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BLOOD-VESSELS IN THE LABYRINTH OF THE EAR

BY

GEORGE E. SHAMBAUGH

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THE DISTRIBUTION OF BLOOD-VESSELS IN THE LABYRINTH OF THE EAR OF SUS SCROFA DOMESTICUS

BY

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INSTRUCTOR IN THE ANATOMY OF THE EAR, NOSE, AND THROAT

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THE DISTRIBUTION OF BLOOD-VESSELS IN THE LABYRINTH OF THE EAR OF SUS SCROFA DOMESTICUS

George E. Shambaugh

The course of the blood-stream through the labyrinth of the ear has been a subject of considerable uncertainty and difference of opinion among anatomists. The reasons are obvious, for the complicated series of cavities that go to make up the labyrinth of the ear makes the study of its blood-supply by the ordinary method from sections very inaccurate unless laborious methods of reconstruction are used. This element of difficulty was successfully overcome, however, when the method was introduced of making celloidin casts of the labyrinth in which the circulation could be viewed in its entirety. But with this accomplished, and with such a complete picture of the blood-supply before one, the complicated network of vessels found in the labyrinth of the adult ear is in many places very difficult, if not quite impossible, to disentangle with any degree of accuracy.

It seemed desirable, therefore, in order to get a correct understanding of the circulation of the adult ear, to work out the angiogenesis of the labyrinth in the hope that in the younger embryo would be found a less complicated circulatory system which would serve as a guide in interpreting the more intricate system of vessels found in the adult ear. Since work of this kind undertaken on the human ear would necessarily be greatly hampered on account of the difficulty in securing sufficient material, it was decided to use the embryo pig, because an abundant supply of fresh material gave ample opportunity for experimenting with methods of injection, until satisfactory preparations could be obtained in sufficient numbers for study. It was thought that an accurate picture of the blood-supply obtained in this way for the labyrinth of the pig's ear would, perhaps, throw light upon some of the doubtful points in the circulation of the human ear. At any rate, such a knowledge of the circulation in the ear of the pig is desirable in itself. That the circulation in the labyrinth of the pig's ear would differ in some respects from that of the human ear is, of course, to be expected, but in general we should look for a more or less close resemblance between the two.

In injecting the vessels of the labyrinth in the embryo, many preparations were rendered useless, either because the pressure used was not sufficient to force the injecting fluid into the labyrinthine vessels, or because the pressure was too great for the delicate vessel walls, and the preparation was ruined by the escape of the injecting fluid into the surrounding tissue. It was found impossible always to gauge accurately the amount of pressure necessary to suit the different ages; hence it became necessary to inject a large number of embryos from which were selected those that proved satisfactory for study. Altogether over 500 embryos were injected, and from this number scarcely more than 100 specimens proved suitable for study. Among these were preparations showing all degrees of injection, from the perfectly injected labyrinth having a complete capillary injection, to the semi-injected ones and those having only the larger trunks injected. In some there was a perfect injection of the arterial tree alone, up to the point where it breaks up into capillaries, and in several preparations there was a similar perfect injection of the venous tree. These latter preparations have been invaluable for determining the general scheme of the course of the arterial and venous streams through the labyrinth, which in the completely injected preparation is often quite obscured by the dense capillary injection about them. On the other hand, from this large number of injections, the completeness with which the capillaries were filled in a few of the preparations gave an opportunity for filling out with perfect accuracy this link between the arteries and veins.

The description that follows is confined to the results of my own work, reference being made only occasionally to the work of others. There is no attempt to cover the literature on the subject, which has been carefully done by Eichler.[1]

A noteworthy addition to that bibliography is the beautifully illustrated monograph by Siebenmann, which appeared in 1894.[2]

The drawings for the two lithographic plates illustrating this article were made by Leonard H. Wilder; the other drawings were made by Edith Capps Shambaugh. All the drawings were done accurately from actual preparations, and under my direct supervision. I wish to take this opportunity to express my deep obligations to Dr. Lewellys F. Barker for his interest and encouragement in this work, which has been carried out in the Hull Laboratory of Anatomy of this University.

METHODS

In this work a method, introduced by Oswald Eichler, of making celloidin casts of the labyrinth, from preparations in which the blood-vessels had been previously injected, was chiefly relied upon. Such celloidin casts, when cleared in creosote, become perfectly transparent, except so far as the network of blood-vessels obstructs, and when studied through the stereoscopic microscope present a beautiful picture of the circulation in its entirety which is invaluable in determining the general scheme for the distribution of the vessels with their anastomosing and branching. In addition to this method, thick serial sections of the injected decalcified labyrinth were made, in order to make sure of some points the interpretation of which at first appeared doubtful from the study of the celloidin casts. The injections were made into the embryo pig, in most cases while the animal was still warm. Material allowed to cool and stiffen did not give the most satisfactory results. Injections were made of pigs from the fœtus at full term, measuring from 28 cm. to 30 cm., to embryos measuring 2.5 cm. in length. The injecting fluid used was a saturated aqueous solution of Prussian blue.

[1] *Anatomische Untersuchungen über die Wege des Blutstromes im menschlichen Ohrlabyrinth*, Leipzig, 1892.

[2] *Die Blutgefässe im Labyrinthe des menschlichen Ohres*, Wiesbaden, 1894.

This penetrates readily the finest capillaries, and with this solution complete injections can be obtained.

For all embryos above 6 cm. in length, injecting through the umbilical cord gave the most satisfactory results. One of the umbilical arteries was selected, into which a small glass canula was secured. The rest of the cord was then tied off with a thread. For the newborn pig successful injections were obtained by injecting into the carotid. Embryos less than 6 cm. long were injected through the heart or liver. A small pointed metal canula was plunged into the apex of the heart or into the substance of the liver. The amount of pressure necessary to fill the vessels of the embryonic labyrinth, and still not rupture their walls, was always a delicate question to decide. Static pressure was chiefly used and was more satisfactory than any other method. For embryos 18 cm. long to the fœtus at full term measuring 28 cm., pressure of an elevation from 80 cm. to 1 meter gave the best results. This was ample for filling even the capillaries and the veins, and it seldom ruined the preparation by rupturing the vessel walls. For smaller embryos the amount of pressure was graduated, as well as could be judged, according to the size of the embryo. For those measuring 2 cm. to 4 cm., pressure of 3 cm. to 6 cm. was used.

The injected embryo was placed in Müller's fluid and allowed to harden for several weeks. The labyrinth was then removed from the head. This, in embryos over 18 cm. long in which ossification was already well advanced, was easily done, for the more hardened capsule of the labyrinth can be readily shelled out from its location in the skull. The smaller the embryo, the more difficult it becomes to shell out the labyrinth in this way. Before ossification begins, however, the cartilage of the labyrinthine capsule can be differentiated from the surrounding tissue, and by working carefully with a small forceps this tissue can be removed and the labyrinth finally shelled out entirely free. By this method the labyrinth was removed in a perfect condition from embryos measuring only 2.5 cm. in length.

In making the celloidin cast of the injected labyrinth and in getting rid of the bony capsule in the older embryos in which the capsule had become ossified, the method employed by Eichler and Siebenmann in working with the adult ear was followed. The technique was varied somewhat, however, so that the work could be carried on more rapidly. The following is an outline of the steps in the process:

The shelled-out capsule of the labyrinth, with the stapes removed, was prepared for imbedding in celloidin by remaining for twenty-four hours in each of the following strengths of alcohol: 60 per cent., 70 per cent, 80 per cent., 95 per cent., 100 per cent.; then for twenty-four hours in absolute alcohol and ether, equal parts. It was then left for twenty-four hours in each of the following strengths of celloidin: 4 per cent., 10 per cent., 16 per cent., 20 per cent. The celloidin was then allowed to harden about the object for several days in a small glass dish covered with a bell-glass. It was further hardened in 80 per cent. alcohol for several days. The celloidin was then scraped completely away from the surface of the preparation, and the work completed by the following process:

(1) Preparation placed in commercial hydrochloric acid for twenty-four hours. (2) Washed in water and the softened bony capsule carefully removed in small fragments with delicate forceps. (3) Washed for several hours in water. (4) Placed in 95 per cent. alcohol for twenty-four hours. (5) Left in 98 per cent. alcohol for a few minutes. (6) Cleared for several days in creosote.

In working with younger embryos before ossification has set in, this method can be materially shortened. Here all that is necessary is to imbed the shelled-out capsule of the labyrinth in celloidin, and after the celloidin has hardened under the bell-glass, as much of it as can be cut away without injuring the preparation is removed. The remaining block of celloidin containing the labyrinth is cleared up in alcohol and creosote as stated above. The clearing of such a preparation in creosote seldom requires more than twenty-four hours, provided it has been left in 95 per cent. alcohol for a sufficient length of time, from twenty-four to forty-eight hours.

The preparation is best left in creosote in a shallow dish where it can be moved about and examined from different view-points until it has been carefully studied and all doubtful vessels identified, when it can be permanently mounted in Canada balsam in a cell.

The stereoscopic microscope was found indispensable in studying these preparations. The perspective gained by the use of this instrument in examining the transparent casts of the labyrinth was necessary to place the vessels in their correct relations to each other.

Before entering upon the description of the circulatory system of the labyrinth, a word should be said regarding several difficulties that present themselves when the study of the injected celloidin cast of the labyrinth is undertaken. In the first place, the differentiation between arteries, veins, and capillaries in these preparations, where but one injecting medium was used, will at first be perplexing. This difficulty can be overcome by noting the character of the vessels, the intensity of the blue injection, and finally by tracing the vessels about which there is doubt to a large trunk, the character of which is easily ascertained. In a completely injected specimen where the arteries, veins, and capillaries are all filled, the arteries appear as blue-black lines, perfectly round and of smaller caliber than the corresponding veins. Through a considerable part of their course they, almost without exception, undergo to a marked degree a series of windings and convolutions. The veins appear as much paler, often considerably flattened bluish bands, and their course throughout is much straighter than the arteries, except as they approach the point where they break up into capillaries, when their course often becomes more irregular than the corresponding arteries. The veins never undergo convolutions as do the arteries. The capillaries in the greater part of the labyrinth present, in a perfectly injected preparation, a meshwork in which each individual loop can be traced. This is especially clearly defined in the vestibule and semicircular canals, except in the regions of the maculae and cristae acusticae, where the network is too dense to allow such close analysis.

