wm. H. Atkinson, I had used freely, I had, like him, laid aside altogether. In July, 1879, I read the work of A. Witzel, and felt sure that every tooth treated with arsenious acid in the manner described in that work would, sooner or later, cause trouble. At the meeting of the American Dental Association held at Niagara Falls in August, 1879, I, as well as Dr. Atkinson, severely criticised Witzel's work and his advised use of arsenious acid. To-day, however, I have to corroborate some of the assertions of Witzel, and believe that without arsenious acid the dental materia medica is incomplete.

I have been asked, "Is the knowledge of the minute anatomy and pathology of the dental pulp of any practical value?" My answer to this question is that I believe it is impossible, without this knowledge, to treat successfully all the difficulties that present themelves. To decide what the mode of treatment shall be,—whether a pulp, when exposed, can be capped, or had better be destroyed,—depends, in a great measure, upon a thorough *scientific* as well as practical understanding of the organ to be treated. If these querists, after due consideration of this paper, are led to corroborate this assertion, I shall feel more than gratified.

In chapter II. of this paper I have described the microscopical appearances of the inflammatory process in the pulp, omitting its clinical features. These will, in connection with the therapeutical part of our subject, be of greater interest.

In order to make the different stages of pulpitis comprehensible, I will describe in few words some of its most characteristic symptoms:

Inflammation of the pulp may occur in one portion or in several independent portions at the same time, or may implicate the whole organ.

It is of importance to be able, as far as possible, to distinguish the different stages of inflammation in the pulp. In a great measure successful treatment depends upon a correct diagnosis of the degree to which the disturbance has advanced; whether there is present a hyperemic condition, an inflammation involving a part or the whole of the pulp-tissue, or a dying pulp.

A hyperemic condition of the pulp exists if the patient experiences pain only when the tooth affected comes in contact with anything hot, cold, salty, sweet, or sour, etc., the pain lasting but a few minutes, and ceasing as soon as the irritant is removed.

When a tooth is attacked by caries, or suffers from any lesion which allows the approach of an irritant near to or into the pulp-chamber, a partial inflammation, in the majority of cases, is, sooner or later, the result. Slight pain, with long painless intermissions, first occurs, but the paroxysms of pain gradually increase in length until they sometimes last an hour, the intermissions being correspondingly shortened. Pressure applied in the vicinity of the exposed pulp produces intense pain, which does not subside with the removal of the pressure. Upon the application of heat or cold the tooth aches for an hour or more, but an application of pure carbolic acid or creasote abates this. The tooth as yet is not at all sensitive upon percussion, and is as useful as before, except when, as in mastication, foreign matter is pressed upon the pulp. If the decayed portion of the dentine, which generally still covers the pulp, is very carefully removed with a sharp excavator, we observe the exposed portion of the pulp as a light-red dot, with a little blood escaping from the pulp-cavity. If such a pulp is left without therapeutical treatment, there occurs either an acute inflammation involving the whole of the organ, or, in case the pulp-cavity is largely perforated, the process may become chronic.

Inflammation of the whole pulp is characterized by very intense throbbing pain in the tooth, intermittent in the beginning, but soon becoming continuous, and which may last from one to three days. After the first or second day of the paroxysm a little sensitiveness becomes noticeable, from pressure or percussion upon the affected tooth, indicating the beginning of pericementitis. When the pulp can be brought to view at this stage, it will appear as a dark-red dot, bulging into the cavity and bleeding quite freely.

If the exposure is large the pulp may protrude from its cavity, and, the pus which is formed escaping, the organ may retain its vitality for some time, and the inflammatory process assume a chronic form. If, on the contrary, the pulp-cavity is not perforated, or the exposure is small, preventing the swelling of the pulp-tissue out of its hard inclosure, then the vessels of the pulp, and especially the afferent vessels, become engorged with blood to such an extent that they are strangulated, resulting in gangrene of the pulp. The pain, shortly before the strangulation of the vessels, is excruciating, but only for a few minutes, when suddenly it ceases altogether.

