A

MONOGRAPH

ON THE

FŒTAL CIRCULATION.

WITH THREE ILLUSTRATIONS ON WOOD.

BY E. R. PEASLEE, A.M., M.D.,

PROFESSOR OF ANATOMY IN DARTMOUTH COLLEGE AND IN THE NEW YORK MEDICAL COLLEGE, AND OF SURGERY IN THE MEDICAL SCHOOL OF MAINE.

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Fœtal Anatomy has, for several years past, received a large share of attention, while fœtal physiology has hitherto been, to a great extent, neglected, except so far as mere development is concerned. It is, indeed, a department of no ordinary difficulty, since the human fœtus passes through various successive phases of function, as well as development. In regard to its circulation, for example, it is at one time analogous to a fish; subsequently to a reptile; and does not become a true mammal, indeed, till after birth.

Still, we may now enter this field with views somewhat extended; and it is the object of this paper to show that the view of the fœtal circulation, which is adopted by the highest authorities, is unsatisfactory and incorrect; and to propose such a view as the present state of science demands.

In this view the last half of fœtal life alone is included; and it is proper to commence with a statement of the ideas, both in regard to the course and to the physiology of the fœtal circulation, which are generally entertained.

I. *The course of the Fœtal Circulation.*

About 150 years ago a violent controversy arose in France, and extended to the neighboring kingdoms, respecting the manner in which the blood passes between the auricles, through the foramen ovale.* It was excited by Meri's

* For the arguments adduced in this controversy, see Senac's Traité de la Structure du Cœur, tome 1, p. 369; and the Supplement, in tome 2.

theory—that it passes from the left to the right auricle—while Harvey had assigned to the current an opposite direction. Boerhaave, Lancisi, Winslow, and others, investigated the subject; and their conclusions have undergone but slight modifications up to the present time.

The course of the fœtal circulation as usually stated—independently of the inferences generally associated with the facts—is as follows:

1. The aerated, or arterial, blood returned by the umbilical vein, from the placenta through the umbilicus, and to the inferior surface of the liver, is thence poured into the inferior vena cava; a part having entered that vessel at once through the ductus venosus,* and the rest having first been transmitted through the liver.

2. The blood in the inferior vena cava is poured into the right auricle, and by the *Eustachian valve turned across into the left auricle through the foramen ovale.*

3. While the left ventricle is thus filled, the right is *filled by venous blood*, from the superior vena cava.

4. The mostly *arterial* blood is sent from the left auricle through the left ventricle into the aorta, and *principally through the branches from its arch* to the head and upper extremities; the *venous* blood in the right auricle is sent through the right ventricle into the trunk of the pulmonary artery; thence in very *slight degree* to the collapsed lungs, but *almost entirely* through the ductus arteriosus into the descending aorta—there to mingle with the *purer* blood which has passed down through the arch of the aorta. 5. This mixed blood is distributed to all the parts supplied in the adult by the descending aorta; and the blood thus carried to all parts below the diaphragm is returned to the right auricle by the inferior vena cava. 6. But the internal iliac arteries are not only distributed in the fœtus as in the adult. They are also prolonged on each side of the bladder, and above it to the umbilicus, and through the latter into the cord, and to the placenta. These prolongations are called the "umbilical arteries;" and by them the blood is returned from the fœtus to the placenta.

This view is illustrated by Fig. 1, here taken from Carpenter's Physiology; and which is placed on another page for the sake of contrasting it with the correct representation of the parts in Fig. 2. Some of the words in the preceding paragraph are also italicized, since they convey incorrect or false ideas, and will be particularly remarked upon in another connection.

II. *The Physiology of the Fœtal Circulation, as at present understood.*

1. The blood arriving in the inferior cava from the umbilical artery, "having been thus transmitted through the *two* great depurating organs—

* This vessel extends from the umbilical vein directly into the vena cava.

the placenta and the *fœtal liver*—is in the condition of arterial blood; but being mixed in the vessels (the inferior cava) with that which has been returned from the trunk and lower extremities, it loses this character *in some degree*, by the time that it arrives at the heart."—Carpenter's Human Physiol., 4 Ed., p. 997.

2. This mixed blood is prevented, "in *great degree*, if *not entirely*," from farther admixture with the venous blood in the right auricle, by the *peculiar action* of the Eustachian valve; which carries it at once through the foramen ovale into the left auricle.—Ditto.

3. The ventricles contracting, the left propels its "*arterial*" blood into the ascending aorta, and supplies the head and upper extremities *before undergoing any admixture;* while the right ventricle sends its *venous* blood through the (trunk of the) pulmonary artery, and the *ductus arteriosus, into the descending aorta*, there to mingle with the pure blood just mentioned, and be distributed to the trunk and lower extremities.—Ditto.

4. "Thus the head and superior extremities, whose development is required to be in advance of that of the lower, are supplied with blood *nearly as pure* as that from the placenta;" and *vice versa* as to the rest of the body.—Ditto, and Wilson's Human Anatomy, p. 555.

5. "In the adult the blood would be circulated through the lungs and oxydated; but in the fœtus the lungs are solid and *almost impervious.* Only a small quantity of the blood passes, therefore, into the lungs; the *greater part* rushing through the ductus arteriosus," &c.—Wilson, ut sup., p. 553.

6. "The pure blood from the placenta is distributed in considerable quantity to the liver, before entering the general circulation. *Hence*, the abundant nutrition of that organ, and its enormous size in comparison with other viscera," in the fœtus.—Ditto.

We find essentially the same statements in all the best authors of the present time; and, therefore, no farther quotations or authorities are deemed necessary. We have here, also, italicized such expressions as need particular consideration, on account of their entire or partial incorrectness.

Each of the preceding six propositions will be separately reviewed, with the intention of showing their incorrectness, and at the same time of demonstrating the only true view of the subject. A few remarks will, however, be premised in this connection, expressive of the author's doubts as to the peculiar—and really incredible—action universally assigned to the Eustachian valve.

The assumed function of the Eustachian valve not probable.

Some experiments, intended to elucidate this subject, and to which a great deal of importance seems to have been attached, were performed by

the late Dr. John Reid.* The following was regarded as the most satisfactory: Having injected both the venæ cavæ, of a fœtus of seven months, at the same time—the superior cava with yellow, and the inferior with red, injection—he found that the "red had passed through the foramen ovale, and filled the left side of the heart without any intermixture with the yellow, except very slightly at the posterior part of the right auricle. Not a drop of the yellow appeared to have accompanied the red into the left side of the heart. From the left side it (the red) ascended the aorta and filled all the large vessels going to the head and upper extremities. The injection in all these vessels had not the slightest tinge of yellow."

The *yellow* "filled the right auricle, free from admixture, except slightly at the posterior part of the auricle, as already mentioned. From the right auricle it filled the right ventricle, passed along the pulmonary artery, and filled the *ductus arteriosus* and branches, going to the lungs. On entering the aorta it passed down that vessel, filling it completely, without any admixture of red; and thus, all the branches of the thoracic and abdominal aorta were filled with yellow. The whole of the red had passed to the upper part of the body," &c.

Dr. Reid's experiments have, however, entirely failed to convince us that the Eustachian valve does, or can, turn the current of blood from the inferior vena cava, across the right auricle, and through the foramen ovale, into the left auricle, without admixture with the venous blood from the inferior cava.