A problem which is also perplexing at first is to determine which vessels are in the membranous labyrinth and which are in the osseous labyrinth or perilymphatic structures. This question can be definitely settled by a careful study of the preparations. Great assistance in determining the exact outlines of the membranous labyrinth in the vestibule and semicircular canals is found in the study of preparations that have never been cleared in creosote, but have been left in 95 per cent. alcohol for several days. Such preparations become partially transparent, and the outlines of the utricle and the membranous ampullae and semicircular canals are clearly defined. Another method that will assist in determining the outlines of the membranous labyrinth is by clearing the celloidin cast in acid-glycerine.[3] In preparations that have been thoroughly cleared in creosote, the utricle and the membranous ampullae and semicircular canals are definitely outlined in the incasing network of capillaries, and when viewed through the stereoscopic microscope their exact outlines can be traced.

THE ARTERIES

A single vessel, the labyrinthine artery, supplies the labyrinth of the ear, sending branches to the vestibule and semicircular canals, as well as to the cochlea. It reaches the labyrinth through the meatus acusticus internus, lying upon the auditory nerve. In this canal the labyrinthine artery breaks up into a number of branches. The first to be given off is a large vessel which follows along the ramus utriculo-ampullaris to the anterior surface of the vestibule, and is called the anterior vestibular artery (Plate V). The labyrinthine artery then divides into two trunks which almost immediately break up into a number of branches. These vessels are wound part way around the stem of the nervus cochleae, as if carried around it by the spiral growth of the cochlear tube (Plate VI). The branches from the two terminal trunks of the labyrinthine artery anastomose freely with each other, and from the anastomotic loops thus formed are given off the arteries which supply the cochlea, and others which, together with the anterior vestibular artery, supply the vestibule and the semicircular canals.

1. *The arterial tree of the cochlea.*—In the adult labyrinth and in the labyrinth of the fœtus at full term the arteries undergo a remarkable series of convolutions described by Schwalbe as "glomeruli." These convolutions make it quite impossible in many areas of the cochlea to follow the vessels with accuracy. In the earlier embryonic stages the arteries do not possess this character, but run their entire course as practically straight vessels, free from spiral windings. This is true for all embryos of the pig measuring less than 12 cm. At about this age the arteries begin to develop much more rapidly than the surrounding structures, and, as a result, are thrown into these convolutions which, before the embryo reaches 16 cm. in length, are already well pronounced.

[3] HCl 2.5, glycerine 100.

To get a clear picture of the arterial tree of the cochlea, it is only necessary to study the circulation in the labyrinth of the embryo before the vessels have assumed their tortuous character. This can best be done in the pig from embryos measuring about 11 cm. Preparations where the injecting fluid has filled the arteries but where the capillaries and veins are practically empty, when viewed through the stereoscopic microscope, give a clear picture of the arterial supply of the cochlea, in which each vessel-trunk, each anastomotic loop, and each terminal branch can be traced. Such a preparation from the right ear of an embryo pig measuring 11 cm. is represented in Plate VII.[4] For the sake of clearness the cochlear spiral is represented as having been partly drawn out. With the exception of this slight distortion, each loop and each branch of the arterial tree has been drawn exactly as found. A correct idea can be obtained from this preparation of the scheme of distribution for the arteries of the cochlea, the details of which, however, in regard to the number and character of the anastomotic loops, differ materially for each individual labyrinth. To avoid confusion, the branches that supply the lamina spiralis in this preparation are not represented in the drawing.

Plate IX represents a preparation of the basal coil of the cochlea viewed from above, taken from the right ear of an embryo measuring 11 cm. The anastomotic arcades are seen to the best advantage from this view. Plate X gives the same view of the basal coil from a fœtus at full term. The most striking difference between these two preparations is the convoluted character of the arteries in the latter, which to a certain extent obscures the arcade formation so clearly seen in the younger embryo. Also, the number of the anastomotic loops found in the younger embryo seems to have diminished somewhat before the embryo has fully developed.

The scala tympani at the proximal end of the basal coil is much larger than the scala vestibuli, and thus encroaches more upon the modiolus than does the scala vestibuli. This character of the scalae of the basal coil is most marked at its beginning, and disappears entirely before the first coil is completed. It is over this broadened part of the scala tympani at the beginning of the basal coil that the arcades are the most pronounced (Plates VII and IX). Near the point where the scala vestibuli begins to arch upward, that is, at the base of the lamina spiralis ossea, branches are given off from the arcades which follow along the lamina spiralis to supply this structure (Plate X). At the same point another set of branches arises, which, after forming an occasional arcade, arch over the top of the scala vestibuli, and ultimately break up into three distinct capillary areas, one over the scala vestibuli, one in the ligamentum spirale, and the third in the stria vascularis of the cochlear duct, in the manner to be described below. The straight character of the vessels radiating over the scala vestibuli, as found in the earlier embryos, is shown in Plates VII and IX, while the convoluted character assumed by these vessels before the embryo has fully

[4] It will be noted that the cochlea of the pig's ear has three and a half coils instead of two and a half, as in the human ear.

developed is shown in Plates V and X. The number of these vessels radiating over the scala vestibuli in the pig is about sixty-five, thirty of which supply the basal coil. The number described by Siebenmann for the human ear is thirty to thirty-five, of which fifteen go to the basal coil.

The upper coils of the cochlea are supplied by several large trunks from the arcades at the base of the cochlea, which pass up through the modiolus (Plates VII and IX). Branches from these trunks anastomose with each other, forming a spiral system of vessels with occasional well-developed arcades. This system follows closely along the coil lying near the base of the lamina spiralis ossea—an area which was called by Schwalbe the tractus spiralis arteriosus (Plate VII). From this spiral system of vessels branches are given off which radiate over the scala vestibuli at regular intervals, as in the basal coil. The arterial supply to the lamina spiralis of a coil above the basal turn of the cochlea, on the other hand, comes only in part from the tractus spiralis arteriosus of that coil. Larger or smaller areas are interspersed where the arteries to the lamina spiralis of a coil comes from the spiral system of vessels of the coil next below (Plate XI, Fig. 1). A similar character was also found in the veins which drain the lamina spiralis of the upper coils.

2. *The arterial system of the vestibule and semicircular canals.*—The arteries for these structures come, in part, from the anterior vestibular artery, which, as has been seen, is the first branch from the labyrinthine artery given off in the meatus acusticus internus. This vessel reaches the vestibule by following along the anterior surface of the ramus utriculo-ampullaris. Its first branch turns back along the anterior surface of the vestibule and, in the younger embryos at least, anastomoses freely with an artery from the anastomotic arcades at the base of the cochlea. The anterior vestibular artery supplies the macula acustica utriculi and the anterior crura of the superior and lateral semicircular canals and their ampullae (Plate V).

Another artery called the posterior vestibular artery springs from the anastomotic arcades at the base of the cochlea, and, crossing over the posterior surface of the vestibule just beneath the nervus ampullaris posterior, is distributed to the ampulla of the posterior semicircular canal and to the posterior crura of the posterior and lateral semicircular canals (Plate VI).

The crus commune is supplied by a single artery which is sometimes a branch from the posterior vestibular artery, sometimes it springs as an independent vessel from the arcades at the base of the cochlea, and crosses over the middle of the posterior surface of the vestibule lying to the anterior side of the aquaeductus vestibuli (Plate VI), and in a few cases it comes from the anterior vestibular artery.

THE VEINS

The circulation of the labyrinth is peculiar in having the exit for the veins at a point distinct from that through which the arteries enter. In the labyrinth of the pig's ear all the veins are collected into one large trunk, the vena canaliculi cochleae.

In embryos between 4 cm. and 6 cm. in length, however, there were sometimes found several veins which left the labyrinth with the aquaeductus vestibuli; but in the later stages, and in the fœtus at full term, these veins had disappeared, and only the vena canaliculi cochleae remained to collect the blood from the entire labyrinth. This differs from the condition usually described for the human ear, where a large part of the venous blood from the utricle and semicircular canals is collected into veins and finds its exit along with the aquaeductus vestibuli. Schwalbe and Siebenmann describe venous trunks in the meatus acusticus internus of the human ear which are supplied in part by veins from the labyrinth. Eichler denied the existence of such veins. In the pig's ear no venous trunks of this kind were found.

1. *The venous tree of the cochlea.*—The blood from the ligamentum spirale of the basal coil is collected by a series of veins with broom-like origins which converge toward the middle of the under surface of the basal coil. These veins for the first half of the coil are collected into a large trunk which often follows along the middle of the under surface of the basal coil to empty into the vena canaliculi cochleae in the manner shown in Plate VI. The vein that collects the blood from the proximal end of the ligamentum spirale is a long vessel that begins where the ductus reuniens (Henseni) joins the ductus cochlearis. Lying first on the anterior surface of the vestibule, it runs forward around the anterior margin of the fenestra cochleae, where it takes a sharp turn backward to the under surface of the basal coil to join the venous trunk near the canaliculus cochleae (Plates V and VI). The veins that collect the blood from the ligamentum spirale of the second half of the basal coil empty into a large vessel called the posterior spiral vein. This vein is made up of two divisions which take their origin at about the junction of the middle and the distal thirds of the basal coil, and run in opposite directions around the coil, lying close along its posterior margin (Plates VI and VIII). At their point of origin anastomotic loops connect these divisions both above and below the coil. Near the beginning of the basal coil these two parts of the posterior spiral vein meet, and the common trunk thus formed empties into the vena canaliculi cochleae (Plate VI).

The scala vestibuli is provided with veins which begin in the capillary area over this scala (Plate X), and run downward and inward toward the modiolus. At the base of the lamina spiralis ossea these veins are joined by others from the lamina spiralis, and the common trunks thus formed take a direction downward and backward to join the posterior spiral vein (Plate X, and Plate XI, Fig. 1). Anastomotic loops are occasionally found between branches from these venous trunks. For that part of the cochlea in which the upper coils are applied closely to the coil beneath, that is, for all but the beginning of the basal coil, the veins which drain the scala vestibuli are joined by the veins from the scala tympani of the coil next above (Plate XI, Fig. 1). Into these common trunks are emptied, as a rule, the veins from the ganglion spirale and from the lamina spiralis of the upper coil. The manner in which these veins are collected into a large vein running through the center of the modiolus is best seen in Plate VIII. An anterior spiral vein running along the inner margin of the scala vestibuli near the base of the lamina spiralis ossea, as described by Siebenmann for the human ear, does not exist in the cochlea of the pig's ear. Its place in the basal coil is supplied by the converging branches of the posterior spiral vein, and in the upper coils by the branches converging into a central venous trunk (Plate VIII).