The conservative treatment of the pulp is of great importance in the teeth of young persons, especially those under the age of sixteen years, where the roots are not quite fully developed. The death of the pulp in these instances frequently terminates, sooner or later, with the loss of the tooth. It is different with the teeth of adults and old persons, in which cases I do not regard the loss of the pulp as a very great injury. Though I do not want to be understood to say that a pulpless tooth is as good as one that contains a healthy pulp, still I consider it safer (when filled properly) than a tooth with a pulp which is composed mainly of fibrous connective tissue, or contains large eburnifications and spicula of bone.

I have now come to the consideration of the question, *Ought every exposed pulp to be saved? I should say, Certainly not.* As soon as the inflammation has invaded the whole of the pulp-tissue, or the formation of pus has commenced, such a pulp ought not to be treated and afterward capped, but should be directly devitalized. In a hyperemic or partial inflammatory condition of the pulp, and when the latter stage has not proceeded further than the liquefaction of the gluey basis-substance in a small territory of the pulp, the organ can be saved, provided the pulp in being exposed has not been wounded deeply, or for any length of time left in contact with the fluids of the mouth or the air. Such pulps, in skillful hands, and with the proper treatment, will be saved every time, and are the only ones that promise satisfactory results after capping.

Regarding the use of pure carbolic acid or creasote in capping, I agree with Drs. Cravens, Barrett, A. Witzel, etc., that neither a hyperemic nor a partially inflamed pulp, when its preservation is desired, should be treated with anything stronger than a five-per-cent. aqueous solution of carbolic acid. Pure carbolic acid is an irritant, and as such, when applied to tissues, excites inflammation just beneath the layer which it has destroyed,—a process which, in the conservative treatment of the pulp, should be prevented. In the capping of this class of pulps we require no other action of carbolic acid than that of a disinfectant, for which the five-per-cent. solution is ample. Some operators use this agent to destroy pulps, and in some instances I have done so myself. Therefore, pure carbolic acid or creasote ought not to be used in connection with anything that is designed to cover an exposed healthy or hyperemic pulp. In shallow cavities, however, which do not reach the vicinity of the pulp-chamber, I always apply pure carbolic acid for a few minutes before the filling-material is introduced. When used in this way, I regard its action as beneficial. It is a powerful disinfectant, and at the same time coagulates and mummifies the ends of the dentinal fibers. Thus the irritation of a metallic filling-material is greatly reduced. Whenever a cavity is large enough to admit of the interposition of cement and gutta-percha between the metallic filling and dentine toward the pulp-cavity, this protection should always be afforded. Since 1877 I have used directly upon the pulp no stronger aqueous solution of carbolic acid than the ten-per-cent., and lately only a solution of five per cent. So far as I know, all the pulps I have capped since 1880 are living,—that is, those teeth which I have seen since have given no trouble, and their appearance is perfectly normal. Their treatment has been as follows: When a cavity is deep, and the symptoms indicate that the pulp-cavity is very nearly or slightly perforated, I at once apply the rubber dam, if possible, and saturate the cavity with the five-per-cent. solution of carbolic acid. I then excavate and clean the side walls of the cavity perfectly before touching the vicinity of the pulp-chamber. If pain is produced by slight pressure with a piece of cotton upon the softened dentine covering the pulp (indicating a perforation of the pulp-chamber), I very carefully remove, with a sharp and large excavator, as much of the disintegrated dentine as possible, but without quite exposing the pulp, and apply the cap. If upon slight pressure into the cavity the patient experiences but little or no pain, I remove all the decay from the cavity. The best material to be placed upon the dentine, either soft or hard, covering the pulp, as well as upon an entirely bare organ, I have found to be zinc oxide mixed to the consistence of thick cream with an aqueous five-per-cent. solution of carbolic acid. Over this, before it commences to dry, I very carefully place a thin wafer of gutta-percha, which, previous to its introduction into the cavity, I moisten with the carbolic acid solution. After three to five minutes, I cover the cap with either oxychloride of zinc or carbolic acid cement (Witzel*). When sufficiently hard, I use oxyphosphate or amalgam to fill up the rest of the cavity. The latter filling I always expect to remain for at least one or two years before I would consider it safe to fill such a cavity with gold.

In a former chapter I stated that, when myxomatous connective tissue is attacked by an inflammatory process, this, as all other tissues, returns to its medullary condition, from which, as long as the single medullary elements are connected with one another, a fibrous cicatricial tissue, bone, or dentine may arise. This tissue can never again return into the myxomatous condition, and consequently, in some instances, when spicula of bone or dentine are developed in the pulp-tissue, severe disturbances may occur. For this reason I advocate the devitalization of pulps the whole tissue of which has, by inflammation, either wholly or to a great extent retrograded into its medullary condition.

