

THE ANASTOMOSES BETWEEN INTERNAL AND EXTERNAL CAROTID CIRCULATIONS IN THE DOG

By P. A. JEWELL*

Department of Pharmacology, University of Cambridge

The present observations were undertaken as part of an investigation to localize the site of osmoreceptors in the dog. Verney (1947) has shown that such sensory elements exist somewhere within the field of distribution of the internal carotid artery. This conclusion is based upon experiments in which the output of anti-diuretic hormone was measured following the infusion of solutions, hypertonic to the blood, into carotid loops in dogs. It was found that such responses were temporarily abolished by ligation of the internal carotid artery near its origin.

It seemed desirable to know by what arterial pathways blood of common carotid origin might reach the brain, and, in particular, after ligation of the internal carotid artery near the carotid bifurcation, what alternative anastomotic channels might still carry carotid blood to the circle of Willis. Accordingly, a number of dissections of injected heads have been made in order to demonstrate the carotid vascular pattern.

The picture of the carotid circulation in the dog, that has evolved from these studies, is one that finds no adequate description in the literature. The standard anatomies of the dog (Ellenberger & Baum, 1891; Bradley, 1948; Sisson & Grossman, 1940; Miller, 1948) mention only the more striking features, and even the excellent text of Ellenberger & Baum is rendered inadequate by the fact that these authors followed too closely a supposed homology with human vessels, and thus left unemphasized some of the more important features of the dog's system. None of these works gives any indication of the functional significance of the numerous anastomoses which exist between intracranial and extracranial vessels, and there is a singular lack of illustration of their morphology.

The classical work of Julius Tandler (1899) gives a valuable description of the carotid circulation in the dog, although it is, unfortunately, an incomplete one. In particular, the nomenclature which he proposes, based on comparative studies of the head arteries in a number of mammalian species, is both accurate and acceptable where that of Ellenberger & Baum is not. Recently Davis & Story (1943) have published an authoritative account of the carotid circulation in the cat, and have directed attention to the large and functionally important anastomoses between intracranial and extracranial vessels which have been developed in this species to compensate for the absence of a patent internal carotid artery. Their work has provided a stimulating comparison for the present observations on the dog, and the close parallel that has been found between the patterns of the vessels in the two species emphasizes the necessity to reconsider the role of these anastomoses in the dog.

* Now at the Department of Physiology, Royal Veterinary College, University of London.

MATERIAL AND METHODS

The description is based upon the dissection of heads of eighteen specimens. Many of the features described, particularly the form of the anastomotic artery, have been confirmed in a further series of animals which were principally used for histological purposes. Two injection masses were used: gelatin coloured with carmine or prussian blue, and an indian ink-plasma mass made by adding 10% indian ink to human plasma reconstituted to three times normal strength. The method employed to inject the masses was that described by Verney (1947).

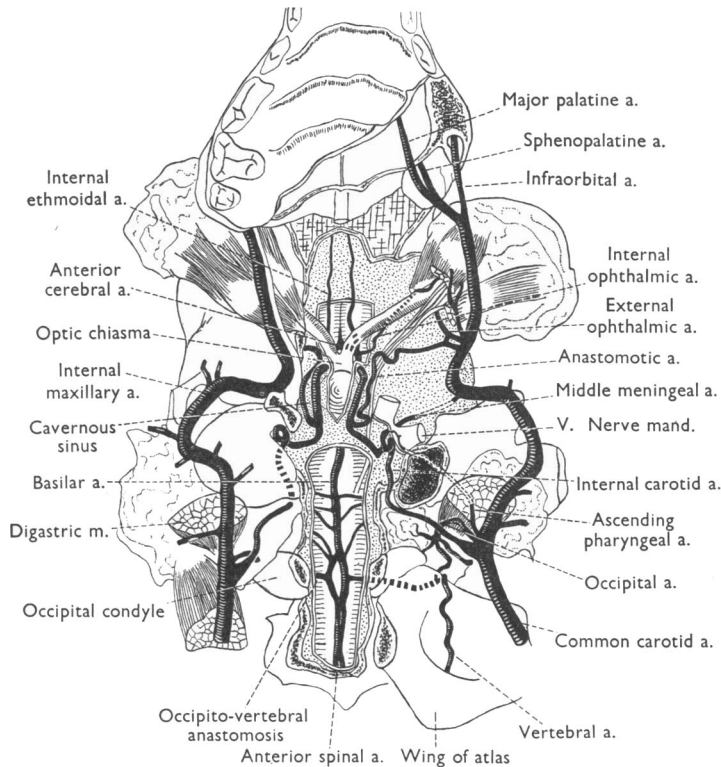


Fig. 1. Dissection of the dog's head to demonstrate the relationship between the arteries of supply to the brain. Ventral aspect; lower jaw and base of cranium removed. The external carotid artery is displaced laterally on the left side.