The veins from the upper coils of the cochlea are collected in a central trunk which runs through the modiolus and empties usually into the posterior spiral vein in the first half of the basal coil (Plates IX and X). Or it joins that division of the posterior spiral vein which collects the blood from the distal end of the basal coil (Plate VIII). The manner in which the tributaries which join this central trunk collect the blood from the upper coils has already been described on p. 10, and is best seen in Plate VIII, and Plate XI, Fig. 1. The first tributary of this central trunk collects the veins from the upper coil of the cochlea, and follows the spiral direction of the coil, as does the artery for that part.

2. *The venous system of the vestibule and semicircular canals.*— The veins of the vestibule and semicircular canals are collected into two large trunks which empty into the vena canaliculi cochleae, either as separate vessels or after uniting into a common trunk (Plate VI). One trunk, called the anterior vestibular vein, follows closely the distribution of the anterior vestibular artery, and collects blood from the anterior surface of the vestibule, from the macula acustica utriculi, and from the anterior crura of the lateral and superior semicircular canals and their ampullae (Plate V) in the manner to be described on p. 15. The anterior vestibular vein begins where the ramus utriculo-ampullaris enters the vestibule. It runs forward and medialward across the anterior upper wall of the vestibule, curving over the recessus sphaericus to join the vein of the aquaeductus cochleae, either as a separate vessel or after joining the posterior vestibular vein.

The other large venous trunk of the vestibule is the posterior vestibular vein. This vein follows the distribution of the posterior vestibular artery. Its first tributary drains the capillaries over the posterior surface of the membranous ampullae of the superior and lateral semicircular canals, and crosses the vestibule by running in front of the crus commune. The posterior vestibular vein receives the blood from the crus commune, from the posterior crura of the lateral and posterior semicircular canals, and from the posterior ampulla. It follows the course of the posterior vestibular artery, lying directly beneath the nervus ampullaris posterior. It crosses the posterior surface of the vestibule, from the base of the posterior ampulla, to empty into the vena canaliculi cochleae (Plates V and VI). About midway across the vestibule it receives a large branch that runs transversely across the posterior surface of the vestibule, at right angles to the main vein. This transverse vein collects the blood from the posterior surface of the vestibule and from the macula acustica sacculae.

THE VESSELS OF THE MEMBRANOUS LABYRINTH

A description of the blood-vessels of the membranous labyrinth is, in a large measure, a description of the capillary areas of the labyrinth. The distribution of the vessel trunks that have thus far been described is limited, for the most part, to the structures of the so-called osseous labyrinth, which is thus seen to serve as the means for carrying blood-vessels which break up into capillaries only when the membranous labyrinth is reached. The chief capillary areas found outside the membranous labyrinth are the capillaries over the scala vestibuli (Plates V and X) and those found among the nerves in the modiolus.

1. *The ductus cochlearis.*—The vascularization of the ductus cochlearis is limited, in the pig, to its lower and outer walls, while the upper wall, formed by the membrane of Reissner, is entirely lacking in blood-vessels. In the embryo of a calf measuring 70 cm., which was examined, Reissner's membrane was found well supplied with capillaries which communicated with the vessels of the lamina spiralis and also with those near the outer attachment of the membrane. Middendorp[5] found vessels in this membrane in young calves and dogs as well as in newborn children. Rüdinger[6] has pictured such vessels in the adult human ear. Neither Eichler nor Siebenmann found blood-vessels in Reissner's membrane of the human ear. The floor of the ductus cochlearis, formed by the lamina spiralis and the basilar membrane, is supplied by arteries which radiate from the modiolus outward, along the lamina spiralis ossea. The arteries leave the arcades in the modiolus as described on p. 8, and run out along the lamina spiralis ossea (Plates X and XI, Fig. 1). The veins from the lamina spiralis of the basal coil are collected in trunks which, uniting with the veins from the scala vestibuli, finally join the posterior spiral vein as described on page 10. In the basal coil the first set of capillaries formed from the vessel of the lamina spiralis is the network distributed in the ganglion spirale. This ganglion, in the proximal end of the basal coil, is lodged well out along the under surface of the lamina spiralis ossea, lying above the scala tympani (Plates VI and X). The vessels to the ganglion spirale of the basal coil shoot downward at right angles to the main trunks of the lamina spiralis and break up into capillaries in the ganglion (Plates X and XI, Fig. 1). In this network, when viewed directly from above or from below, can occasionally be seen small vessels which, for a considerable distance, follow the spiral direction of the coil.

The second capillary area formed from the vessels of the lamina spiralis lies in the crista spiralis. Small vessels leave the trunks near the base of Reissner's membrane, to pass upward and outward into the crista spiralis (Plate XI, Fig. 1), where they break up into loosely arranged, wide-meshed capillary loops, which, when viewed from above, are seen to be elongated somewhat in the spiral direction of the coil. These elongated loops in cross-section give the appearance of spiral vessels and may be readily mistaken for such vessels. The question as to the existence of blood-vessels in the crista spiralis

[5] Cited by EICHLER, *loc. cit.*

[6] *Atlas des menschlichen Gehörorgans*, München, 1866.

has been a subject for contention since the writings of Hushke in 1835. Most of the older writers found blood-vessels in this structure. Voltolini and Schwalbe describe the presence here of spiral vessels. The vessels in the pig's ear, when studied from sections, correspond closely to the vessels described by Schwalbe.

Under the crista spiralis the arteries of the lamina spiralis break up into loosely arranged capillary loops which penetrate the entire thickness of the lamina spiralis and extend outward along the basilar membrane as far as the space under the tunnel of Corti. These loops become more compact under the organ of Corti. The existence of spiral vessels forming the outer boundary for the vessels of the lamina spiralis, that is, lying under the tunnel of Corti, has generally been accepted. Schwalbe described a spiral vessel which, beginning in the basal coil, continued to the top of the spiral. Two parallel spiral vessels have sometimes been described. Middendorp found at places three such spiral vessels. A great deal of confusion regarding the exact nature of these so-called spiral vessels arose from the method of studying the blood-vessels from sections, which would permit the vessels to be followed out for only short distances. In examining a large series of celloidin casts of the labyrinth of the pig's ear, a marked difference in the distribution of vessels in this area for different ears, and in different parts of the same ear, was found. In most of the preparations the terminal loops of vessels were arranged in such a manner that, while often one and sometimes two, or even three, lines were formed extending a certain distance around the coil, the presence of a spiral vessel, in the sense that Schwalbe described it, was not found. In many preparations, especially in the first half of the basal coil, the tendency for two parallel vessels to run under the organ of Corti for a considerable distance in a spiral direction was well marked. The character of the vessels as usually found in this area is shown in Plate X. The arterial twigs break up into capillary loops which, as a rule, extend outward no farther than the space under the tunnel of Corti. Here the capillary loops empty into veins which carry the blood back through the lamina spiralis to the modiolus. The definite boundary thus formed by the terminal loops and their anastomosis with each other make the vessels which form the outer boundary appear often as continuous straight lines which take the spiral direction of the tunnel of Corti (Plate X). The vessels of the lamina spiralis are usually described as having no connection with the vessels of the ligamentum spirale. Middendorp, however, found such a connection in the ear of the rabbit and of the calf. In the pig it is not uncommon to find small veins running at irregular intervals between the loops of vessels under the tunnel of Corti and the veins in the ligamentum spirale (Plates X and XI, Fig. 1). Such vessels were found in the terminal coil as well as in the basal coil. These vessels were by no means constant, and in many well-injected preparations no such vessels could be found.

No blood-vessels whatever were found in the membrane of Corti or in the organ of Corti. This coincides with the findings of previous writers on this subject.

In the outer wall of the ductus cochlearis are two distinct capillary areas, one in the stria vascularis, the other in the ligamentum spirale. In the stria vascularis, the area lying between the attachment of Reissner's membrane and the prominentia spiralis, is found a system of capillary loops which are said to lie in the epithelium lining the ductus cochlearis. This system extends from the beginning of the ductus cochlearis to its termination in the cupula cochleae. The arterial supply for this area is brought through an occasional twig from the arteries radiating over the scala vestibuli, while an occasional branch to the veins of the scala tympani carries the blood away. These vessels usually join the capillary loops near the center of the stria vascularis. The character of the capillary loops of the stria vascularis is shown in Plate XI, Fig. 2. The loops are elongated, extending usually in the spiral direction of the coil. The lateral boundaries are quite definitely limited, so that the vessels have more or less the character of continuous spiral vessels, comparable, to a certain extent, with the so-called spiral vessels of the basilar membrane.

The ligamentum spirale is freely provided throughout its entire thickness with capillary loops. These capillary loops extend into the crista of the ligamentum spirale in such a manner that, at the point where the basilar membrane is attached to the crista, terminal loops are found, similar to the terminal loops in the basilar membrane, and at places form a vessel which, for a longer or shorter distance, takes a spiral course along the crista. The arterial supply for these capillaries comes through the arteries which radiate over the scala vestibuli, while the venous blood is collected by the veins of the scala tympani. It is thus seen that the arteries radiating over the scala vestibuli supply, as has already been stated, three distinct capillary areas: first, the capillary area over the scala vestibuli; second, the capillaries in the stria vascularis; and third, the vessels in the ligamentum spirale. The first of these areas is located in the osseous labyrinth, while the last two are located in structures that are parts of the membranous labyrinth.

2. *The sacculus.*—The blood vessels of the saccule are especially well developed in the region of the macula acustica sacculi. The arterial supply comes through several arteries which spring from the anastomotic loops at the base of the cochlea and run across the recessus sphaericus on the posterior wall of the saccule. A number of very short stems are given off which turn forward toward the epithelial surface of the macula acustica sacculi. These break up into a flat matting of capillaries which presents a smooth surface toward the cavity of the saccule. The venous blood from this area is collected by branches from the transverse vein of the vestibule, which in turn empties into the posterior vestibular vein (Plate VI).