No doubt every dental practitioner of experience has met with patients who have suffered from neuralgic pain, which, after devitalization of a pulp or the extraction of a tooth, suddenly ceased. I have on my record quite a number of such cases, of which I will describe a few:

I. For Miss S., aged fourteen years, I filled, on the 25th of November, 1872, the second lower molar with amalgam. The cavity was

---

* The formula for Witzel's carbolic acid cement is as follows:

℞ Acid. carbol., 5·0;
Alcohol. absol., 2·0;
Aq. dest., 40·0;
Glycerinæ, 20·0.

Mix, and add an equal volume of the zinc chloride used in preparing oxychloride fillings. To a sufficient quantity of this mixture add oxide of zinc to give it the necessary consistence for filling.

This author also mentions a varnish composed of collodion, gutta-percha, and a little carbolic acid, which he applies upon an exposed pulp previous to the adaptation of the cap. This I have found very serviceable.

situated on the buccal, near the mesial surface, and rather extensive. The tooth, after the filling had been inserted, remained sensitive to thermal changes for a long time, but otherwise gave no trouble. In December, 1879, the tooth was decayed on its mesial surface, but in trying to prepare this cavity I found the dentine so extremely sensitive that the patient, being at the time in bad health, would not let me fill the tooth. June 3, 1880, I saw the tooth again, when the decay had reached the pulp-cavity. It had never given very much trouble, except when food, during mastication, was pressed into the cavity. I found the dentine sensitive as before, and concluded, therefore, to devitalize the coronal portion of the pulp, and made an application of arsenious acid. The next day, when the patient entered my office, she told me she felt better that day than she had for many months. When I removed the dressings and examined the state of the pulp, I found a large so-called "pulp-stone" lying in the direction toward the amalgam filling. The patient, since that time, has had no more neuralgia, has got quite strong and vigorous, and the molar, with the coronal portion of the pulp amputated, does good service, and has not given any further trouble.

II. On September 3, 1881, Mrs. R., aged twenty-two, came to me with excruciating pain in the left upper lateral, containing a large gold filling in its mesial surface which had been inserted several years previously. About a year before the patient first noticed lameness of the left upper arm, which, after some weeks, terminated in more or less constant neuralgia, affecting, at times, the whole left side of the body; but no pain was observed in this lateral previous to the 1st of September, two days before the patient applied to me for relief. I opened the pulp-chamber from the lingual surface of the tooth, and found the pulp in a high state of inflammation, which had extended somewhat into the pericementum. An application of carbolic acid, tannin, and morphia was made, which greatly relieved the patient. About one hour later I renewed the application, and after a few minutes introduced the arsenious acid paste, and then dismissed the patient, who felt greatly relieved. The next day I extracted the pulp by means of a broach, and immediately immersed it in a very weak solution of chromic acid. A section of this is exhibited in Fig. 6. The patient, who at that time lived in the country, came back two days afterward to thank me for the cure of her neuralgia, which, up to this time, has not recurred.

III. On the 1st of June, 1878, I inserted for Dr. H. an oxychloride filling in the right upper first molar, which had previously been filled with amalgam. The cavity was large, involving the distal and grinding surfaces, with half of the lingual wall broken off. On the

