THE DEVELOPMENT OF CERTAIN HUMAN DURAL VENOUS SINUSES

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Although Streeter's (1915, 1918) accounts of the development of the human dural venous sinuses have become widely accepted, a critical analysis of these papers suggests that certain contained morphological interpretations are incorrect; in particular, those concerning the superior petrosal and petro-squamous sinuses and the post-glenoid vein.

Rathke (1838) believed that the brain was primarily drained by an external jugular vein which left the skull through a foramen between the temporo-mandibular joint and the tympanic ring, and that later a new vein, the internal jugular, grew cranialwards out of the external jugular and entered the skull by the jugular foramen. Only in man and apes did this new route receive all the intra-cranial venous outflow, lower mammals retaining the primary route to a variable degree. Luschka (1862) held similar views, and named the cranial exit of the external jugular vein the foramen jugulare spurium, and described (1867) its occasional occurrence in adult human temporal bones. Kölliker (1879) confirmed Luschka's interpretations.

Salzer (1895) described dural venous sinus development in man, rabbit, guinea-pig, pig and cat, finding in all a primary head vein consisting of vena capitis lateralis and vena capitis medialis. All species showed a similar mode of dural sinus development therefrom and two important observations were recorded:

(1) The vena capitis lateralis ran in the petrous temporal bone in company with the post-ganglionic portion of the facial nerve.

(2) The post-glenoid vein developed as a secondary connexion between the transverse sinus and the external jugular vein and co-existed with vena capitis lateralis. Grosser (1901) recorded the same mode of development of the head veins in bats.

Hochstetter (1896) found a typical primary head vein in embryonic Monotremes and here, also, the vena capitis lateralis ran in the facial nerve canal. In both adult *Tachyglossus* and *Ornithorhynchus* a petro-squamous sinus entered the anterior end of the facial nerve canal and emerged through the stylomastoid foramen and a persistent vena capitis lateralis joined the *internal* jugular vein. Neither genus manifests a post-glenoid vein. Later, however, he stated (1906) that the vena capitis lateralis left the skull between the nerves V and VII and his ill-worded statement has caused much confusion regarding the relation of the vena capitis lateralis to the post-glenoid vein.

Mall's (1905) account of the development of the human dural venous sinuses is difficult to follow, but he recognized a middle cerebral vein, joining the junction of

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venae capitis medialis and lateralis, which became the superior petrosal sinus: the petro-squamous sinus was ignored. Mall regarded the vena capitis lateralis as being clearly outside the skull, emerging therefrom between the nerves V and VII, along the root of the latter, in line with the foramen jugulare spurium, and communicating with the internal jugular vein.

Markowski (1911, 1922) showed that the human embryonic transverse sinus divided into the sigmoid sinus, joining the internal jugular vein, and the pro-otic vein, entering the junction of vena capitis medialis and vena capitis lateralis immediately caudal to the trigeminal ganglion. He described the pro-otic vein, following the regression of the vena capitis lateralis, as a continuation to the transverse sinus of the vena capitis medialis, and as having, in older embryos, a situation identical with that of the petro-squamous sinus of the adult: the middle meningeal veins were formed from tributaries of the pro-otic vein: the superior petrosal sinus was derived from a small cerebral vein. Streeter (1915, 1918) could not confirm Markowski's account of the superior petrosal sinus and was unconvinced of its identity with the pro-otic vein. Streeter himself regarded the 'foramen jugulare spurium' of the adult skull as the exit of a decadent vena capitis lateralis. The issue was further confused by van Gelderen (1925), who stated that the persistent middle cerebral vein of aplacental mammals was known as either the pro-otic vein or the anterior branch of the transverse sinus in the placental mammals, but in Primates as the superior petrosal sinus. According to this author, the vena capitis medialis, occupying the cavum epiptericum, is intracranial and the vena capitis lateralis, overhung by the otic capsule, is extracranial. But the cavum epiptericum is an extracranial space containing the ganglia of V and VII and traversed by nerve VI, the head vein and the stapedial artery (de Beer, 1937). Boyd (1930) questioned Streeter's interpretation of the post-glenoid vein as a persistent vena capitis lateralis but offered no alternative explanation.

In the rat the main intracranial venous outflow is by the post-glenoid vein, shown (Butler, 1953) not to be a persistent vena capitis lateralis; the pro-otic vein becomes the petro-squamous, not the superior petrosal sinus.

In view of my own findings concerning the relationship of the pro-otic vein to the vena capitis lateralis and vena capitis medialis in the rat it was decided to re-investigate the development of the human dural venous sinuses.

MATERIAL AND METHODS

Twelve human embryos ranging from 7·5 to 30·0 mm. crown-rump (C.R.) length were examined, and graphic reconstructions of the head veins were made of seven. Serial sections of eight foetal heads ranging from 42·0 to 175·0 mm. C.R. length were examined and lateral graphic reconstructions of the head veins made from two of them. The engorged veins in the head of a foetus of 85·0 mm. C.R. length were dissected. The pattern of endocranial vascular grooving was examined in thirty adults. The cavernous sinus was examined in one child of 8 years and in fifteen adults between 27 and 80 years old.

OBSERVATIONS

A. *The embryonic period*, 28–48 *days*

Stage 1. 7·5 *mm. crown-rump length* (Fig. 1)

Anterior cerebral, maxillary and pituitary veins unite, deep to ganglion V, forming the vena capitis medialis. The latter vein turns lateralwards around the caudal margin of ganglion V and, just deep to the ectoderm, turns caudalwards as the vena capitis lateralis which runs lateral to the otic vesicle and to ganglia VII, IX and X. Caudal to ganglion X it turns through 90 degrees to continue as the anterior cardinal