3. *The utriculus.*—The utricle is surrounded by a loose capillary network, and in preparations that have been well injected and where the celloidin cast has been thoroughly cleared in creosote, the exact outlines of this membranous sac can be accurately distinguished by these incasing vessels. In such specimens the utricle is seen as a narrow elongated chamber which is crowded close to the posterior part of the vestibule into the recessus ellipticus. The conspicuous feature of the blood-supply to

the utricle is, however, the vascularization of the macula acustica utriculi. The arterial supply for this area comes exclusively from the anterior vestibular artery through several small branches which run along the anterior surface of the utricle, and, as in the case of the vessels to the macula acustica sacculi, send off a number of short stems which turn abruptly toward the epithelial surface and divide into a dense capillary matting. This capillary network lies in the anterior wall of the utricle and presents a flat, smooth surface toward the cavity of the utricle. The venous blood is collected by tributaries of the anterior vestibular vein.

4. *The ductus endolymphaticus.*—This membranous tube is incased by capillaries which are supplied by a small arterial twig, usually a branch of the posterior vestibular artery, and are drained by a small vein which empties into the transverse vestibular vein. In preparations where enough of the duct is preserved to show its flaring, trumpet-like opening into the saccus endolymyhaticus, a small dural vein can be seen which collects the blood from that end of the duct (Plate VI).

5. *The membranous ampullae.*—These structures receive their blood-supply from the following sources: the superior and lateral ampullae from branches of the anterior vestibular artery, the posterior ampulla from the posterior vestibular artery. The anterior vestibular vein collects the blood from the superior and lateral ampullae, and the posterior vestibular vein from the posterior ampulla and part of the posterior surface of the lateral ampulla (Plates V and VI). The exact form of each membranous ampulla is outlined by a network of blood-vessels spread over its surface. The arterial blood is supplied by one or two branches which approach the ampulla from its base. The venous blood is collected by several branches which, as a rule, take a course similiar to that followed by the arteries. It was often found that, where a single arterial twig supplied the ampulla from one side, a vein would collect the blood from the dome of the ampulla and run back to its base on the opposite side (Plate XII, Fig. 1). Siebenmann, in his work on the blood-vessels in the labyrinth of the human ear, pictures in Plate III a condition in which a large vein arches over the dome of each ampulla and collects the blood by a number of short branches which extend down to the ampulla. This condition was not found in the labyrinth of the pig's ear. The cristae of the ampullae, like the maculae acusticae of the utricle and saccule, are richly supplied by a dense matting of very finely woven capillaries (Plate XII, Fig. 1). The arteries enter the sulcus ampullaris and the veins emerge along with the nerve.

6. *The canales semicirculares.*—The plan of the blood-supply for the semicircular canals of the pig's ear corresponds in general to the distribution of vessels usually described for the human ear. Each canal is supplied with two arteries and two veins, one of each for each crus. The blood-supply for the several canals is as follows: The anterior crura of the superior and lateral semicircular canals receive each a branch from the anterior vestibular artery, while the venous blood is collected by a tributary of the anterior vestibular vein. The posterior crura of the lateral and posterior canals receive

each a branch from the posterior vestibular artery and a tributary of the posterior vestibular vein carries the blood away. The crus commune carries a single artery the origin of which is described on p. 9. This artery divides near the end of the crus into two branches, one of which goes to the posterior semicircular canal, the other to the superior. Two veins, one from each of these semicircular canals, unite at the end of the crus commune near the point where the artery divides. The common trunk thus formed follows the course of the artery through the crus commune, and empties into a branch of the posterior vestibular vein (Plates V and VI). This differs from the observations of Siebenmann on the human ear, where the veins from the posterior and superior canals run through the crus commune as separate vessels.

The semicircular canals were so perfectly injected in a number of the specimens that it was not only possible to follow the arterial and venous trunks throughout their entire course, but with the aid of the stereoscopic microscope every capillary loop throughout the canal could be traced and the character of these loops studied.

The artery for a time after it enters the canal usually clings close to the inner concave surface of the bony canal. It begins soon to gradually approach the membranous canal which lies close to the outer convex surface of the bony canal. The artery does not usually reach the membranous canal until near the center of the arch. Its terminal branch when it reaches the membranous canal breaks up immediately into capillary loops. The artery throughout the semicircular canal takes a course almost straight. It sends off from five to ten small branches which run out to supply the membranous canal (Plate XII, Fig. 1).

The veins which drain the crura of the semicircular canals follow, as a rule, close along the inner surface of the membranous canal, taking an irregular zigzag course. About the point near the center of the arch where the terminal branch of the artery breaks up into capillaries, the vein begins as a separate vessel. Thus for a short space in the center of the arch only the capillary loops which encase the membranous canal are to be found. Throughout its course the vein receives a number of small branches which in turn collect the blood from a network of loosely arranged capillary loops which surround the membranous canal. These capillary loops, when viewed from the convex surface of the arch of the semicircular canal, present a characteristic appearance. The loops come up on either side of the membranous canal, but do not completely surround it, for a zone is left along the middle of its convex surface free from vessels, except for an occasional branch which, crossing over the zone, connects the loops on one side of the membranous canal with those on the opposite side (Plate XII, Fig. 2).

The points of special interest in this description of the blood-vessels in the labyrinth of the pig's ear may be summarized briefly as follows:

1. The several divisions of the labyrinthine artery which go to supply the cochlea amastomose freely with each other through a number of anastomotic loops or arcades at the base of the cochlea, thus insuring for each part a blood-supply reinforced freely from each division.

2. The arterial supply to the cochlea is arranged on such a plan that, as a rule, the vessels which send out the arteries to supply the scala vestibuli of a coil send out another set of arteries which supply the lamina spiralis of the coil next above. The arrangement usually described for the human ear, where the arteries for the scala vestibuli and for the lamina spiralis of the same coil come from the same vessels, is found in the cochlea of the pig's ear, but only as the exception.

3. The venous blood of the cochlea drains entirely into the vena canaliculi cochleae. The veins from the ligamentum spirale of the first half of the basal coil are collected into a large trunk which runs along the middle of the under surface of the basal coil to empty into the vena canaliculi cochleae. The veins from the remainder of the basal coil are collected into the posterior spiral vein which runs along the posterior inner margin of the coil.

4. The venous blood from the upper coils of the cochlea is collected by a tributary of the posterior spiral vein. This vein in its beginning follows the spiral direction of the upper coil. It then passes directly downward through the modiolus to join the posterior spiral vein, receiving tributaries from the upper coils which converge toward this central vessel. The anterior spiral vein which Siebenmann found in the cochlea of the human ear does not exist in the ear of the pig.

5. The veins which lie between the coils of the cochlea are supplied by two sets of tributaries, one of which collects the blood from the scala vestibuli of the coil beneath; the other set collects the blood from the scala tympani of the coil above.

6. The so-called spiral veins of the cochlea, which are usually described as running under the tunnel of Corti, in the crista spiralis, in the crista of the ligamentum spirale, and in the prominentia spiralis, are formed in the ear of the pig from capillary loops which form the boundary line for distinct capillary areas in these parts.

7. There was often found in the cochlea of the pig's ear a connection between the vessels of the lamina spiralis and those of the ligamentum spirale. This connecting link consisted of straight veins which ran from the terminal loops under the tunnel of Corti across to the veins in the crista of the ligamentum spirale, and were found in the terminal as well as in the basal coil.

8. The arterial supply for the vestibule and the semicircular canals comes in part from the anterior vestibular artery, and in part from arteries which spring from the anastomotic loops between the arterial trunks which supply the cochlea.

9. The venous blood from the vestibule and the semicircular canals is collected into two large trunks which empty into the vena canaliculi cochleae. This is in striking contrast to the condition found by Siebenmann and Eichler in the human ear, where the veins from the semicircular canals left the labyrinth with the aquaeductus vestibuli.

10. The capillaries are distributed almost exclusively to the membranous labyrinth. In the semicircular canals this is shown the most clearly. Here the capillaries surround the membranous canal while the veins run along its inner concave surface,

and the artery, for the most part, clings to the inner concave surface of the osseous canal, sending an occasional twig to the capillary loops around the membranous tube.

11. The capillary loops of the membranous semicircular canals do not, as a rule, completely surround this tube, but leave a zone along its convex surface free from vessels except for an occasional connecting loop which runs across this space.

EXPLANATION OF PLATES

NOTE.—The arteries are in red, the veins and capillaries in blue. The explanations of Plates V and VI appear on page 20.

PLATE VII

The arterial tree of the cochlea from the right ear of an embryo measuring 11 cm. in length. The coils of the cochlea are represented as having been partially drawn out, in order to show better the branching and anastomosis of the arteries. The drawing is from a preparation in which only the arteries were injected.

a, *a*. The two arterial trunks of the cochlea.

b, *b*. Anastomotic loops at the base of the cochlea.

c, *c*, *c*. Tractus spiralis arteriosus.

d. Terminal branch of the arteries forming the tractus spiralis arteriosus.

e, *e*. Arteries radiating over the scala vestibuli.

PLATE VIII

The venous tree of the cochlea from the right ear of an embryo measuring 11 cm. in length. The coils of the cochlea are drawn out as in Plate VII. From a preparation in which only the larger veins were injected.

a, *a*. Vena spiralis posterior.

b. Anastomotic loop between the two branches of the vena spiralis posterior.

c. Veins which collect the blood from the lamina spiralis.

d. Veins which collect the blood from the scala tympani.

e. Central venous trunk, collecting blood from the upper coils.

f. Vein from terminal coil, following the spiral direction of the coil.

g. Vena vestibularis anterior.

PLATE IX

Basal coil of the cochlea from the right ear of an embryo measuring 10 cm. in length. Showing character of the anastomosis at the base of the cochlea in a young embryo before the arteries have become convoluted.

a, *a*. Arterial trunks of the cochlea.

b. Anastomotic loops.

c, *c*, *c*. Stumps of arteries which supply the upper coils.

d. Anastomotic loops of arteries lying over the scala tympani.

e, *e*. Arteries radiating over the scala vestibuli.

f, *f*. Vena spiralis posterior.

g. Stump of central venous stem which collects blood from the upper coils.

h. Vena vestibularis anterior.

i. Vena vestibularis posterior.