21st of August, 1880, I restored the last portion of the tooth with gold, but left much of the oxychloride cement over the pulp-cavity. The walls of the cavity were quite sensitive under the bur, so much so that my patient, who in all other operations I had previously performed for him never said a word of the pain produced by excavating, in this instance remarked that the drilling in some places was very painful. There had been no pain in the tooth whatever previous to the introduction of the gold, but about a week after the operation was completed the tooth became sensitive upon percussion and mastication, without signs of pulpitis. About two weeks later my patient was suffering from an alveolar abscess situated above the buccal roots of this molar tooth. I immediately tried to open the pulp-chamber, but could only go a little way into the dentine, when the patient informed me that the drilling caused him severe pain, which was analogous to the excavating of a sensitive tooth. I abstained from drilling any further, filled the small hole with gutta-percha, and began the treatment of the abscess through the gum at the buccal surface, but with no success. The abscess was continually discharging until the beginning of December, when I removed the gutta-percha, and, with a sharp drill, perforated the pulp-chamber, but, to my surprise, found the pulp alive and bleeding freely. I then, as quickly as possible, capped the pulp in the usual way, and filled the outer portion of the drill-hole, which had been widened with a larger bur up to the cap, with oxyphosphate cement, concluding to wait a few weeks longer, and then, if the abscess did not heal, to devitalize the pulp. On the 23d of January, 1881, I removed the filling, together with the cap, in order to destroy the pulp, but found that the pulp had died recently, as there was no smell of putrefaction present in the pulp-chamber. I took out a large filling in the mesial surface of the tooth, and from this situation thoroughly exposed the pulp-chamber, from which I extracted a very large so-called "pulp-stone" of the size of a small pea, occupying the neighborhood of the buccal roots. This is the specimen which I have described in chapter II, No. 4, "So-called 'pulp-stones' composed of dentine with the features of primary dentine." The canals of the tooth were then examined, and I found the two buccal canals in a very putrid condition, but the lingual canal contained its recently-dead portion of the pulp without large calcified or eburnified masses. After the disinfection and filling of the pulp-canals the abscess began to heal, and the tooth to-day is as serviceable and comfortable as any other tooth in the mouth.

A few years ago I tried to save every pulp, even after an acute total inflammation had been present, treating them with every suitable remedy, but cautiously avoiding arsenious acid. Many times

I have rather let my patient suffer a great deal of pain than devitalize the pulp in the usual manner. Such practice to-day I regard just as one-sided as to try to fill every cavity with gold and adhere to the opinion that nothing but that material will be able to save teeth from decay, and *vice versa* of other filling-materials. I have experimented with arsenious acid in quite a number of cases, but am not quite ready yet to say anything about them. This, however, I can state, that so far as I know I have met with the same results as described by Witzel, namely, that arsenious acid applied upon a healthy or a superficially inflamed pulp (for from twelve to twenty-four hours), which has previously been treated with a solution of tannin in carbolic acid, does not devitalize the whole of the pulp, and when after twenty-four hours the arsenious acid, together with the destroyed portion, is removed, the remainder of the pulp, which appears to be quite healthy, can be capped and preserved. As this subject is of very great interest, I will give a very brief abstract of the method as published by Witzel in "Die Antiseptische Behandlung der Pulpakrankheiten des Zahns" (Berlin, 1879):

"Before excavating I insert a piece of spunk moistened with the carbolic acid and tannin solution into the carious cavity for a few minutes, clean the surrounding gum of the mucus-like saliva with a soft brush or a piece of spunk, and make the cavity accessible. And now I begin to clean the cavity either with broad spoon-shaped excavators or sharp oval burs. Before the introduction of the arsenious acid I make an application of the carbolic-acid-tannin solution,* until the pain in the tooth has entirely ceased, which is generally the case in five or ten minutes. The arsenious acid and morphine made into a thin paste is then laid directly upon the exposed pulp, and the cavity hermetically sealed. If the coronal portion of the pulp is to be amputated and the stumps preserved, this application should not remain longer in the tooth than from twelve to twenty-four hours. If, however, the whole pulp is to be extracted, the arsenious acid paste should remain in the tooth for forty-eight hours. Before the removal of the whole dressing the cavity must be moistened with a weak solution of carbolic acid. Then take a sharp, new bur, with the engine, now remove the last dressing, and with a few quick revolutions of the bur amputate the coronal portion of

---

* ℞ Acid. carbol., ·150;
Tinct. aconit rad.,
Aq. menth. pip., āā ·050;
Glycerinæ, ·020;
Acid. tannic., ·030;
Ol. menth. pip.,
Ol. caryophylli, āā gtt. xxv.—M.

the pulp, and immediately fill the cavity with carbolic acid solution until the bleeding has ceased; then place a piece of spunk moistened with the carbolic-acid-tannin solution over the amputated stumps. The amputation of a portion of the pulp is to the patient somewhat uncomfortable—about as painful as exposing a pulp. With very sensitive patients I make an application of a solution of iodine with carbolic acid previous to the amputation for about a quarter of an hour, which makes the operation painless. The whole treatment must be done quickly, very cleanly, and without exposing the amputated stumps much to the action of the air. The cavity is now to be syringed out well, dried, the stumps touched with carbolic acid, mastic, and pulp-varnish, and quickly capped with carbolic acid cement; then a layer of oxychloride and gutta-percha is placed over it, and, lastly, the rest of the cavity is filled either with amalgam, oxyphosphate, or other material."