RESULTS

Five separate anastomoses linking extracranial and intracranial arteries have to be considered, although their relative importance as channels which may transport blood between the two systems is greatly different. The vessels concerned are depicted in Fig. 1, in which is shown their general relation to cranial and orbital structures, and to the vertebral arterial supply.

The anastomosis between occipital and vertebral arteries. The common carotid artery ascends to the level of the atlanto-occipital joint where it divides into internal and external carotid arteries. Immediately after its origin the external

carotid artery gives rise to the occipital and ascending pharyngeal arteries. The origin of the occipital artery is very close to that of the internal carotid, being slightly lateral and ventral to the latter. For the first centimetre of their course the two vessels run nearly parallel, the occipital artery coming to occupy a position lateral to that of the internal carotid. As the artery approaches the occipital condyle it gives rise to an important branch which curls over the cranial border of the wing of the atlas to gain its dorsal surface, and there anastomoses with a parallel and terminal branch of the vertebral artery (Fig. 2). The vessel formed from the fusion of these two passes through the oblique foramen of the atlas, pierces the

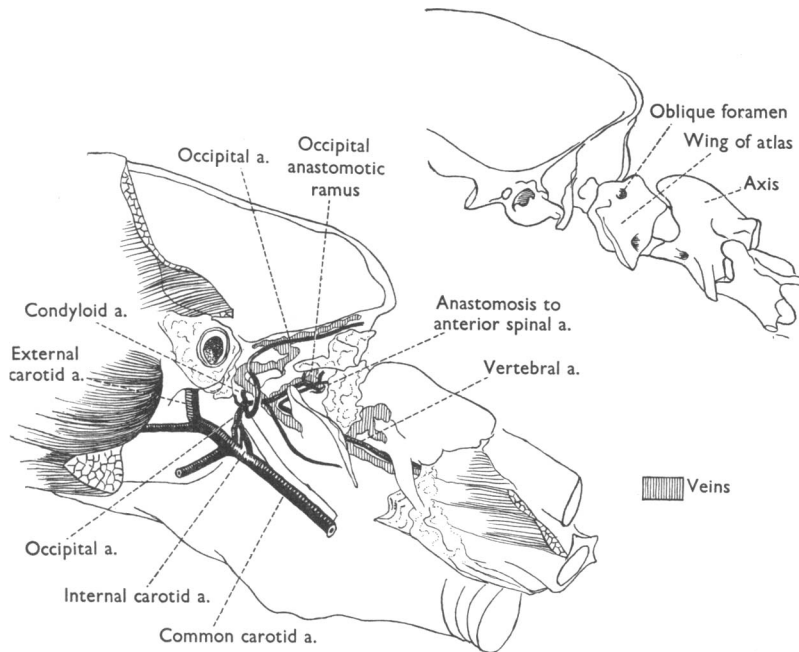


Fig. 2. Dissection of the occipital region of the dog's head to demonstrate the anastomosis between occipital and vertebral arteries. Left side, lateral aspect.

meninges, and runs across the ventral surface of the spinal cord to anastomose with the ventral spinal artery. The product of this union runs forward as the basilar artery to form the posterior limbs of the circle of Willis. The anastomosis was present in all specimens, and was of considerable size in some. It is not possible to say whether it normally carries a contribution of carotid blood to join the basilar flow, but it is certain that it will do so if additional demands are placed upon the basilar supply to the circle of Willis by operative interference with the internal carotid artery.

Neither Davis & Story (1943), nor Legait & Racadot (1949) make any mention of this anastomosis in the cat, and although it is present in other carnivores, existing comparative studies are inadequate to give any further clue to its functional significance.