PLATE X

Basal coil of the cochlea from the right ear of a fœtus at full term. A section of the scala vestibuli is removed to show vascularization of the lamina spiralis. At this age the arteries have assumed the characteristic convolutions of the adult labyrinth.

a, a. Arterial trunks of the cochlea.
b, b. Anastomotic loops of the arteries.
c. Arteries radiating over the scala vestibuli.
d, d. Vena spiralis posterior.
e. Stump of vein which collects blood from the upper coils.
f. Capillary areas of the scala vestibuli.
g. Vein on upper margin of fenestra cochleae.
h. Vessels of the lamina spiralis.
i. Capillaries of the ganglion spirale.
j. Terminal loops of blood-vessels lying under the tunnel of Corti.
k. Veins connecting vessels of lamina spiralis with those of the ligamentum spirale.

PLATE XI

FIG. 1.— A thick section through the center of the cochlea, one-half only being represented. Semi-schematic.

a, a, a. Ganglion spirale.
b, b, b. Crista spiralis.
c, c, c. Terminal loops of vessels under the tunnel of Corti.
d, d. Venous connection between vessels of the lamina spiralis and those of the ligamentum spirale.
e, e. Venous trunks lying between coils of the cochlea which collect blood from the scala vestibuli of the coil beneath, also from the scala tympani of the coil above.

FIG. 2.— Section from the basal coil of the cochlea. A piece is removed from the outer wall of the ductus cochlearis to show the blood vessels in the stria vascularis.

a. Blood vessels of the stria vascularis.
b. Ductus cochlearis.
c, c. Arteries radiating over the scala vestibula.
d, d. Veins of the scala tympani.

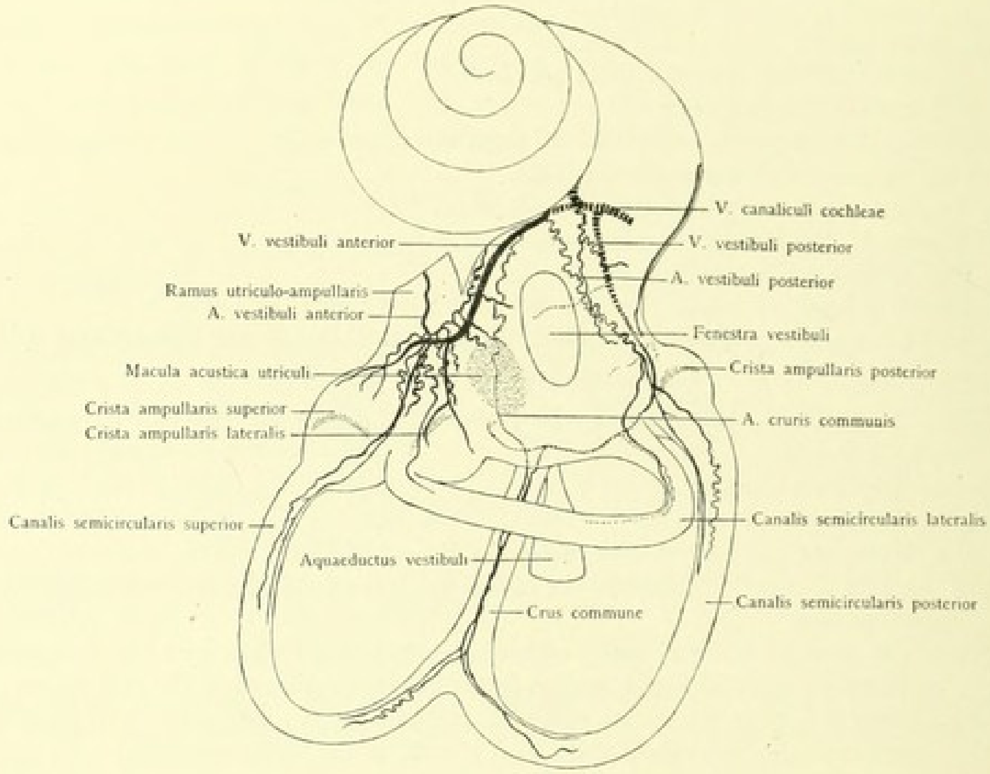
PLATE XII

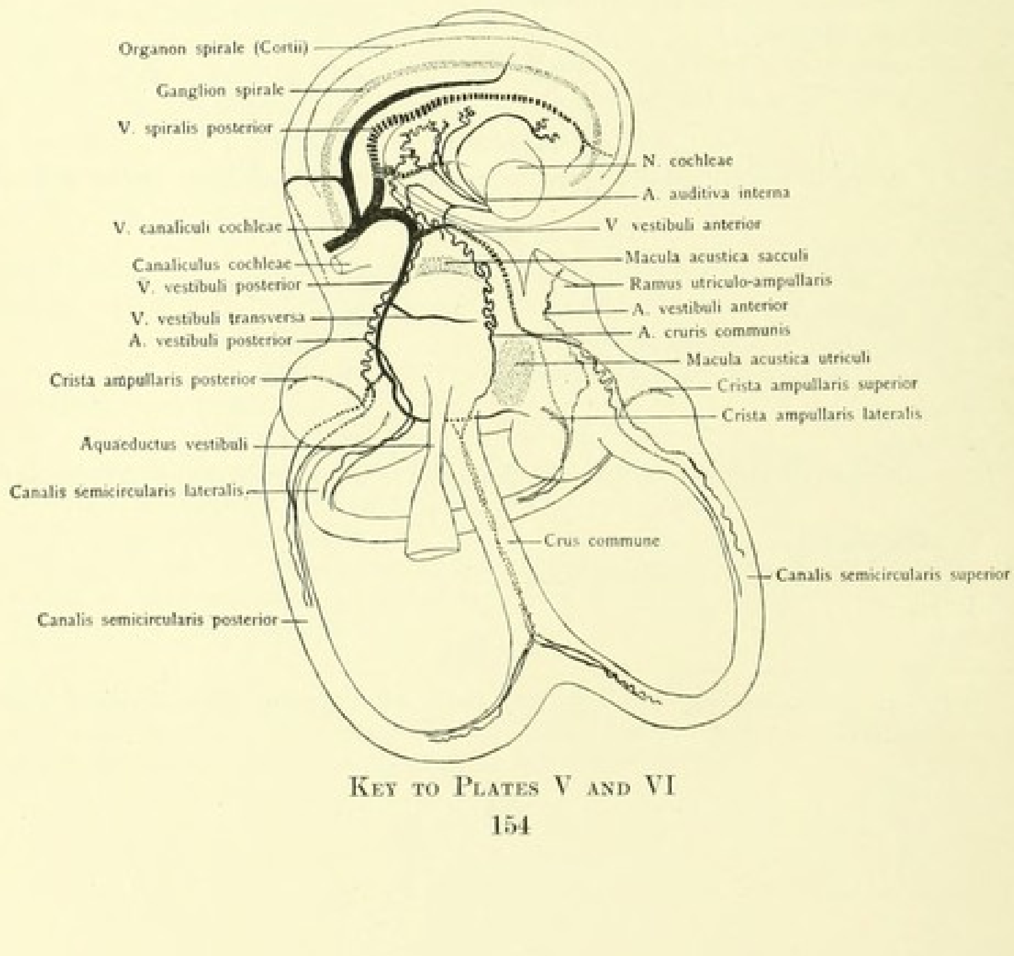
FIG. 1.— Canalis semicircularis lateralis from the right ear of a fœtus at full term. Viewed from above.

a. Ampulla ossea.
b. Ampulla membranacea.
c. Crista ampullaris.
d. Canalis semicircularis (osseus).
e. Ductus semicircularis (membranaceus).
f, f. Arteries.
g, g. Veins.

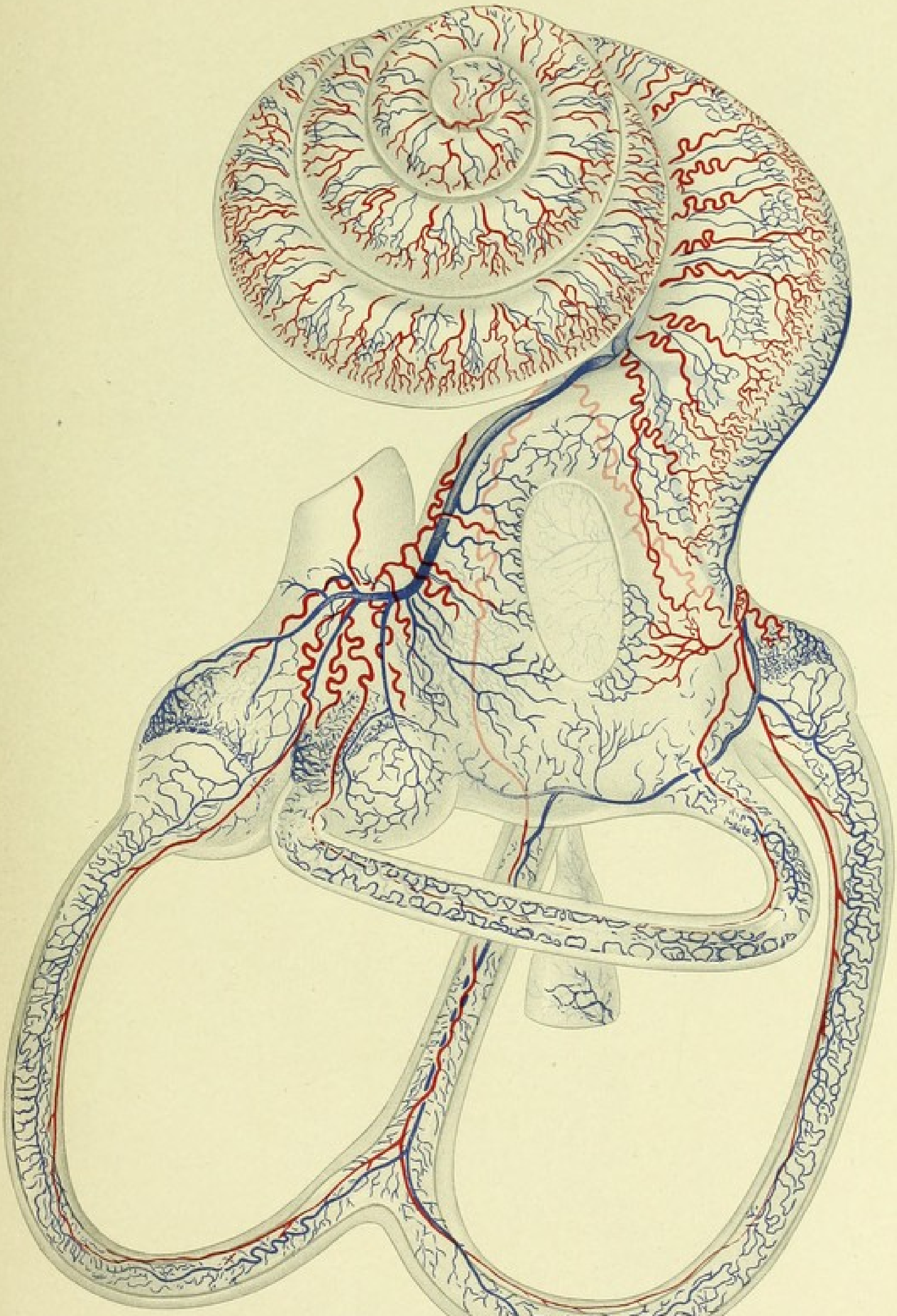
FIG. 2.— Section of the canalis semicircularis lateralis taken from near the center of the arch.