It is to be remarked, in the first place, that the complete isolation of the red and the yellow injections occurred only once in three similar experiments, and then in a fœtus of seven months, the others being of four months, and at full term. Dr. Reid accounts for failure in the last case, since "the Eustachian valve is supposed to be less perfect at the full time than at an earlier period." What Dr. R. supposed, is really the fact, but would it be so, *if* the valve perform the part assigned to it? On the contrary, we should suppose the necessity for the separation of the venous from the arterial blood would increase (if such necessity at any time exists) as the fœtus becomes farther developed; and, therefore, that the valve would be most perfect just at the very end of intra-uterine life. It will, however, be shown that no such necessity actually exists at any time during fœtal existence.

Again, we cannot suppose two currents of injection, forced through the venæ cavæ of a dead fœtus, would comport themselves precisely as would the two currents of blood during life; even were the heart a passive organ. But when we consider its cavities, as exerting both a forcing and a suction power, the difference is vastly increased. In this view, the experiment

* Edinburgh Med. and Surgical Journal, Vol. 43, p. 11, &c.

appears utterly valueless, therefore. But if we are still inclined to regard the result as reliable, then it proves altogether too much—such a perfect non-admixture of the two currents during life being altogether inconceivable.

A distinguished anatomist remarks, in regard to the assumed crossing of the two blood-currents in the right auricle, without intermixture: "how this crossing is affected, the theorist will wonder; not so the practical anatomist."* He then speaks of the direction of entrance of the two venæ cavæ, of the opening of the inferior almost directly into the left auricle; and of the use of the Eustachian valve—as enabling the anatomist at once to perceive the correctness of this theory. We confess, that, in our own case, the theory is more satisfactory without the anatomy than with it. Or, perhaps, we should rather say, that if our mere anatomy admits the belief in such a non-admixture in a dead fœtus, our physiology will not for a moment, in a living one. And if there *is* an admixture, the assumed function of the Eustachian valve must be relinquished and another be assigned to it, if possible.

On merely *anatomical* grounds, the anterior termination in the auricle of the superior cava may be regarded as necessitated by the relations of its primitive branches, and, therefore, of its trunk; the former being in front of the arteries rising from the arch of the aorta, while the termination farther back in the auricle of the inferior vena cava is demanded, by the liver being in front of it. Thus, also, its termination in the right auricle, so near the foramen ovale, may be necessitated by its relations to the aorta, and to the middle line of the trunk before perforating the auricle; and, therefore, the Eustachian valve may be considered as having a more important relation to the opening of this same vein, and the passage of blood through it, than to the circulation through the foramen ovale—though it may incidentally exert some influence on the latter.

These suggestions, be it observed, are made on merely anatomical grounds. They are made to meet the inferences just objected to, and to show that the latter alone cannot form a reliable basis for the physiology of the fœtal circulation. Other facts, however, will be adduced in favor of the inferences just made; and the anatomy itself will receive some important corrections as we proceed. Meantime, we will regard the assumed function of the Eustachian valve as not proved, and as improbable.

Objections to the physiological views generally entertained.

1. No importance is attached to the fact that most of the blood from the placenta circulates directly through the liver; except so far as its influence upon the development of the liver itself is concerned, and so far as the

* Wilson's Anatomy, p. 554.

liver is a depurating organ. Indeed, it is incorrectly assumed, that the major part of the blood passes through the ductus venosus into the vena cava inferior.

2. The fact that venous blood is returned from the lungs through the pulmonary veins to the left auricle, is entirely overlooked; it being assumed, also, that almost no blood enters the lungs at all,—since,

3. It is incorrectly stated that almost all the blood in the trunk of the pulmonary artery passes into the descending aorta through the ductus arteriosus.

4. No stress is put upon the dilatation or the contraction of the auricles, as having any influence in mixing the blood contained in the two auricles, through the foramen ovale.

5. It is assumed that the greater development of the head and upper extremities at birth, is owing to their having received a very pure blood during fœtal life; and greatly different in this respect from that sent to the trunk and lower extremities.

The validity of these objections, and others hereafter to be suggested, will appear in a subsequent part of this paper. Some remarks, however, in regard to the relative size of the ductus venosus and the umbilical vein, and of the ductus arteriosus and pulmonary artery, are proper in this connection.

I. *Relative size of ductus venosus and umbilical vein.*

To settle this question, I carefully dissected fœtuses of from six months to eight and a half months. They were not injected, from the fact that injection passes more easily through the ductus than through the liver, in the dead fœtus; and, therefore, the former becomes enormously distended, while the umbilical veins, and especially those in the substance of the liver, are less so. Hence it is impossible, in this way, to get a true idea of the relative size of these vessels. I have an injected fœtus at full term, in which the ductus venosus is $\frac{22}{100}$ inch (.22) in diameter, but contracting to $\frac{10}{100}$ inch (.1) just before entering the vena cava; while the umbilical vein is only $\frac{25}{100}$ inch (.25) in diameter, and the inferior cava is considerably *smaller* than the ductus. Each umbilical artery, moreover, is as large as the aorta actually is in the living fœtus at full term. It is from such exaggerations that we have heretofore acquired our ideas of the relative size of these vessels.

To avoid this source of error, I carefully dissected these vessels, and completely emptying them, laid them in their collapsed state upon a plane surface, expanded to their fullest width by the required manipulations and pressure. The width thus obtained equals the semi-circumference, or $\frac{1}{\pi}$ of the diameter. The results are not absolutely accurate, for reasons at once apparent. But when vessels of the same structure are thus compared (as veins with

veins and arteries with arteries), the relative size is thus more nearly obtained than in any other way which has occurred to me.

In a fœtus of about eight and a half months, I found the ductus venosus to have a semi-circumference of less than $\frac{5}{100}$ inch (.05); and the umbilical vein of $\frac{15}{100}$ inch (.15). In a fœtus of six months, the former had a semi-circumference of $\frac{4}{100}$ inch (.04), and the latter, of $\frac{12}{100}$ inch (.12)—the proportion being about one to three in both cases. Each of the three hepatic veins is quite as large as the ductus venosus; and these, with the latter, carry into the vena cava inferior all the blood brought from the placenta by the umbilical vein, and from the formative branches of the vena portæ. (Fig. 2d, 7.) Admitting that one of the hepatic veins is sufficient to transmit the last mentioned blood (and the small size of the vena portæ before entering the liver warrants this supposition) we have two hepatic veins and the somewhat smaller ductus venosus, to transmit to the vena cava *all* the blood from the placenta; and can perceive no adequate reason why the ductus should transmit more than one-third of that blood. Anatomy leads to this inference; though anatomical *experiments*—injected preparations—have led to a different conclusion. We consider the former far the more reliable. In the adult, the blood passes through the pulmonary artery and its branches, and through the capillaries of the lungs, and thence through the pulmonary veins into the left auricle—just as rapidly as it passes through the aorta, and just as rapidly as it could pass through the trunk of the pulmonary artery if it terminated at once in the aorta. Probably the same obtains in the case of the fœtal liver. The living blood passes rapidly through its capillaries, because nutrient changes are there going on; while an injection is first stopped by these minute vessels, then flows back through the large trunks to distend them, and finally distends to the utmost, the ductus venosus; and thus at last finds its way almost entirely through this passage into the inferior vena cava and the right auricle.