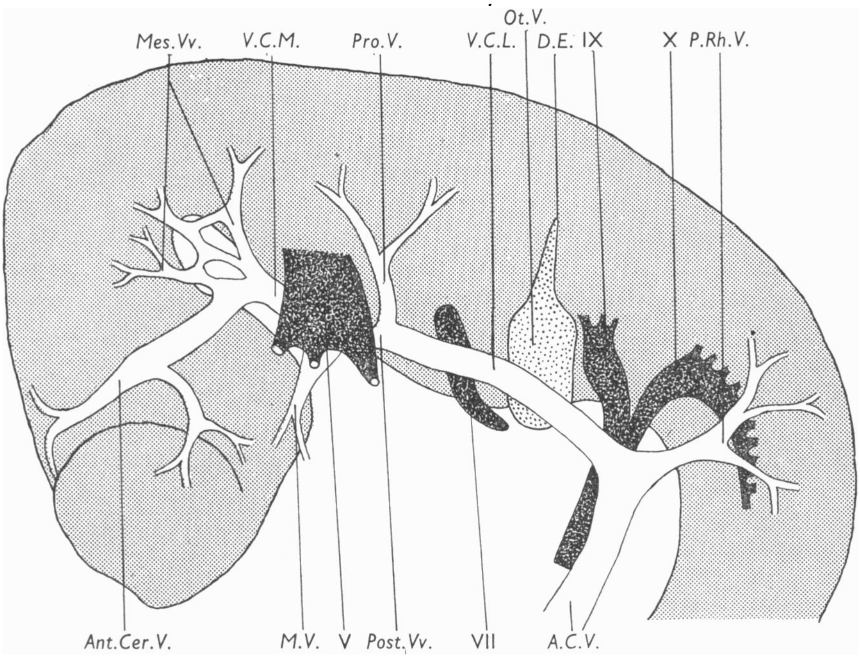

Fig. 1. Left lateral reconstruction of the head veins in a 7·5 mm. c.r. length embryo. The meaning of abbreviations for all figures are given on p. 526.

vein. The laterally directed part of the primary head vein running surfacewards between ganglia V and VII will be here called the post-trigeminal vein. It receives a large pro-otic vein into its dorsal surface. A large posterior rhombencephalic vein enters the junction of vena capitis lateralis and anterior cardinal vein caudal to ganglion X.

Stage 2. 14·0 *mm. crown-rump length* (Fig. 2)

The primary head vein is constituted as in the previous embryo but its tributaries are more complex. The commencement of the anterior cerebral veins, lying between the cerebral hemispheres, are coalescing to form a plexiform, midline channel, the superior sagittal sinus. Immediately anterior to the pineal evagination the two anterior cerebral veins diverge to run along the caudal margin of the cerebral hemisphere before crossing the lateral aspect of the midbrain to join the vena capitis medialis. Each receives dorsally numerous mesencephalic veins and ventrally small cerebral veins and a lateral diencephalic vein.

Prior to passing medial to the anterior margin of ganglion V each anterior cerebral vein passes between nerves III and IV, just below their crossing point.

A small peri-trigeminal vein runs forwards across the lateral surface of ganglion V joining the termination of the anterior cerebral vein to the post-trigeminal vein. The single pro-otic vein of the previous stage is replaced by several channels occupying the interval between ganglion V and the mesenchymal otic capsule: the smallest and most anterior of these crosses the root of ganglion V and joins the anterior end of the peri-trigeminal vein, the primitive superior petrosal sinus which lies, at its termination, between ganglion V and nerves III and IV.

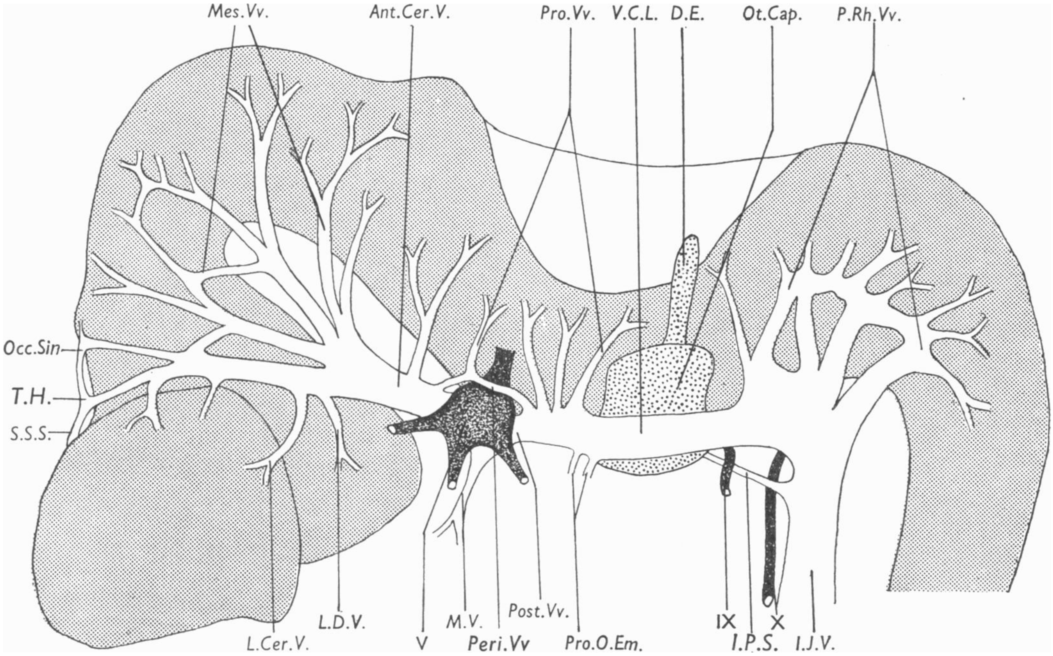

Fig. 2. Left lateral reconstruction of the head veins of a 14·0 mm. C.R. length embryo.

Similarly, the single posterior rhombencephalic vein is now replaced by several large channels joining the junction of the vena capitis lateralis and anterior cardinal vein. A small plexiform inferior petrosal sinus surrounds nerves IX and X and joins the anterior cardinal vein beyond the entry of the vena capitis lateralis, this junction marking the commencement of the internal jugular vein.

The vena capitis lateralis is in contact with the lateral surface of the mesenchymal otic capsule and receives only small tributaries into its lateral aspect. These connect it to the subectodermal venous plexus, the forerunner of the external jugular venous system in the otic region. The most prominent of these small veins, the pro-otic emissary veins, join the junction of vena capitis lateralis and the post-trigeminal vein opposite the entry of the main pro-otic veins.

Stage 3. 16·0–18·0 *mm. crown-rump length* (Fig. 3)

This stage is marked by the sudden appearance of a large supra-otic anastomosis connecting the pro-otic and posterior rhombencephalic veins. This new channel, together with the terminal part of the posterior rhombencephalic veins, forms the sigmoid sinus.