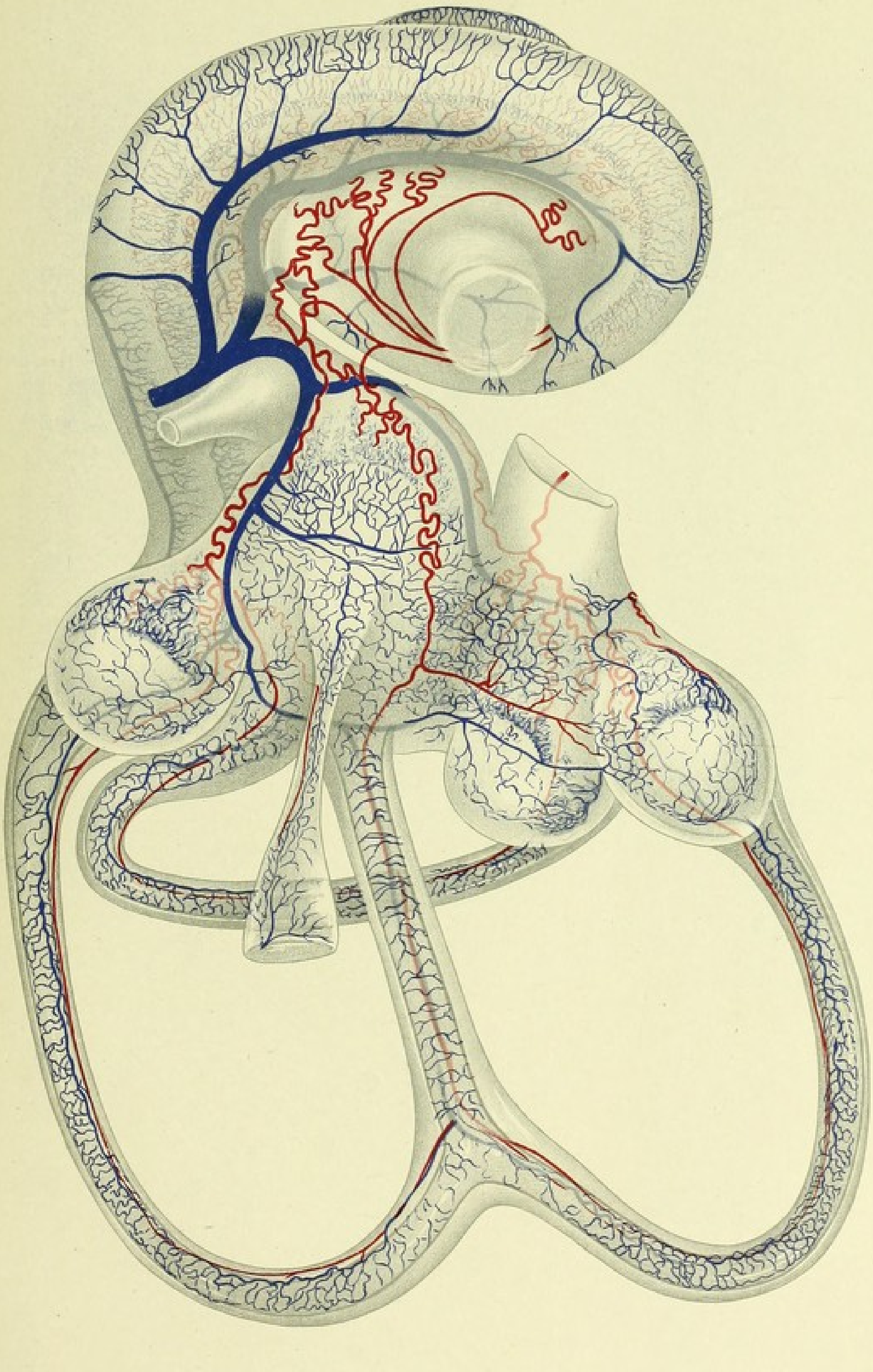
a. Canalis semicircularis (osseus).
b. Ductus semicircularis (membranaceus).
c. Artery.
d. Vein.
e, e. Capillary loops.
f, f, f. Vessels connecting the capillary loops on opposite sides of the ductus semicircularis.