Therefore, it is believed to be within the limits of truth to say that not over one-third, at most, of the blood returned from the placenta through the umbilical vein, is carried into the inferior vena cava by the ductus venosus.

II. *Relative size of ductus arteriosus and pulmonary arteries.*

In a fœtus of six months, I found the semi-circumference of the pulmonary artery, before its division, to be $\frac{12}{100}$ (.12) of an inch; and that of the ductus arteriosus, $\frac{4}{100}$ (.04). In a fœtus of eight and a half months, the semi-circumference of the pulmonary artery was $\frac{25}{100}$ (.25) inch; and of the ductus arteriosus, $\frac{8}{100}$ (.08) inch. In both cases the ductus was perceptibly smaller than either of the two branches of the pulmonary artery, sent to the lungs. In the older fœtus it was also somewhat smaller than either carotid artery; in the youngest I omitted to notice this comparison. In these cases,

I measured the vessels in a collapsed state, as before described. The ductus tapered towards its distal extremity, in the older fœtus; and was somewhat smaller at its union with the descending aorta, than the dimensions above given.

The *anatomical* inference is, therefore, that the ductus arteriosus does not transmit any more blood into the descending aorta than each branch of the pulmonary artery carries to its lung. If it be remarked that the blood may rush more rapidly through the ductus than through the pulmonary arteries, and therefore a greater quantity be discharged, I reply that it cannot be transmitted in a current more rapid than that in the descending aorta, with which it blends; and as the latter cannot be more rapid than that in the main trunk of the pulmonary artery (since the latter and the aorta, at their commencement, transmit the same amount of blood, as nearly as may be), it follows that the current through the ductus is not more rapid than that through the pulmonary artery; and the ductus being one of its three branches, it is doubtless far less so. But, it will be remembered, that the two branches of the pulmonary artery, in the adult, transmit as much blood as the aorta, and, of course, with a rapid motion. Is there any assignable reason why the rapidity is not as great in the lungs of the fœtus as in the adult? or, therefore, why they will not transmit as much blood, in proportion to their capacity, and thus carry two-thirds of that received by the pulmonary trunk, while the ductus arteriosus receives but one-third of the same? We think not. But if it should hereafter be proved that the ductus carries even one-half of the blood in the pulmonary trunk, into the descending aorta, from having a more rapid current than the two pulmonary branches, the relative size of the ductus and the pulmonary artery remains as before stated; and it will appear that the physiology of the circulation is the same, whether the proportion is greater or less within these limits.

The relative size of the *umbilical arteries* is also greatly exaggerated in injected preparations. Each of these is actually a little more than one-half the diameter of the umbilical vein; and once and one-half the diameter of the external iliac artery; still being hardly larger than the carotids. When, therefore, we consider how many branches have been previously given off, from the arch to the descending aorta, it cannot be supposed that more than one-fourth, and probably not over one-eighth, of all the blood sent by the left ventricle into the aorta, can be by them returned to the placenta. Only the same amount is, of course, returned from the latter by the umbilical vein; and the mistake of supposing all the blood of the fœtus to be transmitted rapidly through the placenta, as that of the adult is through the lungs, is thus corrected; for the fœtus has a *reptile* circulation.

The accompanying figures will explain the preceding statements.

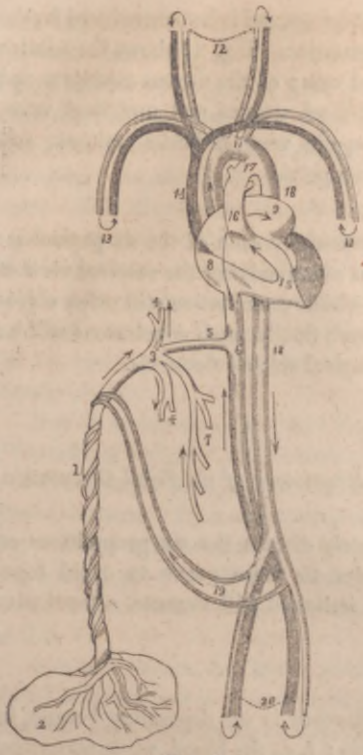

Fig. I.

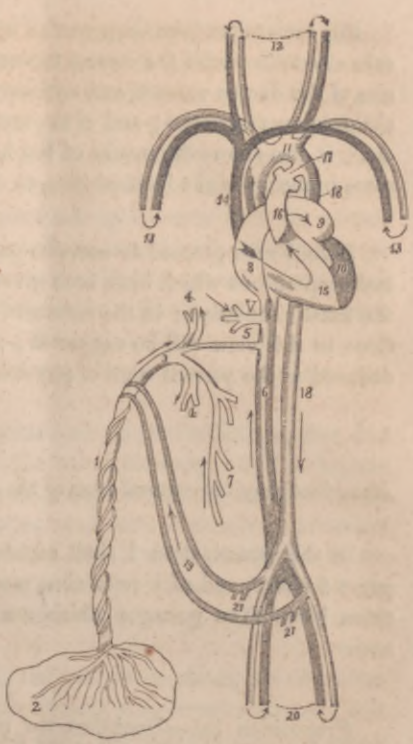

Fig. II.

Fig. I.—Diagram representing the anatomy and physiology of the fœtal circulation—from Carpenter, and Wilson. The numbers represent the same parts as those in the next figure.

Fig. II.—Illustrating the anatomy and physiology of the fœtal circulation—as demonstrated by the writer's dissections.

1—The umbilical cord, with its vein and two arteries, proceeding from 2, the placenta. 3—The umbilical vein, giving off, 4, 4, two principal branches entering 7, the vena portæ; and a third, 5, the ductus venosus (here of its natural size, as compared with 3 and 4), which enters 6, the inferior vena cava. V—The hepatic veins receiving all the blood carried into the liver by 4, and 7; and discharging it into the inferior vena cava above the ductus venosus. The three branches generally terminate separately in the vena cava. 6—The inferior vena cava. 7—Formative branches of vena portæ, from alimentary canal, &c. 8—The right auricle; the arrow indicating the course of the blood thence into 9, the left auricle. 10—The left ventricle. 11—The aorta. 12, 13—Arrows, showing the return of blood from the head and superior extremities to 14, the superior vena cava; and thence into 8, the right auricle, and 15, the right ventricle; and, in the course of the bent arrow, from the latter into 16, the pulmonary artery. 17—The ductus arteriosus (actual size) terminating in 18, 18, the descending aorta. 19—The umbilical arteries (continuations of the internal iliac, and larger than the external iliac) returning a part of the blood in the descending aorta to 2, the placenta. 20—The external iliac arteries, distributed to the lower extremities; the arrows at their extremities show the return of venous blood, by the iliac veins, to the inferior vena cava. 21—The remaining branches of the internal iliac (besides the umbilical arteries), and which are distributed, as in the adult, to the organs in the pelvis, &c.

Fig. 1st is taken from Carpenter's Physiology, and is here introduced for the sake of contrast with the correct representation. Fig. 2d shows the relative size of the ductus venosus and umbilical vein; of the ductus arteriosus and the pulmonary arteries; and of the umbilical arteries and umbilical veins, &c. It also shows the trunks of the hepatic veins, hitherto omitted; and some branches of the internal iliac, to the pelvis.