The anterior cerebral vein has a marked dorsal convexity, caused by the continued expansion of the cerebral hemisphere. Prior to its termination in the vena capitis medialis it receives a lateral cerebral and a lateral diencephalic vein. Close to its termination in the vena capitis medialis the maxillary vein receives the large superior ophthalmic vein and the maxillary vein is now recognized as the inferior

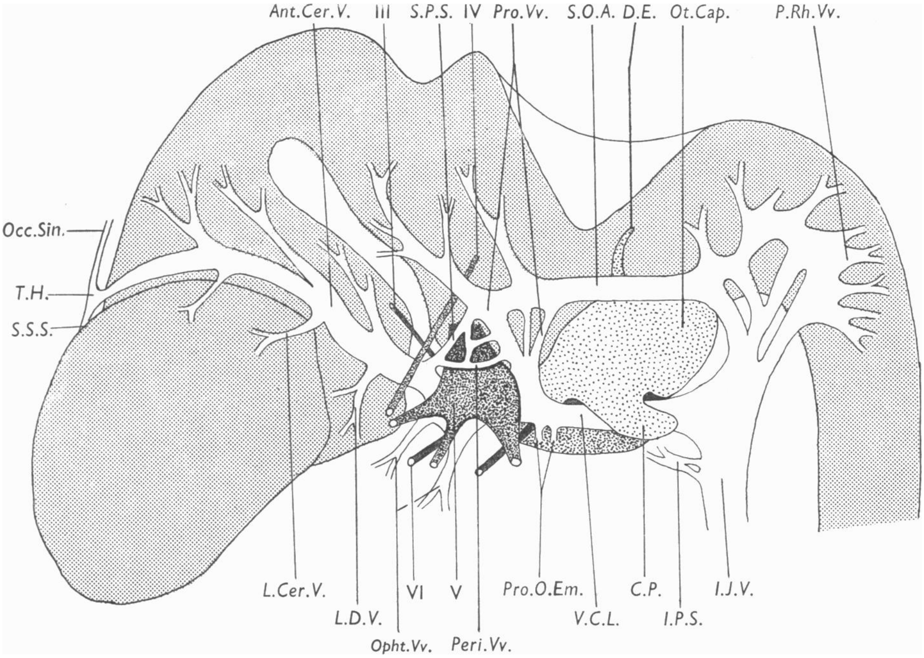

Fig. 3. Left lateral reconstruction of the head veins of 16·0–18·0 mm. C.R length embryos.

ophthalmic vein. The post-trigeminal vein still joins vena capitis medialis to the vena capitis lateralis. The latter vein runs caudalwards under the crista parotica (future tegmen tympani) lateral to the post-ganglionic part of nerve VII and medial to the stapedial artery. At the caudal end of the facial canal nerve VII turns laterally and forwards around the caudal extremity of the crista parotica, whereas the vena capitis lateralis continues caudally to enter the widely open occipito-capsular fissure. Here it joins the terminal part of the sigmoid sinus.

The post-trigeminal vein and its tributaries provide the key to the understanding of the subsequent history of the pro-otic veins, and it is therefore important to establish their relationships to the cranial nerves and chondrocranium. These veins are in the cavum epiptericum in close relation to ganglia V and VII. The geniculate ganglion is postero-medial to the junction of the post-trigeminal vein, the vena capitis lateralis and the pro-otic veins; the greater superficial petrosal nerve runs antero-laterally below this junctional region. Two or three small, laterally directed veins connect this junctional region of the primary head vein to tributaries of the external jugular vein. They run lateralwards across the anterior aspect of the proximal end of Meckel's cartilage and are identical in position and connexions with the pro-otic emissary veins of the rat (the forerunners of the post-glenoid vein). They are in line with the termination of the pro-otic veins which now connect the commencement of the supra-otic anastomosis to the junction of the vena capitis lateralis and the post-trigeminal vein. The main pro-otic vein follows closely the caudal margin of ganglion V and is still a considerable distance anterior to the otic capsule. Smaller plexiform pro-otic veins, the diminutive superior petrosal sinus, now appears as an anteriorly directed branch of the main pro-otic vein joining either the peri-trigeminal vein or the termination of the anterior cerebral vein. The superior petrosal sinus lies in the cavum epiptericum close to the anterior layer of dura forming the tentorium cerebelli.

Two or three mastoid emissary veins pass through the upper part of the occipito-capsular fissure and connect the sigmoid sinus to occipital tributaries of the external jugular veins.

Stage 4. 21·0–23·0 *mm. crown-rump length*

(*a*) 21·0 *mm. embryo* (Fig. 4). The lateral sinus has been completed by the sudden appearance of an anastomotic channel, in line with the supra-otic anastomosis, connecting the anterior cerebral vein to the pro-otic veins. At the same time, the anterior cerebral vein disappears between the entry of the lateral cerebral vein and the vena capitis medialis. The completed lateral sinus is composed of: (1) the transverse sinus formed from the anterior cerebral vein from the torcular to the entry of the lateral cerebral vein (Fig. 4, *a–b*) and the new anastomosis between the anterior cerebral vein and the pro-otic veins (Fig. 4, *b–c*); and (2) the sigmoid sinus formed from the supra-otic anastomosis (Fig. 4, *c–d*) and the posterior rhombencephalic veins from the entry of the supra-otic anastomosis to their union with the internal jugular vein (Fig. 4, *d–e*).

The transverse sinus runs across the cavum epiptericum between the two layers of the tentorium cerebelli and, when the cavum epiptericum becomes reduced in size, will come to lie in the attached margin of the tentorium. During subsequent development the transverse sinus and the tentorium will rotate backwards through 180 degrees as a result of the continued caudal expansion of the cerebral hemispheres and the accentuation of the cerebral flexures.

The vena capitis medialis is greatly reduced in size, receiving the ophthalmic veins and the superior petrosal sinus, anteriorly, and the pituitary vein, medially. It continues behind the Vth ganglion as the post-trigeminal vein to join the greatly reduced vena capitis lateralis. Here the remnant of the primary head vein is joined by the somewhat more plexiform pro-otic veins which are still closer to the Vth ganglion than the otic capsule. A small pro-otic emissary vein joins the junction of the post-trigeminal vein and the vena capitis lateralis opposite the entry of the main pro-otic channels.

(*b*) 22·0 *mm. embryo*. The general pattern of veins is as in the previous embryo, but the middle part of the reduced vena capitis lateralis has disappeared in the region of the stapes, only its cranial and caudal ends remaining.

(*c*) 23·0 *mm. embryo* (Fig. 5). Vena capitis lateralis has completely disappeared and important changes have occurred in the pro-otic veins.