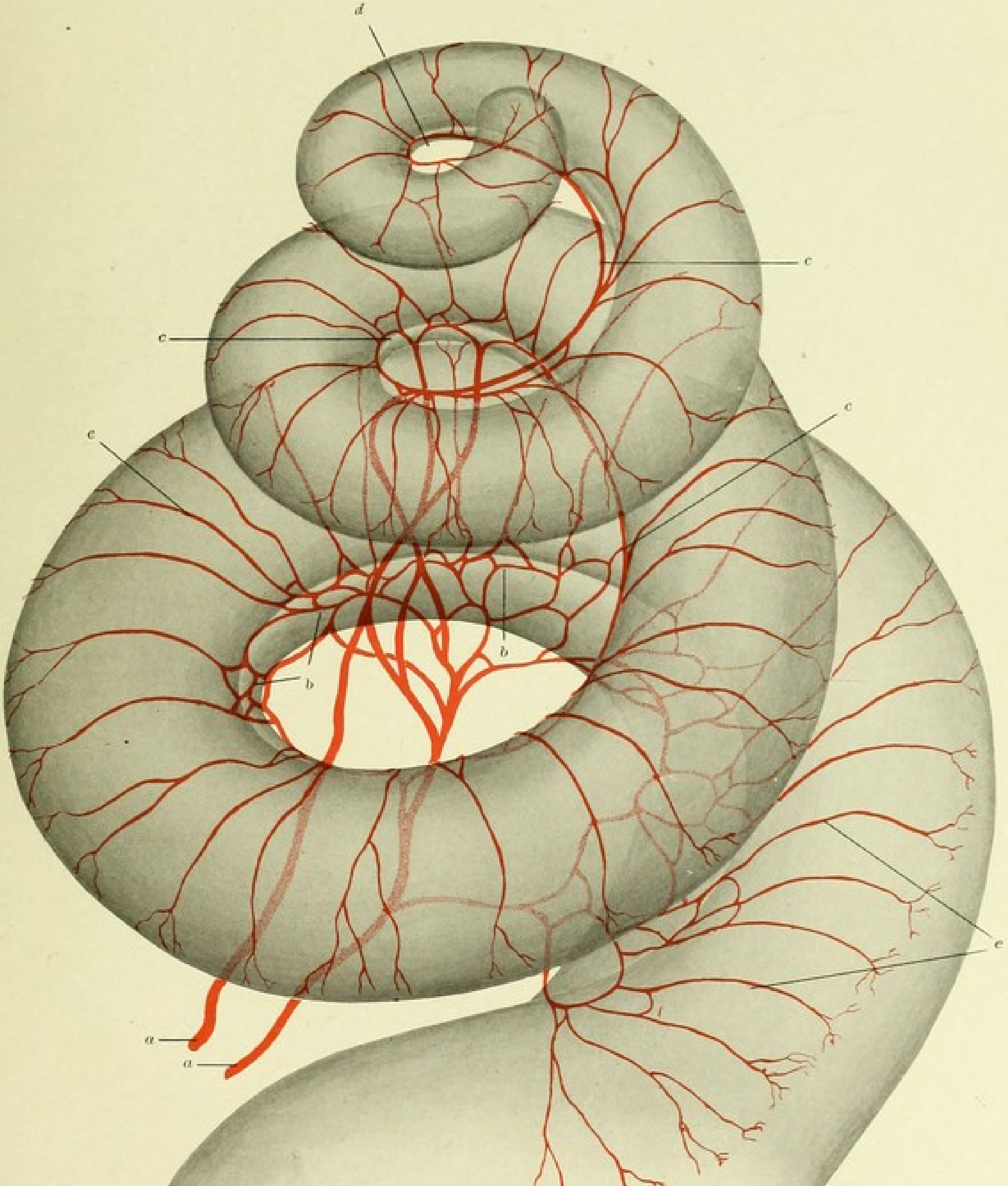




KEY TO PLATES V AND VI



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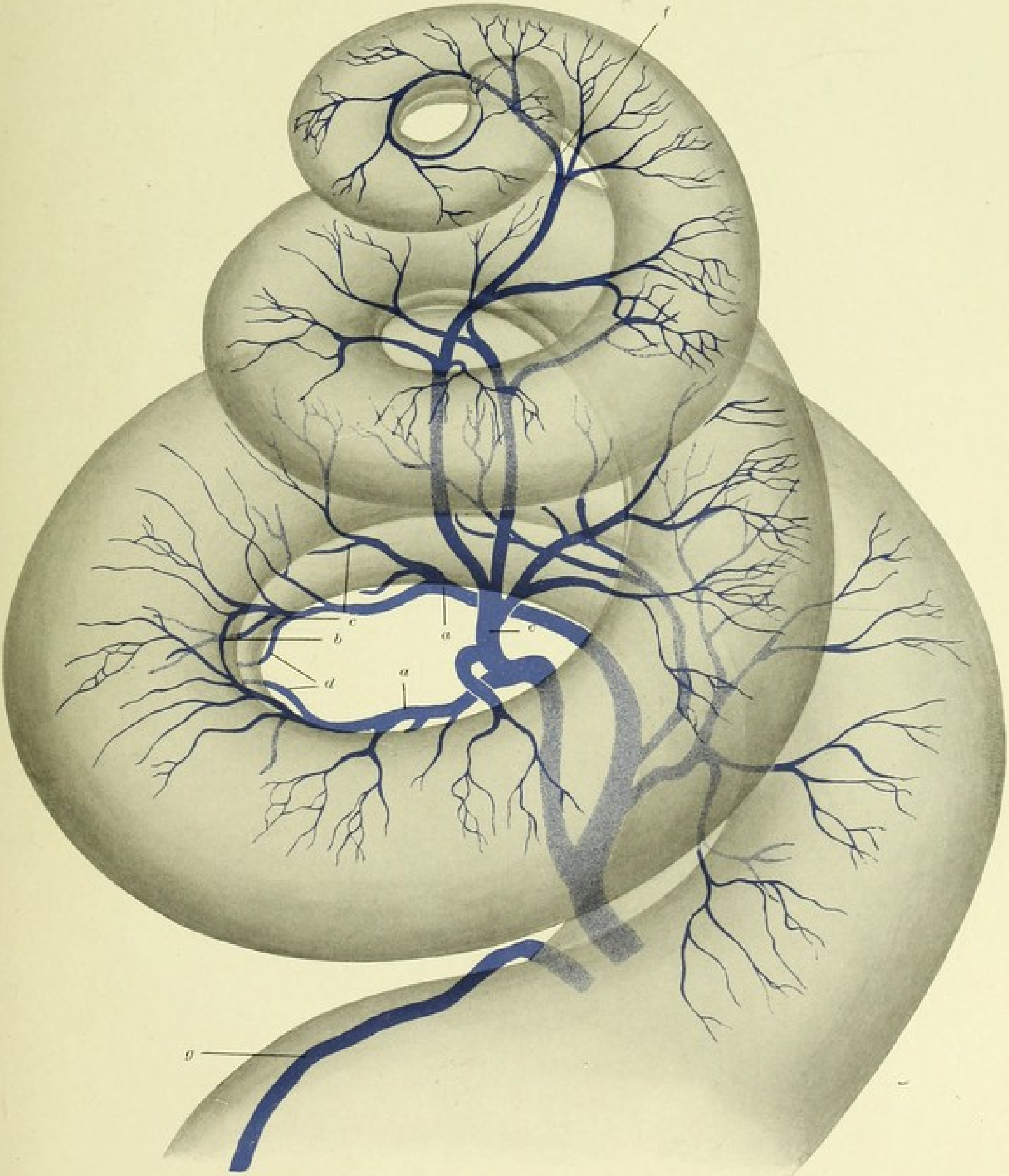
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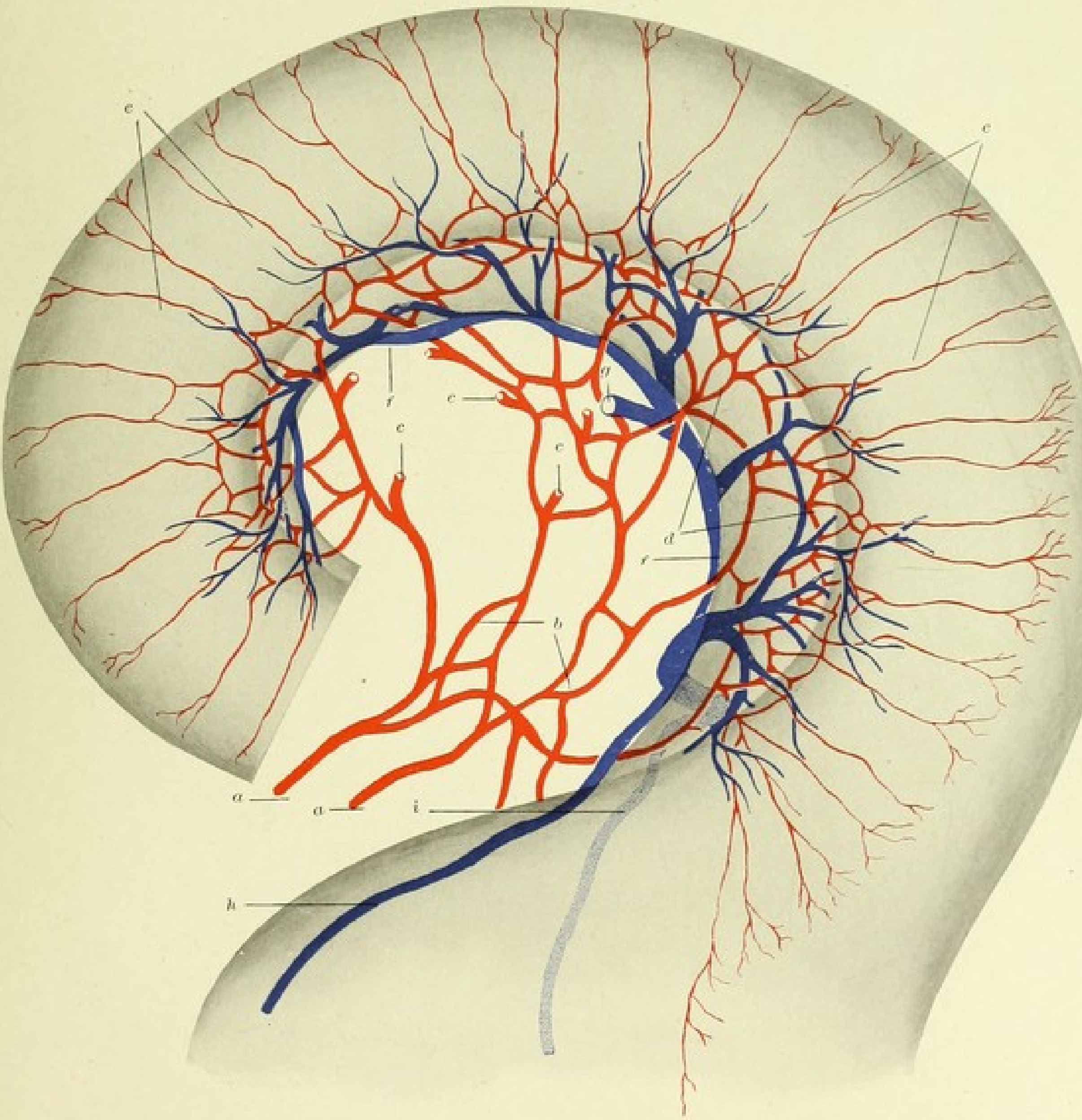
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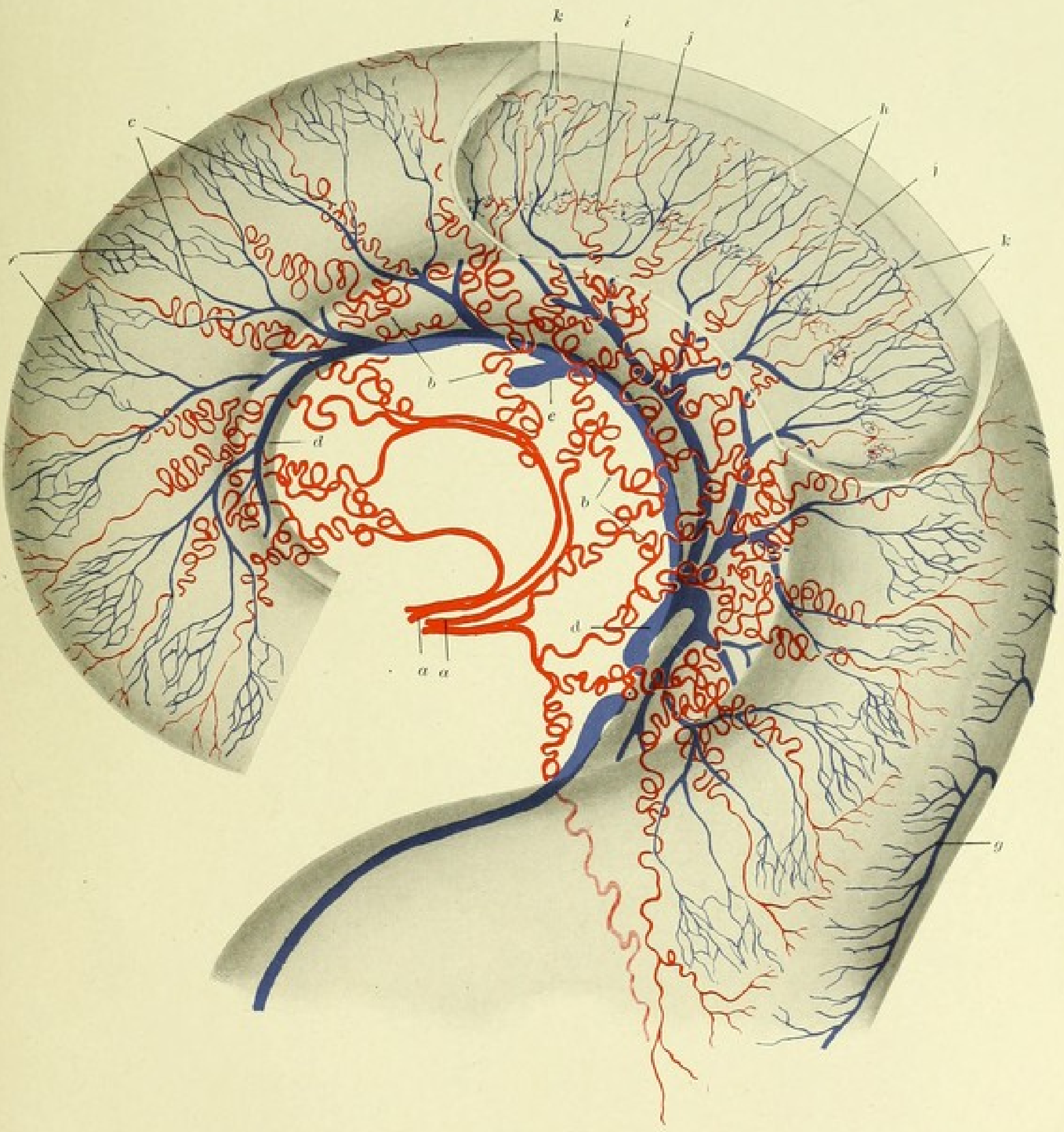
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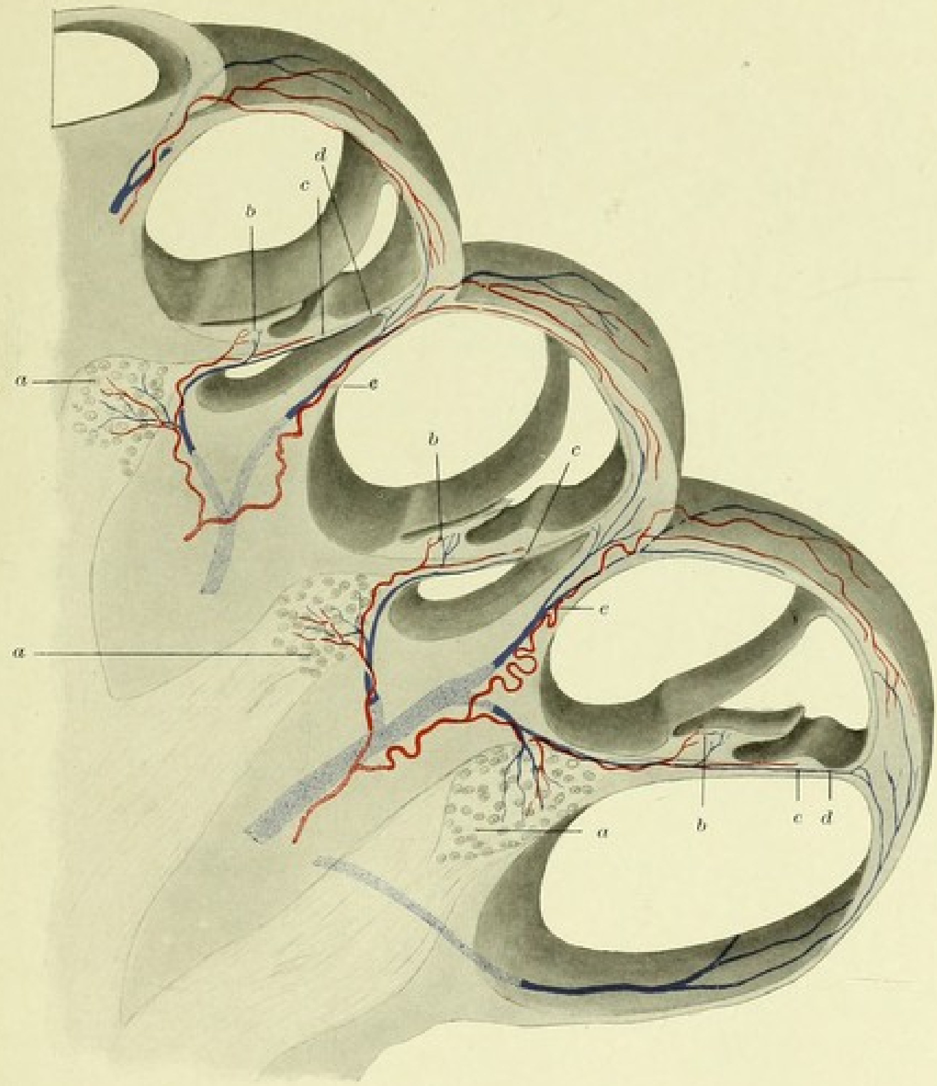