I shall now proceed to examine particularly each of the six physiological propositions which have been given as embodying the received view of the fœtal circulation; in the course of which examination still other objections to this view will be suggested; and, finally, such conclusions will be deduced as the present state of physiological science demands.

Examination of the received view of the Physiology of the Fœtal Circulation.

In this examination I shall separately discuss the six propositions on pages 2 and 3, and will refer the reader to those pages to avoid repetition here. The passages which are italicized will demand a particular notice.

Proposition 1st.—Doubtless the placenta is a "*de*purating" organ, in its influence upon the blood of the fœtus: *i. e.*, the blood, while traversing its minutest vessels, parts with some of its carbonic acid gas, and receives instead, from the mother's blood circulating in the maternal portion of the placenta, an amount of oxygen gas. Thus the blood becomes aerated, and in the adult would properly be termed arterial blood. This pure blood is, however, not found unmixed in the arteries of the fœtus as it is in the adult, and therefore I shall term it instead, *placental* blood, to avoid all misunderstanding. The *arterial* blood, *i. e.*, the blood *in the arteries* of the fœtus, is a mixture of *placental* and *venous* blood, as will be shown.

But of the pure *placental* blood, not more than one-third, as has been seen, at once enters the inferior vena cava through the ductus venosus; the remaining two-thirds, or more, being distributed to the liver through the vena portæ. The former one-third, blending with the venous blood in the inferior vena cava (at least two or three times as much in quantity) is then carried as *mixed* blood (venous and placental, and probably considerably more than two-thirds *venous*) into the right auricle, where we leave it for the present. The remaining two-thirds of placental blood are, 1st, blended

with the venous blood brought to the liver from the formative branches of the vena portæ (fig. 2—7), which may be equal to one-third the placental blood in the vena portæ; and thus this also becomes mixed blood, and three-fourths placental. But from this mixed blood, the liver is nourished; and thus, according to all analogy, it becomes entirely venous blood, on emerging from the capillaries of the liver into the radicles of the hepatic veins. This blood must, therefore, enter the right auricle from the inferior cava as venous blood; and thus the pure placental blood, passing through the ductus venosus, has been mixed with *five times* as much* venous blood, at least, by the time it has arrived in the right auricle; and the mixture is now but one-sixth placental, and five-sixths venous blood. This, also, will be the blood to enter the left auricle, provided no further admixture previously obtains.

But it is also assumed that the fœtal *liver*, as well as the placenta, is a "depurating" organ; and, therefore, the blood discharged by the hepatic veins is arterial (*i. e.*, aerated) blood, as well as that transmitted by the ductus venosus. By a *depurating* organ must here obviously be meant an organ that renders impure or venous blood arterial; or that eliminates carbonic acid gas from it, and replaces the same by oxygen. No one, however, it is believed, will distinctly assert that the liver has any such function as this.

It is well known that in the adult, the liver is an eliminator of carbon from the blood, and is therefore, in this respect, a depurating organ. It is, however, such, only so far as it secretes bile; and in doing this, it does *not* convert venous into arterial blood. We may, therefore, admit that in the fœtus also, the liver separates carbon from the blood, so far as it secretes bile; while, at the same time, there is no reason to believe that it can possibly in any degree convert venous into arterial blood; or, much less, render placental blood more highly arterialized.

To what extent, therefore, the liver secretes bile in the fœtus, is an important inquiry in this connection. In the adult, bile is secreted for two entirely distinct objects,—1st, to aid the process of digestion; and, 2d, to separate, at the same time, certain hydro-carbon compounds from the blood, as a depurating organ, in the sense last specified. These impurities are separated from *venous* blood; and such as, being collected by the vena portæ from the alimentary canal and its appendages below the diaphragm, contains the crude elements of the food, abounding in the hydro-carbon compounds alluded to.

* *Twice* as much in inferior vena cava; *as much* from branches (7) of vena portæ and *twice* as much from two hepatic veins.

On the other hand, in the fœtus, the bile cannot be secreted in aid of digestion at all. Moreover, the blood from the alimentary canal does not here differ from venous blood in other parts of the fœtus; it being nowhere laden with the hydro-carbon compounds derived, in the adult, from the food. Very little bile, then, it may be supposed, is separated as an impurity from this venous blood in the formative branches of the vena portæ, though a very small quantity may possibly be there separated. But there is no other source for bile besides, except the pure placental blood in the liver from the umbilical vein; and to suppose this secretion to be separated from arterial blood, is both to adopt an idea opposed to all analogy, and, at the same time, to assume a necessity for the production of such a secretion from elements assumed to exist in the placental blood; while there is not a shadow of reason for believing either in such a necessity, or in the existence of such elements.

But we are still pointed to the fact, that the meconium found in the alimentary canal at birth contains none of the peculiar elements of bile; and to this fact we are by no means indisposed to give its due weight. It has already been admitted that the fœtal liver may secrete a small amount of bile from the venous blood derived from the formative branches of the vena portæ; and the following facts go to prove that the amount actually *is* very small. 1. The whole quantity of meconium secreted during fœtal life (none being evacuated till after birth) is small; and yet more than the last half of fœtal life* is required to produce the small amount found in the intestines at birth—a fact showing how slowly it is separated from the blood. But, 2d, only a comparatively small part of the meconium is actually bile. According to Dr. Davy's analysis,† 100 parts of meconium consist of—

Water, ...	72.7
Mucus and epithelium scales, . .	23.6
Cholesterine and margarine, . . .	0.7
Coloring and sapid matter of bile and oleine,	3.0

Here we find less than 3.7 per cent. of matter peculiar to bile, while at least 8 per cent. of such matters are found in the pure secretion. The inference, therefore, is, that less than one-half of the meconium is actually bile. Simon's analysis of *dried* meconium leads to a similar conclusion; it containing only 40 per cent. of matter peculiar to bile, while dried *bile* contains 80 per cent. of such matter.

We cannot, therefore, regard the fœtal liver otherwise than as a very feeble depurating organ, though it is such in the sense last explained. But I sub-

* No meconium is found in the duodenum till the fourth month is completed.

† Simon's Chemistry of Man, Vol. II.

mit that the bile is secreted, not mainly to depurate the blood of the fœtus, but to secure the discharge of the mucus and epithelium scales from the alimentary canal immediately after birth, and thus to prepare it for the reception of food. At all events, it is believed that the conversion of the placental blood into venous, in the capillaries of the liver, as before explained, would far more than compensate for all the depurating power the liver can possess as a secretor of bile; and, therefore, that the placental blood transmitted by the hepatic veins into the vena cava does *not* enter the latter vessel in a purer state than it entered the liver.

Consequently, it does not leave the fœtal liver "in the condition of arterial blood;" and to say that, after it enters the vena cava, it "loses this character in some degree by the time it arrives at the heart," has been shown to be altogether too feeble an expression to cover the facts—five-sixths of *all* the blood entering the right auricle from the vena cava inferior being venous.*

Why, then, is the liver so enormously developed in the fœtus, if not a powerful depurator of the blood, as a secretor of bile? Because it has another entirely distinct and but recently discovered function to perform. But this question will be more appropriately answered in our remarks on the sixth proposition.