The transverse sinus now has a more vertical course and, when it reaches the antero-superior aspect of the otic capsule, it divides into two equal channels:

(1) The pro-otic vein or petro-squamous sinus running antero-ventrally in the angle between the parietal plate of cartilage and the otic capsule to enter the diminished interval between the last-named structure and the Vth ganglion. Here it lies in contact with the caudal margin of the ganglion, around which it bends medially

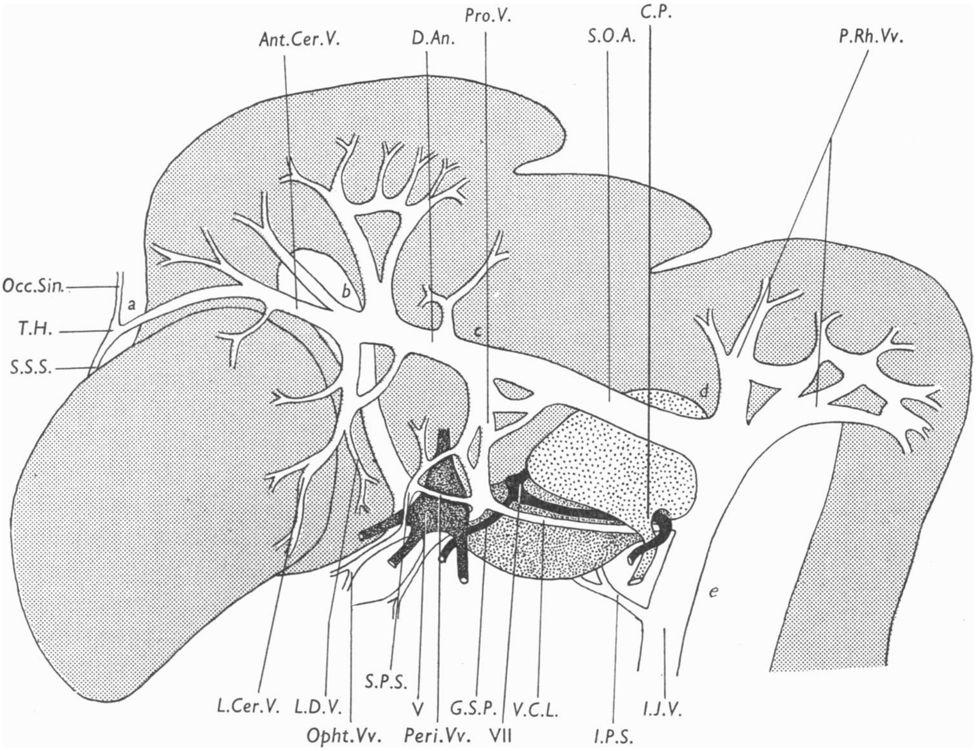

Fig. 4. Left lateral reconstruction of the head veins of a 20·0 mm. c.r. length embryo. *a–b–c* is the transverse sinus, *c–d–e* is the sigmoid sinus.

as the post-trigeminal vein terminating in the vena capitis medialis. As it bends around the Vth ganglion it receives two tiny pro-otic emissary veins. The greater superficial petrosal nerve runs forward below the termination of the petro-squamous sinus in the post-trigeminal vein. It is probable that the definitive petro-squamous sinus has formed from the more caudal of the earlier, multiple pro-otic veins and is thus an example of spontaneous migration of a venous channel (Streeter, 1915, 1918). It gives off a small anteriorly directed branch which crosses the superior surface of the Vth ganglion to join the anterior extremity of the vena capitis medialis; the superior petrosal sinus.

(2) The sigmoid sinus which follows the superior and posterior surfaces of the otic capsule, lateral to the ductus endolymphaticus, first in the parieto-capsular

angle and then in the occipito-capsular angle. It leaves the medial and inferior end of the occipito-capsular fissure which has now been cut off from the superior part of the fissure by the jugular process of the ex-occipital to form the jugular foramen. The superior part of the occipito-capsular fissure is reduced to two foramina, lying at the superior aspect of the otic capsule, and transmitting large mastoid emissary veins. Outside the jugular foramen the inferior petrosal sinus joins the internal jugular vein.

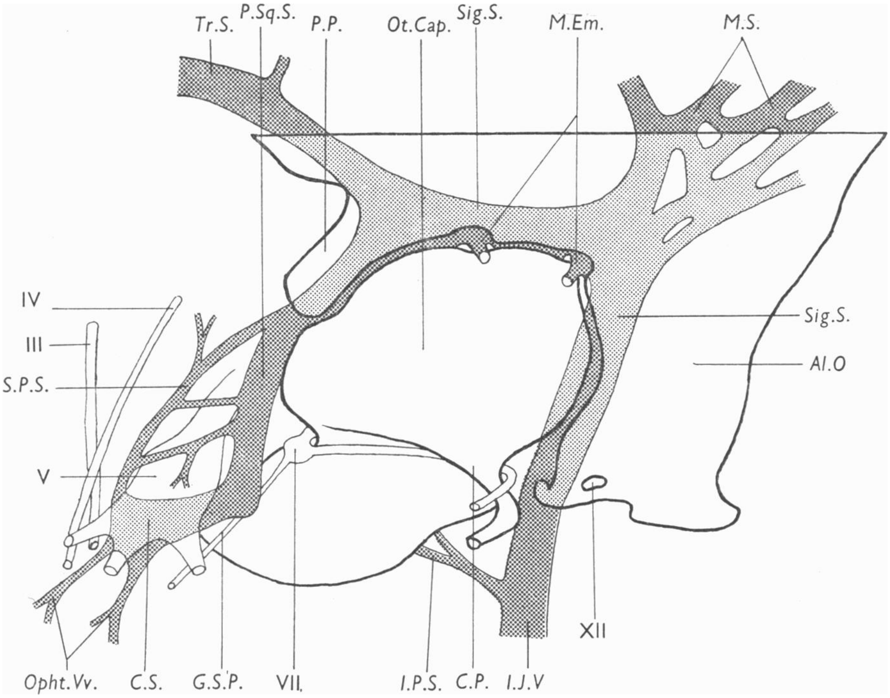

Fig. 5. Left lateral reconstruction of the otic region of the chondrocranium and associated dural venous sinuses and cranial nerves. 23·0 mm. C.R. length embryo.

This embryo is unusual in so far as the terminal part of the anterior cerebral vein is still present, albeit reduced in size. It is recognized because, as it enters the anterior end of the vena capitis medialis, it passes between nerves III and IV. It follows the caudal margin of the cartilaginous ala orbitalis of the sphenoid and, were it to have persisted into adult life, would have become the inconstant sinus alae parvae.