Since December last I have tried a new remedy (iodoform), which of late has been reported as doing great wonders in surgery. The very disagreeable smell of this drug had prevented me from using it before. In a German dental journal (*Vierteljahrsschrift für Zahnheilkunde*) I noticed an article on iodoform by Dr. Julius Scheff, of Vienna, who has been very successful with it in capping slightly inflamed pulps, using it in the form of a paste, the formula of which was original with Dr. Paschkis, and is as follows:

℞ Iodoform pulv.,
Kaolin pulv., āā 4·00;
Acid. carbol. cryst., 0·50.

Mix; add sufficient glycerin to form a paste; then add ol. menth. pip., gtt. x.

I have tried this paste in a small number of exposures, and apparently with good results. I placed the iodoform paste over the exposed pulp, covering it with a wafer of gutta-percha and a layer of carbolic acid cement, and filled the rest of the cavity with either gutta-percha or oxyphosphate of zinc. None of these teeth have given any trouble since then; but in what state their pulps are I am unable to say at present. I have found another very valuable use for iodoform,—in chronic alveolar abscesses. For this purpose I use the saturated solution in sulphuric ether, which, when forced through the end of the affected root into the old abscess, acts, I believe, as a very powerful disinfectant, and is therefore of great service as an application previous to filling the roots of pulpless teeth. I have also used the solution of iodoform in ether as an injection into the antrum, the mucous membrane of which was inflamed. In this case it did not quite stop the formation of pus, but prevented it longer than any of the other agents which, in this case, I had used previously or intermittingly.

the pulp, and immediately fill the cavity with carbolic acid solution until the bleeding has ceased; then place a piece of asbestos moistened with the carbolic acid-tannic solution over the amputated stumps. The amputation of a portion of the pulp is in the case of somewhat uncomfortable patients as painful as exposing a pulp. With very sensitive patients I make an application of a solution of iodine with carbolic acid previous to the amputation for about a quarter of an hour, which makes the operation painless. The whole treatment must be done quickly, very slowly, and without exposing the sensitive stumps much to the action of the air. The cavity is now to be syringed out, well dried, the stumps touched with carbolic acid, iodine and gum-varnish, and quickly capped with carbolic acid cement; then a layer of oxychloride and gutta-percha is placed over it, and lastly the rest of the cavity is filled either with amalgam, oxyphosphate, or other material.

Since December last I have tried a new remedy (iodoform) which of late has been reported as doing great wonders in surgery. The very disagreeable smell of this drug had prevented me from using it before. In a German dental journal (*Vierteljahrsschrift für Zahnheilkunde*) I noticed an article on iodoform by Dr. Julius Scheff of Vienna, who has been very successful with it in capping slightly inflamed pulps, using it in the form of a paste, the formula of which was original with Dr. Bacchini, and is as follows:

℞ Iodoform pulv.

Balsam peruvian.

Acid. carbol. cryst.

Mix; add sufficient glycerin to form a paste; then add of mastic, ...

I have tried this paste in a small number of exposures, and apparently with good results. I placed the iodoform paste over the exposed pulp, covering it with a disk of gutta-percha dipped in a mixture of carbolic acid-cement, and filled the rest of the cavity with either gutta-percha or oxyphosphate of zinc. None of these teeth have given any trouble since then; but in what state their pulps are, I am unable to say at present. I have found another very valuable use for iodoform—in the treatment of chronic alveolar abscesses. For this purpose I use the saturated solution in sulphuric ether, which, when forced through the end of the affected root into the old abscess sac, I believe to be a very powerful disinfectant, and is therefore of great service as an application previous to filling the roots of pulpless teeth. I have also used the solution of iodoform in ether as an injection into the antrum, the mucous membrane of which was inflamed. In this case it did not quite stop the formation of pus, but prevented it longer than any of the other agents which, in this case, I had used previously or intermittingly, as iodine, &c.