Proposition 2d.—In regard to the non-admixture of the blood from the inferior vena cava (five-sixths venous), while in the right auricle, with that entering the same cavity from the superior vena cava, certain doubts have already been expressed. Of course, all belief in the complete non-admixture is based upon the supposed peculiar action of the Eustachian valve, which (it is said) carries it at once through the foramen ovale into the left auricle. It has been shown that Dr. Reid's experiments on this point are entirely inconclusive, and that, on anatomical grounds, it is as probable that this valve has a more important relation to the circulation through the inferior vena cava, than to that through the foramen ovale. But such as still insist on this non-admixture, are requested to explain how, by any *possibility*, the two auricles can contract from 140 to 150 times a minute (as in the fœtus) without securing some admixture, through the foramen ovale, of the blood

* This proposition is adopted, it will be remembered, on the calculation that the ductus venosus carries one-third of all the placental blood into the vena cava inferior. But if even *one-half* be assigned to this duct, and no allowance at all be made for the blood carried into the liver by the formative branches of the vena portæ, it would still follow that three-fourths of all the blood poured into the right auricle from the inferior cava is venous blood. No one, it is believed, can demand such an assignment, however, with a knowledge of the facts I have stated, or will doubt that five-sixths is a more accurate calculation.

distending the two auricles? And if this result does occur at all, then the object of the supposed non-admixture of the two currents in the right auricle is just so far frustrated; and it is hardly probable that a special mechanism is provided to keep the blood from mixing when it first arrives in the right auricle, and another which secures its admixture the $\frac{1}{112}$th part of a minute afterwards. Or, if it be remarked that the *valve* of the foramen ovale prevents the mixture of the blood *through* the foramen, we will recur to the period of fœtal life, when there was no septum at all between the auricles, and the subsequent period when the foramen exists, but no valve is yet formed. Must there not be a *complete* admixture of all the blood in the auricles up to this time? And must not this admixture through the foramen continue, only diminishing in proportion as the valve of the foramen becomes more complete.

In a fœtus of somewhat more than six months, I find the valve occludes near three-fourths of the foramen, and in one of eight and a half months, about five-sixths of it. It will, therefore, admit still of a considerable degree of mixing of blood through it; and not until the foramen is completely closed (which, of course, never occurs till after birth), can all admixture through it be prevented. But this partial prevention of admixture is not the object of the development of the valve of the foramen, but merely incidental to its formation. Nor is the well-being of the fœtus at all compromised by such admixture, though the contrary has been hitherto affirmed. The following considerations will illustrate this point.

It has already been stated, that at one period of fœtal existence, the circulation is analogous to that of a fish. At this time the heart consists, as in the fish, of a single auricle, a single ventricle, and a bulbus arteriosus. Subsequently, the ventricle is divided into two cavities, by the formation of a septum, completed at the ninth week; and now the fœtal heart is, in respect to its function, precisely that of the reptile, and consists of two ventricles and a single auricle.* This is, in fact, the type of the fœtal circulation till birth. The septum between the two auricles, first appearing at about three months, is for some time very imperfect, from the opening called the foramen ovale remaining very large; then the valve of the foramen ovale gradually diminishes the opening, as it increases in size, and in the same proportion interferes with the mixture of the blood in the two auricles during their contraction. But we must regard the formation of the valve merely as a gradual approximation to the type of circulation to come at once after birth, and to the construction of the true *mammal* heart—of two auricles and two ventricles—which is required by that new mode of

* The precise difference between the fœtal and the reptile heart in *structure*, will appear on a subsequent page.

existence. We can only say, the valve, by its gradual development before birth, has, by that time, produced a *mammal* heart, as *nearly as is consistent with a reptile circulation;* and which may at once act as a mammal heart when birth takes place. The foramen ovale is perfectly closed in about eight days after birth; and then the true mammal heart becomes perfect, in structure as well as in function.

But though the valve of the foramen ovale *may*, incidentally, to some extent prevent admixture of the blood in the two auricles, while they are contracting during the last few weeks of fœtal life; still, this result is of no importance whatever, since it will now be shown that the blood in the left auricle is, on its first arrival in that cavity, probably quite as impure as that in the right auricle.

This proposition implies that the Eustachian valve does *not* prevent an intermixture in the right auricle of the blood from the inferior vena cava with that from the superior cava, by directing the former current at once from the vein through the foramen ovale—as is assumed. Objections to Dr. Reid's experiments have already been made, and others will now be added.

1st. If the Eustachian valve is formed to turn the current from the inferior vena cava at once through the foramen ovale, it must be admitted that its position is very unfavorable for the accomplishment of that object. The best position would evidently be secured, if it projected from the outer wall of the vein, and thus presented its free border towards the foramen ovale, in a line extending antero-posteriorly. According to my observations, it actually projects from the anterior wall of the vein, though obliquely, so as to terminate at the antero-inferior border of the foramen ovale. Sometimes, however, it is attached even to the middle of the posterior (or left) border of the foramen ovale; a position far more unfavorable than the one just mentioned. A glance at the following figure will illustrate this point.

2d. It has been remarked, that if the Eustachian valve does keep the purer blood from the inferior vena cava from mixing with the less pure blood from the superior cava, we should expect it would remain perfect till birth; while in fact it becomes atrophied from the seventh month, and continues to diminish, while the valve of the foramen ovale increases in size.

3d. The increase of the latter valve, while the Eustachian is diminishing, might seem to imply that the former comes, in some degree, to supply the place of the latter. But it is impossible that the former can, in any degree, direct the blood from the inferior vena cava *through the foramen ovale.*

Fig. III.—Modified from Weber. The Eustachian valve at six months. A—Inferior vena cava. B—Superior vena cava. C—Eustachian valve in front of termination of A; its inner extremity attached even to the middle of the posterior border of the foramen ovale, D. The upper end of the probe passing through the inferior vena cava, rests on the posterior wall of the right auricle; and just below it is the opening of the coronary vein, partly closed by its valve.

It is inferred, therefore, that the Eustachian valve is not formed to "prevent in great degree, if not entirely," the admixture of the blood from the inferior with that from the superior cava. That it may have some effect of this kind while the valve is largest, is possible; but this possible effect is incidental to another function, and in itself, if actual, is of no physiological importance whatever.

What, then, is the true function of the Eustachian valve? After much reflection, and study of its form and relations, the ideas of Winslow,* published nearly one hundred and fifty years ago, seem the most philosophical, viz., that it opposes the regurgitation of the blood from the right auricle into the inferior vena cava; while it also, as Lancisi maintained, prevents the current from the superior cava from falling too forcibly upon that of the cava inferior. The effects of such a regurgitation in preventing the arrival of the placental blood in the heart, need not be specified; and it is equally apparent that if this be the true function of this valve, it is replaced, so far as regurgitation, from the left auricle, and then into the inferior cava is concerned, by the valve of the foramen; and, therefore, in proportion as the latter is developed, the former may become atrophied, as already explained. It may, also, be added, that the position of the Eustachian valve, though unfavorable for directing the blood through the foramen ovale, is the only possible one in which it could both prevent regurgitation and break the impetus of the current from the superior vena cava, and, at the same time, *not much* OBSTRUCT the passage of the blood through the foramen ovale. These three results are, however, unimportant after birth, and when no placental or arterial blood is to enter the right auricle; and hence the valve is atrophied and useless after that event.