The diminished vena capitis medialis lies in the depths of the reduced cavum epiptericum between the Vth ganglion and the pituitary. The internal carotid artery and the VIth nerve run forwards below it and the nerves III and IV are anterior. These relationships establish, without any doubt, that it is the forerunner of the cavernous sinus although it appears as a wide, blood-filled space with no evidence of trabeculation and has not yet expanded so as to include the surrounding structures in its wall. The middle meningeal artery ascends in the lateral part of the cavum epiptericum lying upon the lateral surface of the petro-squamous sinus. Its anterior and posterior branches are accompanied by venae comitantes which enter the petro-squamous sinus.

B. *The foetal period*, 9–25 *weeks*

Stage 5. 30·0–47 *mm. crown-rump length* (Fig. 6)

The main feature of this stage is the petro-squamous sinus which is almost as large as the sigmoid sinus. It curls around the caudal margin of the Vth ganglion to enter the caudal end of the cavernous sinus. About half-way along its length it gives off a small, often plexiform, anteriorly directed branch which crosses over the Vth ganglion to enter the cranial end of the cavernous sinus; the superior petrosal sinus.

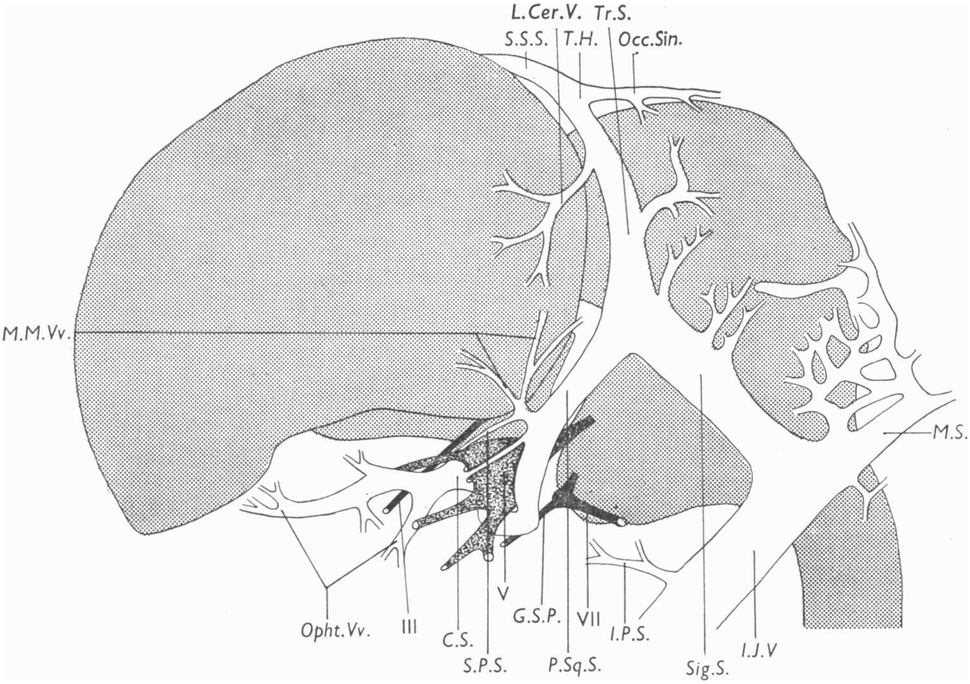

Fig. 6. Left lateral reconstruction of the dural venous sinuses of a 45·0 mm. C.R. length foetus.

The venae comitantes of the anterior and posterior branches of the middle meningeal artery join the petro-squamous sinus at the origin of the superior petrosal sinus. As yet there are no venae comitantes with the stem of the middle meningeal artery. The pro-otic emissary veins have disappeared, although they may occasionally persist into adult life. The arrangement of the remaining dural venous sinuses shows little change.

Stage 6. 60·0–175·0 *mm. crown-rump length* (Fig. 7)

In the older foetuses of this stage the tentorium cerebelli and contained transverse sinus have become rotated almost into their adult position. In addition, there has been considerable expansion of the temporal lobe of the cerebrum and a corresponding excavation of the middle cranial fossa. In the 99·0 mm. foetus (Fig. 7) the petro-squamous sinus is beginning to disappear and, in order of size, the three divisions of the transverse sinus are:

(1) The sigmoid sinus, by far the largest, running in the sigmoid groove to the jugular foramen. It gives off two large mastoid emissary veins passing out of the skull through a pair of superior occipito-capsular foramina. These are now situated posterior to the otic capsule which has been tilted backwards as a result of the excavation of the middle cranial fossa (cf. Figs. 5 and 7).

(2) The petro-squamous sinus is now considerably reduced, particularly at its commencement. It runs along the antero-lateral face of the otic capsule, in the parieto-capsular angle, then across the medial part of the middle cranial fossa to end

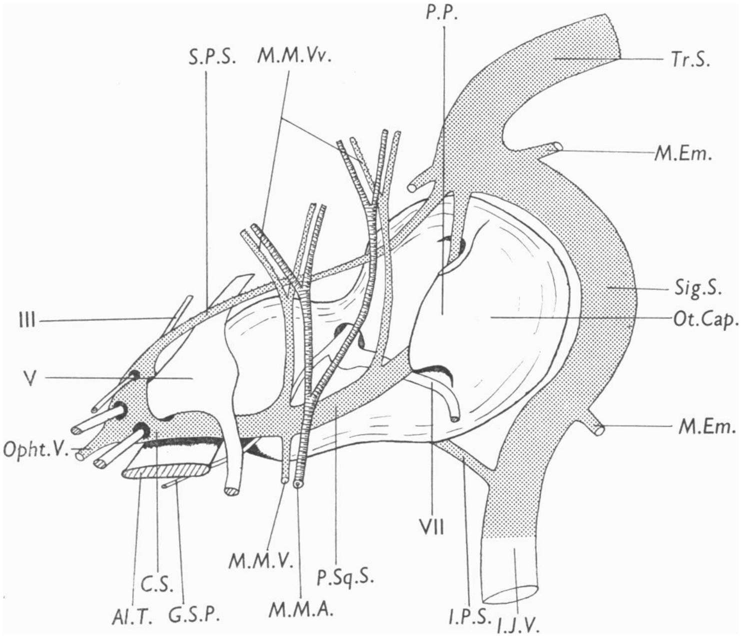

Fig. 7. Left lateral reconstruction of the otic capsule and associated dural venous sinuses and cranial nerves. 99·0 mm. c.r. length foetus.

in the cavernous sinus deep to the Vth ganglion. The venae comitantes accompanying the anterior and posterior branches of the middle meningeal artery now join the petro-squamous sinus separately and some distance apart. The main reduction in the petro-squamous sinus occurs prior to the entry of the posterior group of middle meningeal veins. Via the terminal part of the petro-squamous sinus the middle meningeal veins drain into the cavernous sinus but a new drainage route is now apparent. Around the stem of the middle meningeal artery there are venae comitantes connecting the petro-squamous sinus to the pterygoid venous plexus. They leave the skull, with the artery, in the fissure between the ala temporalis and the otic capsule. Thus is laid down the dual termination of the adult middle meningeal veins. In the older foetuses a large anastomotic channel connects the anterior and posterior middle meningeal veins. It was seen first in a foetus of 85·0 mm. c.r. length and lies parallel to, but considerably lateral of, the petro-squamous sinus from which it is separated by the cranial surface of the tegmen tympani (Fig. 8).