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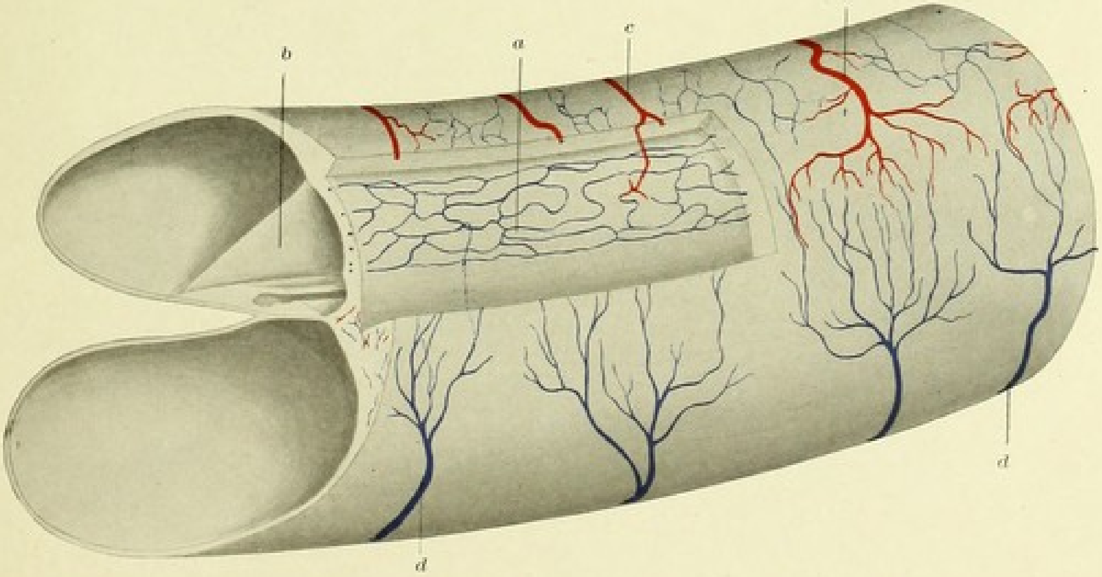

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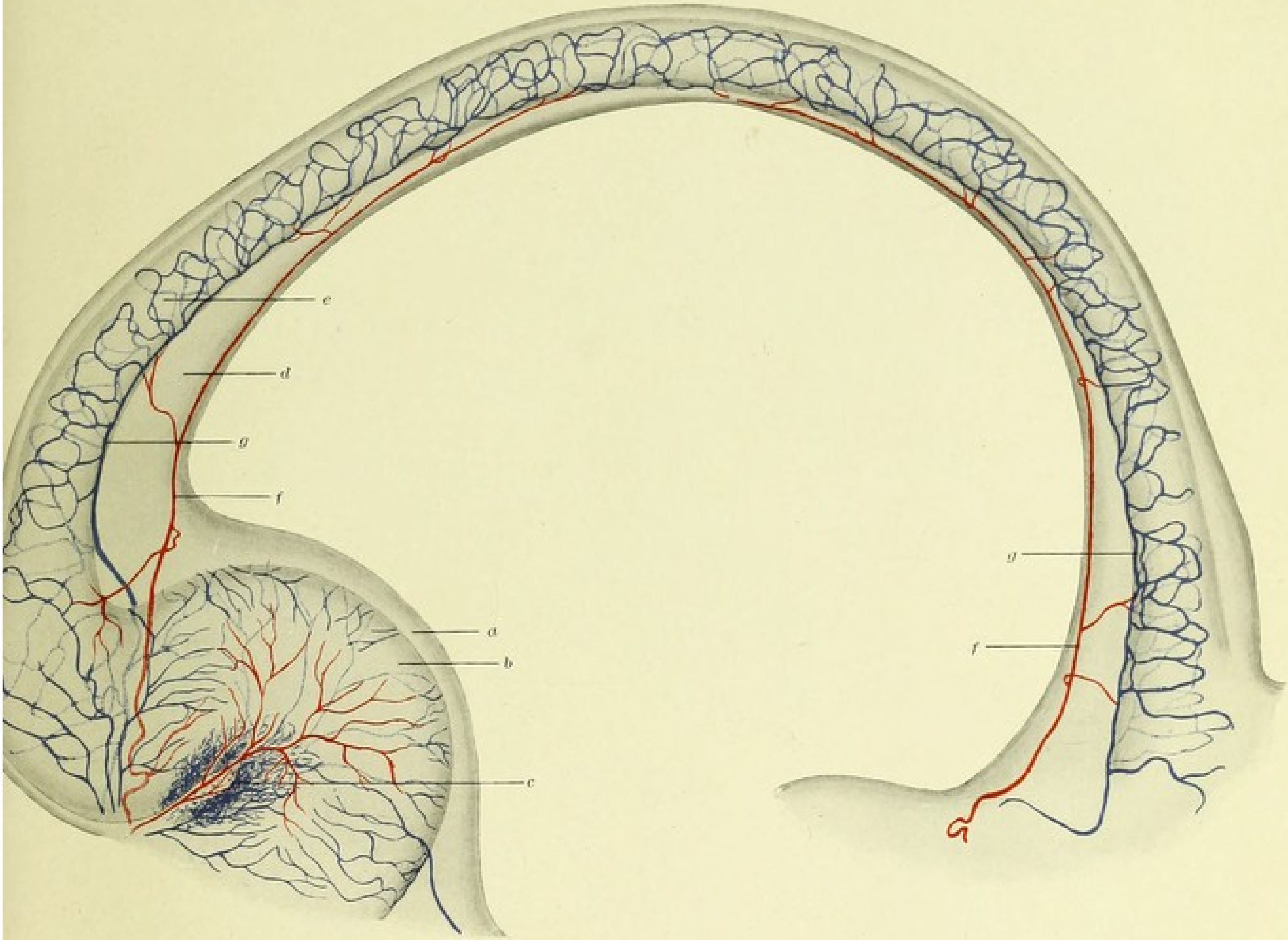

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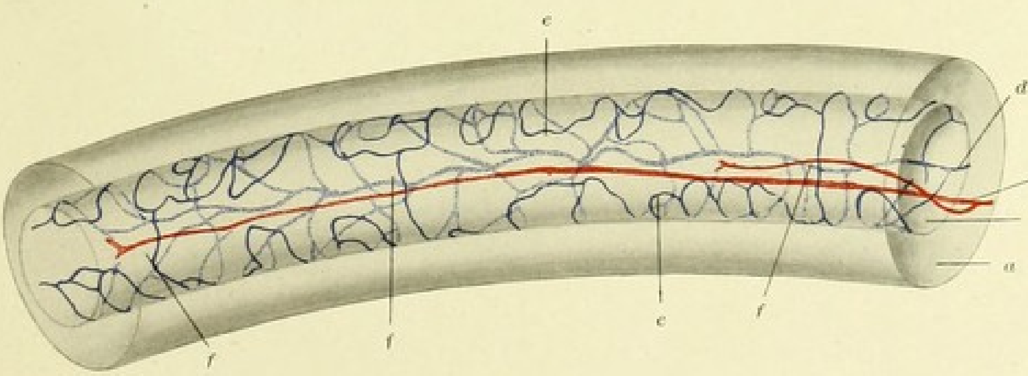

FIG. 2