* Memoires de l'Academie Royale, 1717.

3d Proposition.—Before entering upon this, we may recapitulate the two principal points just established, viz.:

1. That of the blood arriving in the right auricle from the inferior vena cava, about one-sixth is pure placental blood, and five-sixths are venous; and,

2. That the Eustachian valve has little, if any, power (and none, certainly, in the last part of fœtal life) to prevent the admixture of the blood arriving in the right auricle from the two venæ cavæ.

Now, admitting that the superior vena cava discharges but one-half as much blood as the inferior—and which is certainly a sufficiently *low* estimate—it will add three parts more of venous blood to the three of venous and one of placental blood from the inferior vena cava; and thus, of all the blood filling the right auricle, one-ninth will be placental and eight-ninths venous.* It has also been shown that the same mixed blood must enter the foramen ovale and fill the left auricle, except so far as the Eustachian valve may possibly, incidentally, and in less degree as the full term approaches, direct a somewhat larger proportion of the blood from the inferior cava through that opening, than of that from the superior cava. If, however, any difference as to the purity of the blood in the two auricles be produced in this way, it must be before the Eustachian valve is much atrophied; and, therefore, at the time when, the valve of the foramen ovale being still slightly developed, the blood in the two auricles will be mingled through the foramen ovale at each contraction. We, therefore, conceive no essential difference as to the purity of the blood in the two auricles can exist. If, however, it be still asserted that the blood would not be mixed to any considerable extent through the foramen during the last four to six weeks before birth, let it be remembered, both that the Eustachian valve cannot then perform its assumed function, and also that the blood in the left auricle is constantly rendered less pure by the venous blood entering it directly from the lungs, through the pulmonary veins. The amount of venous blood thus returned is far greater than has been hitherto admitted, being about two-thirds of all sent through the pulmonary arteries. The improbability is therefore extreme, that the blood in the left auricle is essentially, or indeed in any degree, purer than that of the right auricle. It may also be remarked that the dilatation or *diastole* of the auricles, exerting a suction power on the blood entering these cavities from the veins, would also commingle the blood as it enters the right auricle, and then passes through the foramen ovale to the left; and even before the auricular contraction takes place.

* If three-fourths instead of five-sixths be insisted on (note, p. 13), then the blood filling the right auricle would be one-sixth placental and five-sixths venous. In either case, its *highly venous* character is established.

We, therefore, perceive that when the ventricles contract, after receiving the blood from the auricles, the *left* ventricle does *not* send "arterial" blood, *before undergoing any admixture*, into the ascending aorta, &c.; but it sends a *mixed* blood, probably eight-ninths venous (and certainly more than five-sixths venous) into that vessel. Neither does the *right* ventricle send more *venous* blood into the pulmonary artery and onwards; the latter blood being as pure as the former, or five-sixths to eight-ninths venous.

The same is true of the reptile, though the heart of the latter consists of two auricles and but a single ventricle. One auricle receives the venous blood from the whole body, like the right auricle of the human adult; the other receives the aerated blood from the lungs. Both contracting simultaneously, these two kinds of blood are forced into the single ventricle, and there mixed; and the latter sends this *mixed* blood through the aorta to the body generally, and also through another much smaller vessel—the pulmonary artery—to the lungs, for further aeration; equally pure blood being sent through both these vessels.

The fœtus has a *single auricle* (*actually* at the third month and later, and *practically* until birth), and two ventricles. Yet, precisely as in the reptile, the same *mixed* blood is poured into the aorta and the pulmonary artery; it being mixed, in the reptile, in the single ventricle, and, in the fœtus, in the (practically) single auricle, before it enters the double ventricle. Why, then, is not the auricle of the fœtus double and the ventricle single, as in the reptile? A little reflection will show that the arrangement actually existing in the fœtus, is the only simple one which is compatible with the requirements of the case, viz., a *temporary reptile circulation to be instantly changed to a permanent mammal circulation.*

What has so long been taught, therefore, in regard to the ductus arteriosus carrying *venous* blood into the descending aorta for a particular reason, must at length fall to the ground.

4th Proposition. It does *not*, therefore, follow that the "head and superior extremities are supplied with blood *nearly as pure as that from the placenta*;" though it is true that these parts are developed in advance of the trunk and lower extremities. Nor is it the fact that the last mentioned parts are supplied with a less pure blood than the others. It has been shown that the pulmonary artery receives *as pure* blood as the aorta. This is necessitated, also, from the physiological fact that the pulmonary artery is the *nutrient* artery of the lungs;* as the history of the development of

* Dr. Heale has recently demonstrated the same proposition; and shown that the ronchial arteries only give the vasa vasorum to the pulmonary, and supply the leura, also, in part. See April ('54) No. of the Monthly, p. 302.

these organs clearly indicates; though it would carry me too far from my present purpose to explain this point at length. It has also been shown that the blood entering the aorta from the left ventricle is as impure as that contained in the right side of the heart. If still farther proof is required, it may be remembered that in cases of cyanosis, or patency of the foramen ovale after birth, the livid color of the face, and all other parts of the surface, affords a visual demonstration of the assertion that the aorta circulates highly *venous* blood. And can we suppose the blood in the aorta is purer before birth than afterwards?

It has been assumed that the earlier development of the head and superior extremities, is at the same time an effect of their being nourished by a purer blood, and also a proof of such superior purity—a good illustration of what logicians term "reasoning in a circle." It has been shown that no such difference in the purity of the blood can exist. But this question will also be briefly considered, on independent grounds, since so much importance has been attached to this assumption.

It is true that the organs of sensation, deglutition, and prehension, are early needed and early developed; and this implies an early development of the brain and spinal cord—and, in a word, of the head and superior extremities. These parts are also supplied with blood from the arch of the aorta. But, it is equally true, that the alimentary canal, and the urinary apparatus, are quite as far developed at birth; though the latter organs are all supplied by the descending aorta. A difference in the purity of the nutrient blood cannot, therefore, account for the more early development. Or, if it still be insisted that we may thus account for the facts, how then shall blood of *equal* purity, sent to the upper and lower extremities *after* birth, enable the latter to gain upon and overtake the advanced development of the former?

And, again, if a purer nutrient blood produces a more rapid development of the head and superior extremities of the human fœtus, the same should obtain in all the mammalia—the fœtal circulation being in all essentially the same; and we may inquire, why the posterior extremities of the calf, the sheep, and the dog, are, at birth, equally developed with the anterior extremities and the head?

Thus comparative physiology again leads us to the conclusion that there is no difference as to the purity of the blood contained in the ascending and the descending aorta, as it previously has indicated that the blood in the pulmonary artery and the ascending aorta are, in respect to purity, the same.

How, then, shall we account for the earlier development of the head and superior extremities? We can only say it is an ultimate fact—*a law of development*. And yet, it is certainly no more difficult to explain how they are *first* developed while they receive the *same* blood as the lower extremi-

ties, than it would be to explain why the alimentary canal and kidneys are *equally* developed with them, on the other supposition—that the latter are nourished by an *inferior* blood.