(3) The superior petrosal sinus is now only slightly smaller than the commencement of the petro-squamous sinus and runs along the upper margin of the otic capsule and then above the Vth ganglion in the roof of the cavum Meckelii. As it joins the cavernous sinus it lies between the Vth ganglion below, and the IIIrd and IVth nerves above.

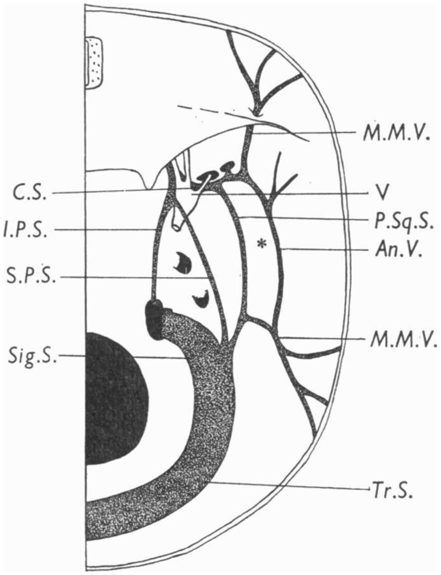

Fig. 8. Middle meningeal veins and certain dural venous sinuses of an 85·0 mm. C.R. length foetus. * = cranial surface of the tegmen tympani.

The wall of the cavernous sinus is now invaginated by the surrounding structures: internal carotid artery, V*a*, V*b*, and the IIIrd, IVth and VIth nerves. There are no trabeculae and in no way does the sinus resemble cavernous tissue. Each sinus lies, with the surrounding artery and nerves, in the depths of the greatly reduced cavum epiptericum.

C. *Adult period*

(1) *The middle meningeal veins and petro-squamous sinus*

The vascular grooves in thirty adult skulls revealed patterns in accord with the arrangement of the foetal middle meningeal veins. Fig. 9A shows a skull with a well-marked groove for the petro-squamous sinus receiving widely separated grooves for the anterior and posterior middle meningeal veins and is to be compared with the arrangement seen in a 99·0 mm. C.R. length foetus (Fig. 7). The petro-squamous sinus now terminates in the anterior middle meningeal vein and so joins the pterygoid venous plexus via the foramen spinosum. Not infrequently, however, its primitive connexion with the cavernous sinus may persist as a channel draining the anterior middle meningeal vein into the cavernous sinus. Fig. 9B is essentially the same but with the addition of a groove for the anastomotic vein between the anterior and posterior middle meningeal veins, such as was seen in an 85·0 mm. C.R. length foetus (Fig. 8). One example of each of the above types was found. Fig. 9C shows a pattern in which the terminal part of the posterior middle meningeal vein has disappeared but a small petro-squamous sinus persists. Two such examples were found and in one of them a small post-glenoid foramen opened internally into the terminal groove, common to the middle meningeal veins and the petro-squamous sinus. The remaining twenty-six skulls showed the pattern usually depicted (Fig. 9D), and in two of them a small post-glenoid foramen opened into the groove for the common stem of the middle meningeal veins.

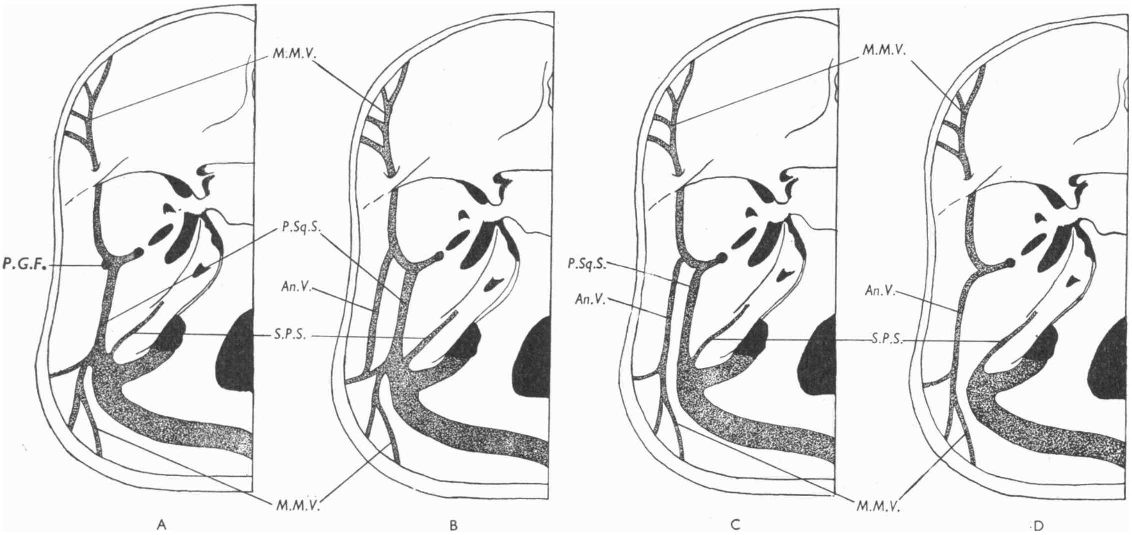

Fig. 9. Patterns of vascular grooves found in adult human skulls.

(2) *The cavernous sinus*

Dissection of sixteen cavernous sinuses, from individuals aged between 8 and 80 years, revealed very few trabeculae. These were situated mostly around the periphery of the sinus, close to the entry of tributaries. Small Pacchionian bodies projected into the cavity of the sinus.

DISCUSSION

In general, it may be said that the morphological interpretation of the developing human dural venous sinuses described above is in accord with that given by Markowski (1911, 1922) and not that of Streeter (1915, 1918). The functional interpretation put forward by Streeter, i.e. the manner whereby the developing head veins adjust themselves to growth changes of the brain and cranium was amply confirmed.

(1) *Vena capitis lateralis*

The human vena capitis lateralis is identical in position and relationships with that found in other mammalian embryos (guinea-pig, Salzer, 1895; monotremes, Hochstetter, 1896; bats, Grosser, 1901; and rat, Butler, 1953). It is extra-dural and therefore morphologically extra-cranial in the sense defined by Sutton (1888). It does, however, emerge from the chondrocranium at the posterior end of the spheno-parietal fontanelle before running caudalwards, with the VIIth nerve, beneath the crista parotica. The otic region of the chondrocranium becomes covered by the squamous temporal and the tympanic ring except the extreme anterior tip of the crista parotica, which obtrudes into the Glaserian fissure, and the pars mastoidea of the petrous temporal. Therefore, should this vein persist into adult life it would become embedded in the adult cranial wall, running in the facial nerve canal and emerging via the primitive stylo-mastoid foramen to lie upon the outer surface of the pars mastoidea. It would then join the terminal part of the sigmoid sinus as it emerges from the jugular foramen to form the commencement of the internal jugular vein. Such an arrangement is found in adult monotremes (Hochstetter, 1896) where vena capitis lateralis does persist into adult life, but these animals have no post-glenoid vein.

It was shown in the rat (Butler, 1953) that the post-glenoid vein is developed from small pro-otic emissary veins which connect vena capitis lateralis, at the point where it enters the facial canal, to temporal tributaries of the external jugular vein. These small veins run lateralwards across the anterior surface of the proximal end of Meckel's cartilage. They enter the vena capitis lateralis directly opposite the termination of the petro-squamous sinus, and it is only this small junctional region of vena capitis lateralis which enters into the formation of the post-glenoid vein.

The oft-repeated statement that the vena capitis lateralis leaves the skull between nerves V and VII (Mall, 1905; Hochstetter, 1906; Evans, 1912) is only true if by skull is meant chondrocranium. The post-trigeminal part of the primary head vein, linking the vena capitis medialis to the vena capitis lateralis, does run lateralwards between these two nerves to leave the posterior end of the spheno-parietal fontanelle as the commencement of the vena capitis lateralis. The vena capitis lateralis cannot leave by the post-glenoid foramen formed between the squamous temporal and the tympanic ring because it has disappeared before these bones are laid down. It is the pro-otic emissary veins, running lateralwards from vena capitis lateralis, which come to lie between these bones.

(2) *Petro-squamous sinus*

The main channel which develops in the pro-otic group of veins lies, at first, along the caudal border of the Vth ganglion some distance anterior to the otic capsule. It gradually moves caudally, probably by spontaneous migration, so as to lie on the anterior surface of the otic capsule in the parieto-capsular angle (Fig. 10 A). It never lies upon the superior margin of the otic capsule and is close to the inner surface of Dürer's membrane and is in contact with the middle meningeal artery, laterally. At its termination in the junction of vena capitis lateralis and the post-trigeminal vein it lies between the Vth and VIIth ganglia. The pro-otic emissary veins join the lateral aspect of this junctional region and the greater superficial petrosal nerve runs forwards below it. Dorsally, the main pro-otic channel joins the junction of the transverse and sigmoid sinuses. In view of these relationships this channel must be the petro-squamous sinus. Despite the fact that Streeter only indicates the membranous labyrinth and the Vth ganglion in his reconstructions, the channel that he calls superior petrosal sinus can be none other than the pro-otic vein of Markowski (1911, 1922) which, as has been explained, is the petro-squamous sinus.

During early foetal life (30·0–47·0 mm. C.R. length) the petro-squamous sinus is almost as large as the sigmoid sinus and it receives the middle meningeal veins (Fig. 6). In foetuses of 60·0 mm. C.R. length and more, it usually declines in size but frequently persists into post-natal life. It receives scant attention in most modern text-books of anatomy, being generally regarded as an occasional variant. Bell (1829) reckoned it a normal feature of adult anatomy, calling it the anterior petrosal sinus. Knott (1882) found a petro-squamous sinus in twenty-six out of forty-four adult cadavers (seven bilateral, nineteen unilateral). Cheatle (1889) stated: '... it

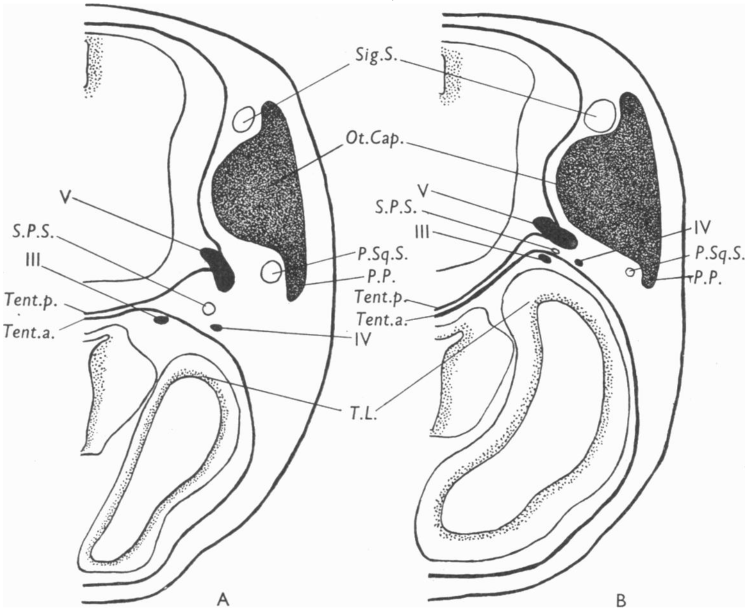

Fig. 10. Diagrams to illustrate the reduction of the cavum epiptericum by the expansion of the temporal lobe of the cerebrum. Constructed from sections: A, 23·0 mm. C.R. length embryo; B, 60·0 mm. C.R. length foetus.

is the rule rather than the exception for remains of the sinus to be present in some form or other all through life. It is usually well marked in infancy and childhood and anteriorly joins the middle meningeal veins.' Only four of the thirty skulls examined showed a petro-squamous groove, but a sinus may be present without a groove in the bone. The large size of the petro-squamous sinus in early foetal life is in accord with its prevalence in adults and it should be regarded as a usually occurring sinus and not an occasional variant.