The great law of development appears to be, that "the parts and organs first needed are first developed;" and is applicable also to different parts of the same apparatus, and even to different portions of the same organ, e. g., the ribs are developed earlier than the sternum—the bones at the base of the cranium earlier than those of the vertex—the laminæ of the vertebræ before the bodies, and those of the dorsal region first of all—and the organ of sight previously to that of smell. But, as the parts and organs needed, immediately after birth, vary in different animals, we find a corresponding difference in development up to that period. The young of the marsupialia, remaining, for some time after birth, in a pouch, and attached to the mammilla of the mother, is an embryo, rather than a fœtus, when born, so far as development is concerned. The herbivora and carnivora, needing immediately to be able to stand and walk, have all the four extremities equally developed at birth. The human infant is very differently circumstanced in this latter respect; and to distend the uterus during gestation with a pair of well-developed inferior extremities, which are not to become available for several months after birth, would certainly be productive of some inconvenience, without any compensating advantage; especially since, as things now are even, the motor powers of these less-developed limbs are not seldom by mothers found to be inconveniently energetic.

Thus, the idea of a purer blood being sent to the head and upper extremities, is shown to be untenable, from whatever point of view we consider it. And, as it was suggested at first, from a mere desire to account, and for the special purpose of accounting, for the earlier development of the upper parts of the fœtus—and other facts have been perverted to support it—it is, at last, high time to remand it back to the brain, now long since mouldering in dust, which first conceived it.

5th Proposition.—We have next to show the incorrectness of the assertion, that "in the fœtus the lungs are solid and *almost impervious;*" and that the "*greater part*" of the blood in the pulmonary artery "rushes through the ductus arteriosus" into the descending aorta.

It is true that the fœtal lungs are more solid than they are after birth, but no more so than the liver or the kidneys; and therefore we discover no reason why they are more impervious to the circulation than these organs—which transmit an abundance of blood. Moreover, we have discovered a reason for admitting a free circulation through the fœtal lungs, in the comparatively large size of the pulmonary arteries and veins; and a *necessity* for such a circulation, since the pulmonary arteries are the *nutrient* arteries

of the lungs. It has been seen that, if we may judge from the size of the two branches of the pulmonary artery, compared with that of the ductus arteriosus, about two-thirds of all the blood sent from the right ventricle traverses the lungs; and is, of course, returned as *venous* blood to the left auricle, by the pulmonary veins. In the fœtus, a *mixed* blood is sent through the lungs for their nutrition, for entirely venous blood will not accomplish that object; in the adult, *venous* blood is sent through the lungs first for "oxydation," or aeration; and secondly, for the nutrition of the lungs after aeration is secured.*

Thus, also, the "greater part" of the blood in the trunk of the pulmonary artery does not rush through the ductus arteriosus—only about one-third of that blood is transmitted through this duct. It has also been shown that the blood it transmits is as pure as that sent from the left auricle directly into the ascending aorta. The ductus does not, therefore, terminate in the descending aorta, in order to avoid mixing its impure blood with that sent to the head and upper extremities, but for some other reason; and we deem it unnecessary to look for it beyond the fact that the commencement of the descending aorta is the *nearest* point in that vessel which the ductus can enter. What, then, is the true function of the ductus arteriosus? It is, we conceive, merely a "waste pipe," to conduct at once into the aorta all that part of the blood in the trunk of the pulmonary artery which the collapsed fœtal lungs cannot receive. Hence, as soon as the lungs are distended by the first inspiration, and thus made capable of receiving and transmitting *all* the blood sent from the right auricle and ventricle into the trunk of the pulmonary artery, the ductus becomes at once useless, and, together with the foramen ovale and the ductus venosus, becomes completely closed about eight days after birth.†

But while the fact is insisted on, that the pulmonary artery and the aorta carry equally pure blood, it must be remembered that in both these vessels there is not more than one part of pure placental blood to six or eight of venous blood. Thus the blood in the arteries of the fœtus is but slightly more pure than the venous blood of the adult. It seems to have been taken for granted that the organs of the fœtus (the head and upper extremities, at least) must be developed from pure arterial blood—blood as pure as the arterial blood of the adult. It is now apparent that no such blood exists in any artery possessed by the fœtus; but only in the umbilical

* For an explanation of this, see the MONTHLY, April No., 1854, p. 303.

† Billard found that of nineteen infants who had lived but one day, the foramen ovale was completely open in fourteen; in two, it had begun to close; and in two it was completely shut. Of twenty who had died on the eighth day, five only still had the foramen open.—*Traité des Maladies des Enfans nouveau-nés*, 1828.

vein, and the ductus venosus. All the organs of the reptile are also developed from a mixed blood.

But while blood of equal purity is sent through the pulmonary artery and the aorta in the human fœtus, the blood returned to the placenta for farther purification is just *as pure* also. The umbilical arteries are merely continuations of the internal iliac arteries, and, of course, contain the same blood as the aorta. But here, again, the analogy to the reptile is perfect; the *mixed* blood in the single ventricle being sent, in part, through the pulmonary artery and lungs for farther aeration, while the rest is sent through the aorta and its branches, for the nutrition of the body generally. In the reptile, moreover, the pulmonary artery is smaller than the aorta, and less blood passes through the lungs than through the aorta and to the tissues generally. In the fœtus, also, much more blood passes through the aorta than to the *placenta*—it having been shown that the umbilical arteries cannot transmit more than one-sixth of all the blood received by the aorta at its commencement. In the human adult, as much blood is sent through the lungs as through the aorta and its divisions; and it is calculated that the whole mass in the body may pass through them, and therefore become aerated in the space of three minutes; the standard of aeration in the adult is therefore high. In the fœtus, on the other hand, the umbilical arteries can return the blood to the placenta only about one-sixth as rapidly in proportion as it is circulated through the lungs in the adult; and, therefore, the standard of aeration in the fœtus, as in the reptile, is low. And the *mixed* blood in the umbilical arteries being returned as pure *placental* blood by the umbilical vein, this low standard of aeration of the mass of blood in the arterial system of the fœtus is thus constantly maintained, though the quantity of *pure* blood returned to the heart through the ductus venosus is so small.

There are other peculiarities of arterial fœtal blood, besides its *venous* character and appearance, as (compared with the mother's blood) its abundance of colored corpuscles, and its deficiency of fibrine. But, upon these peculiarities I need not dwell; nor is farther proof required, it is believed, of the incorrectness of the proposition now under consideration. And should it, at any time, be proved that even one-half of the blood in the trunk of the pulmonary artery traverses the ductus arteriosus, its physiological inaccuracy would remain unchanged.

6th Proposition.—There can be no doubt that the large size of the fœtal liver is the direct result of the distribution to it of a large amount of the pure placental blood. Indeed, it has been shown that while all other organs in the fœtus are nourished from a mixed blood (not more than one-sixth placental) this organ alone is nourished by a mixture of three-fourths placental blood. A comparatively early and enormous development might reasonably be expected, therefore; and it is found actually to obtain.

But we cannot regard this enormous development as merely a casual result of the distribution of a great amount of pure blood to the fœtal liver, as the quotation constituting the proposition now under consideration seems to imply. We believe the law of development, before mentioned, is as applicable here as elsewhere; and that the blood is sent to the liver on purpose to develop it—it being largely and early developed, because early needed, in the fœtal economy.

What, then, is the function of the fœtal liver requiring so early and so enormous a development? The liver of the reptile is also largely developed, and here we discover another analogy with the human fœtus. We have also seen, that it cannot be as a secreter of bile that the liver is so early needed. Bile is not found in the intestine at all till the fifth month; and it has been shown that only a small quantity, in the aggregate, can have been secreted previously to birth. On the other hand, the liver is one of the first organs becoming distinct in the embryo, constituting, at from three to five weeks, over one half the weight of the entire embryo; almost entirely filling the abdomen at twelve weeks; and constituting $\frac{1}{18}$ part of the weight of the whole body at birth. The inference is, therefore, that the liver performs some function before it becomes a secreter of bile, to a perceptible extent—that this is a more important function than the one later manifested—and that it continues in full activity till birth, when it diminishes.

Those who are familiar with the recent experiments of Bernard, of Paris, will not hesitate to decide, that the function of the liver, as a *blood-making* organ, is the one in question. For, it must not be forgotten, that the fœtus makes its own blood; not deriving a particle of *blood* from the mother's vessels—but merely the *elements* from which it forms its own vital fluid. That the liver is the organ most important in the blood-making process, has been demonstrated by Bernard; and, surely, there is no time when its action is so much required as when the first blood is to be formed, and increased, and all the tissues are to be developed—from elements obtained from the blood of the mother. Hence the large development of this organ in the fœtus.

But the liver actually diminishes in size at once after birth—the diminution affecting principally the left lobe; and which, in the fœtus, is about as large as the right. Indeed, it is not till the infant is from ten to twelve months old, that the liver has again become as large as it was at birth. Doubtless the withdrawal of the pure placental blood from this organ at birth, and the substitution of mere venous blood in the vena portæ, is the immediate cause of this atrophied condition of the organ for a time. Still we cannot regard this condition as merely accidentally owing to that cause. The blood of the new-born infant is to be formed from elements contained in food, and not derived, as before, directly from the mother's blood-current. True, the milk naturally destined for its nourishment, is also obtained from

the mother's blood. But the gland secreting it has elaborated its elements from the blood; and, it being digested before entering the liver, less of the peculiar action of the latter organ is probably required in the blood-making process. When, however, the child begins to take a variety of aliment—or when somewhat more than a year old—the liver is found to have regained its weight at birth, and now gradually proceeds to its full development in the adult, when it constitutes about $\frac{1}{36}$ part of the entire weight of the body. These remarks are, however, made, not so much to explain the atrophy of the liver after birth, but as naturally suggested by and associated with its occurrence.

The vena portæ in the fœtal liver is, therefore, in all respects, an *artery*; it carries the pure blood from the placenta, and is the *nutrient* artery of the liver, as the pulmonary is of the lungs. It is, however, also, something more. The formative branches constitute the true vena portæ in the fœtus, as well as in the adult; and, therefore, its branches in the substance of the liver, containing the venous blood from these—mixed with the placental blood, as before explained—represent the vena portæ in the liver of the adult, containing only venous blood, from which the bile is secreted—at the same time that it is also the nutrient artery of this organ. After birth, the hepatic artery, which, in the fœtus, does hardly more than afford the vasa vasorum to the vena portæ, becomes the sole nutrient artery of this organ, as it alone transmits arterial blood. For the assumption appears well founded, that after birth the tissues can be developed and repaired from arterial, or completely aerated, blood alone; while the tissues of the fœtus are formed, as has been proved, from a mixed blood, of which (except, in case of the liver alone) the venous forms from five to eight times as large a proportion as the placental or aerated blood.

Having completed my examination of the propositions under consideration, I now conclude with a recapitulation of the conclusions which have been arrived at, and which together constitute, it is believed, such a view of the fœtal circulation, during the last half of fœtal life, as the present state of physiological science demands.

The view of the fœtal circulation required by the present state of physiological science.

1st. The human fœtus, during the last half of fœtal existence, has a *reptile* circulation—the mammal circulation commencing at birth; and the structure and the function of each particular part of its circulatory apparatus are in subservience to this fundamental fact. The characteristics of a reptile circulation are—1, the circulation of a *mixed* blood (and of the same degree of impurity) through both the aorta to the tissues, and through the

pulmonary artery to the lungs; and 2, the transmission of far less blood to the aerating apparatus than is sent through the aorta.

2. The foramen ovale with its valve is the only simple mechanism which could answer the requirements of the case, viz., a temporary reptile circulation with a capability of instantaneous change to a permanent mammal circulation, the foramen becoming permanently closed about eight days after birth.

3. The ductus arteriosus is merely a "waste pipe," conducting into the nearest portion of the aorta that part of the blood sent into the trunk of the pulmonary artery, which the collapsed lungs of the fœtus are unable to receive. After birth the latter admit all the blood, and the ductus is, therefore, useless. It does not enter the descending aorta to avoid sending its blood to the head and upper extremities.

4. Though the lungs are more solid in the fœtus than after birth, they are probably permeated by about two-thirds of the blood entering the trunk of the pulmonary artery, and this is returned as *venous* blood to the left auricle.

5. The blood arriving in the right auricle from the two venæ cavæ is completely intermixed by the diastole and systole of this cavity; and the same mixed blood is therefore transmitted through the foramen ovale into the left auricle. Or, if by any possibility more placental blood enters that cavity, the venous blood returned by the pulmonary veins most probably counterbalances that advantage.

6. The Eustachian valve cannot prevent the admixture of the blood from the venæ cavæ, nor direct that from the inferior cava at once through the foramen ovale; it merely prevents regurgitation from the auricle into the inferior vena cava, at the same time incidentally preventing the current from the superior cava from impinging so forcibly upon that of the inferior. Hence the valve of the foramen ovale replaces it to some extent, in respect to its principal function; and, therefore, it becomes atrophied in proportion as the latter is developed.

7. No artery in the body of the fœtus contains *arterial* blood. The aorta and pulmonary artery, and all their branches, contain a *mixed* blood, about five parts, at least, venous to one part placental. The precise proportions, however, are unimportant, the blood being of a *highly venous* character, and as impure in the aorta as in the pulmonary artery. Only the umbilical vein and the ductus venosus contain pure aerated placental blood.

8. The umbilical arteries contain the same mixed blood as the aorta, and possibly return one-sixth of the blood received by that vessel; but this amount, aerated in the placenta and returned by the umbilical veins, suffices to maintain the low standard of aeration in the fœtus.

9. The head and upper extremities of the fœtus do not receive a purer

blood than the lower parts of the body. They, as well as the digestive and urinary apparatus, are earlier developed, in accordance with a general law of development.

10. The fœtal liver is a *depurating* organ only so far as it secretes bile, and therefore, to a slight extent, though it does not thus convert venous into arterial blood. Its large development, from the placental blood abundantly distributed to it, has relation to its function as a *blood-making* and not as a *bile-secreting* organ; and this blood becomes *venous* in the capillaries and the hepatic veins, as all analogy proves.

11. The trunk of the vena portæ is, in the fœtus, both the *nutrient artery* of the liver, and also corresponds to the vena portæ of the adult—its formative branches containing venous blood from which the bile in the meconium is probably secreted.

12. Anatomy, the history of development, and comparative physiology, combine to sustain the preceding propositions.

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