(3) *Post-glenoid vein*

A rudimentary post-glenoid foramen occurs in slightly under 1·0% of adult human skulls (Cheatle, 1889; Boyd, 1930), and this is in accord with the small size and transitory appearance of the pro-otic emissary veins of the human foetus.

(4) *Superior petrosal sinus*

In adult man this sinus leaves the postero-superior aspect of the cavernous sinus and runs caudally below the nerves III and IV and bridges over the superior aspect of the Vth ganglion in the roof of the cavum Meckelii. The main pro-otic channel, which Streeter called the superior petrosal sinus, does not have these nervous relationships, but they are fulfilled by the smaller and most anterior group of pro-otic veins. These run forwards across the lateral face of the Vth ganglion and join either the peri-trigeminal vein or the vena capitis medialis (the cavernous sinus). At their termination they lie between the nerves III and IV anteriorly, and the Vth ganglion posteriorly.

When first developed the anterior layer of the tentorial fold is reflected on to the inner surface of the orbital cartilage, well anterior to the otic capsule, and the cavum epiptericum is wide in an antero-posterior direction. The IIIrd and IVth nerves and the superior petrosal sinus are close to the anterior dural fold and well in front of the otic capsule, from which they are separated by the Vth ganglion (Fig. 10A). The posterior tentorial fold runs along the superior border of the otic capsule and then sweeps on to the posterior surface of the otic capsule. As the temporal lobe of the cerebral hemisphere expands and excavates the middle cranial fossa it presses the anterior tentorial layer backwards, together with the IIIrd and IVth nerves, the Vth ganglion and the superior petrosal sinus, towards the otic capsule. The cavum epiptericum is thereby reduced in size and the line of attachment of the anterior tentorial fold comes to lie alongside that of the posterior layer, along the superior border of the otic capsule (Fig. 10B). Thus the nerves and the sinus attain their adult positions and the superior petrosal sinus runs above the Vth ganglion and below the nerves III and IV (Figs. 7, 10B). The expanded cavernous sinus now protrudes anteriorly and superiorly of the Vth ganglion and here receives the superior petrosal sinus.

(5) *Cavernous sinus*

This is developed from the vena capitis medialis and, in late foetal life, it expands to envelop the internal carotid artery and nerves V*a*, V*b*, III, IV and VI. No trabeculae were present in the embryonic or foetal material and very few appeared in adult specimens. There was no evidence that the sinus was formed by the coalescence of a capillary plexus such as gives rise to the superior sagittal sinus and its contained chordae Willisii. Such trabeculae as were found occurred at the periphery of the sinus, close to the entry of tributaries, and it is suggested that they may have been formed by the taking up of plexiform tributaries during the expansion of the cavernous sinus. (No trabeculae were found in the cavernous sinus of adult rats, and Eyster (1944) reported a similar absence of trabeculae in the cavernous sinus of the macaque monkey.)

Sections through a distended adult cavernous sinus showed no hint of cavernous tissue but, when the sinus is collapsed, as is usual in dissecting room cadavers, its cavity is encroached upon by the nerves and Pacchionian bodies in its wall. This readily gives a spurious resemblance to cavernous tissue.

(6) *Middle meningeal veins*

The variations in these veins need little comment and are intimately related to the petro-squamous sinus. The mode of middle meningeal vein development offers a ready explanation for their dual termination in the cavernous sinus and the pterygoid venous plexus.

SUMMARY

1. The development of certain human dural venous sinuses has been investigated in a series of twenty embryos and foetuses ranging from 7·5 to 175·0 mm. C.R. length.

2. The pro-otic veins form the large petro-squamous sinus and the much smaller superior petrosal sinus. In foetuses of 40·0–45·0 mm. C.R. length the former sinus is as large as the sigmoid sinus. Thereafter it declines in size but frequently persists into post-natal life. It receives the middle meningeal veins.

3. Minute pro-otic emissary veins, forerunners of the post-glenoid vein, are found in embryos up to 23·0 mm. C.R. length. Thereafter they usually disappear, though a post-glenoid foramen is found in a little under 1·0 % of adult human skulls.

4. The cavernous sinus is the expanded remnant of the vena capitis medialis. Very few trabeculae occur in the adult sinus, which bears no resemblance to cavernous tissue.

My thanks are due to Prof. J. D. Boyd, Anatomy School, Cambridge, for the generous way in which he placed his unique collection of sectioned human embryos and foetuses at my disposal and to Dr A. M. Barrett, Pathologist to the University of Cambridge, for specimens of adult cavernous sinuses.

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ABBREVIATIONS

Ant.Cer.V.	anterior cerebral vein
A.C.V.	anterior cardinal vein
Al.O.	ala occipitalis
Al.T.	ala temporalis
An.V.	new channel between anterior and posterior middle meningeal veins
C.P.	crista parotica
C.S.	cavernous sinus
D.An.	dorsal anastomosis
D.E.	ductus endolymphaticus
G.S.P.	greater superficial petrosal nerve
I.J.V.	internal jugular vein
I.P.S.	inferior petrosal sinus
L.Cer.V.	lateral cerebral vein
L.D.V.	lateral diencephalic vein
M.Em.	mastoid emissary vein(s)
M.M.A.	middle meningeal artery
M.M.V.(Vv.)	middle meningeal vein(s)
M.S.	marginal sinus
M.V.	maxillary vein
Mes.Vv.	mesencephalic veins
Ot.V.	otic vesicle
Ot.Cap.	otic capsule
Occ.Sin	occipital sinus
Opht.V.(Vv.)	ophthalmic vein(s)
Pro.V.(Vv.)	pro-otic vein(s)
Pro.O.Em.	pro-otic emissary veins
Post V.	post-trigeminal vein
Peri V.	peri-trigeminal vein
P.P.	parietal plate of cartilage
P.Sq.S.	petro-squamous sinus
P.G.F.	post-glenoid foramen
P.Rh.V.(Vv.)	posterior rhombencephalic vein(s)
S.S.S.	superior sagittal sinus
Sig.S.	sigmoid sinus
S.P.S.	superior petrosal sinus
S.O.A.	supra-otic anastomosis
T.H.	torcular Herophili
Tent.a.	anterior layer of the tentorium cerebelli
Tent.p.	posterior layer of the tentorium cerebelli
Tr.S.	transverse sinus
T.L.	temporal lobe of cerebrum
V.C.M.	vena capitis medialis
V.C.L.	vena capitis lateralis
III	third nerve
IV	fourth nerve
V	trigeminal ganglion
VI	sixth nerve
VII	seventh nerve
IX	ninth nerve
X	tenth nerve
XII	hypoglossal foramen