The anastomosis between ascending pharyngeal and internal carotid arteries. Davis & Story (1943) drew attention to the unusual form assumed by the ascending

pharyngeal artery in the cat. In this animal there is a rather remarkable development whereby the ascending pharyngeal artery performs the function of a supply route to the brain which the vestigial internal carotid artery has relinquished. The foramen lacerum medium is quite perforate and the ascending pharyngeal artery passes through it, from the roof of the pharynx, to reach the middle cranial fossa, where it contributes to the formation of the circle of Willis. These authors have shown, however, that the intracranial part of this vessel represents the distal end of the internal carotid artery which has assumed direct continuity with the ascending pharyngeal by the enlargement of an anastomosis through the foramen. I have confirmed their observation of the existence of this anastomosis in the dog, where a small terminal twig of the ascending pharyngeal artery pierces the thin fibrous covering of the foramen lacerum medium and joins the internal carotid artery. The internal carotid artery makes a tortuous loop within the depth of the temporal bone at this point, and the ascending pharyngeal anastomosis joins it at the apex of this loop (Figs. 1, 3 and 5*f*). It is safe to conclude that in the dog this anastomosis is of little or no functional significance. Indeed, according to Davis & Story, it is only in the domestic cat, amongst the carnivores, that it has any

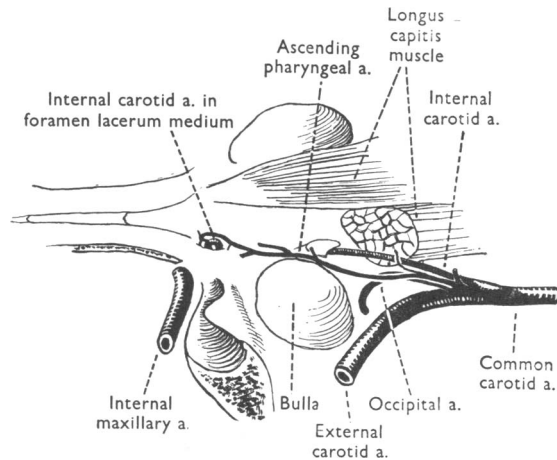


Fig. 3. The anastomosis between the ascending pharyngeal artery and the internal carotid artery through the foramen lacerum medium. Left side, ventro-lateral aspect.

important role. In the bears and in the giant panda it is entirely absent. It is valuable to know of its existence, however, for it is one route by which the proximal segment of the internal carotid artery might be by-passed. No doubt it was this vessel that Bouckaert & Heymans (1935) were tying when they ligated the internal carotid and occipital arteries 'and the tissues between the origin of the internal and external carotids' in order to prevent blood reaching the brain from the region of the carotid bifurcation. When the proximal segment of the internal carotid alone is ligated in a survival experiment it is possible that this anastomosis would subsequently increase in size.

The internal carotid artery itself, although considerably smaller than the external carotid, is a vessel of fair calibre in the dog. It runs forward from its origin at the carotid sinus to enter the carotid canal of the temporal bone. Upon emerging from

the canal the artery enters the cavernous sinus and traverses its whole length before bending dorsally to pierce the meninges and form the circle of Willis. In the whole of this long and tortuous course the internal carotid artery gives no branches, except sometimes a small branch to the posterior lobe of the pituitary gland and nutrient twigs to the meninges. On the other hand, it receives two anastomoses—that from the ascending pharyngeal artery already described, and a large anastomosis originating from the internal maxillary artery.

Anastomoses between intracranial vessels and the internal maxillary artery. The branches of the external carotid artery to the lower jaw, the ear, and superficial temporal structures do not concern us here; but the continuation of the external carotid artery, distal to the superficial temporal artery, as the internal maxillary artery, is of singular importance for from it arise a series of anastomoses by which the extracranial and intracranial vessels are united.

The internal maxillary artery, coursing medially from behind the post-glenoid process to circumscribe the mandibular condyle, comes to occupy a position closely applied to the wall of the cranium. For a short part of its course it runs within the alisphenoid canal of the sphenoid bone and there gives rise to the middle meningeal artery, which runs into the cranial cavity in proximity to the emerging mandibular branch of the trigeminal nerve. The internal maxillary artery leaves the alisphenoid canal in association with the maxillary branch of the trigeminal nerve, and runs with it across the floor of the orbit. Almost immediately upon leaving the canal it gives rise to the orbital artery, which crosses the maxillary nerve dorsally and divides into the arteries of supply to orbital structures. It is concerning the names of these arteries, which form the orbital complex, that confusion has arisen in the literature, and it would seem best to discuss the nomenclature used here before proceeding further. The vessels are illustrated in Fig. 4.

The orbital artery was called by Ellenberger & Baum the 'ophthalmic' artery. As Tandler has shown, however, this artery is under no circumstances the homologue of the ophthalmic artery in man, which arises from the internal carotid artery; neither has it a true homologue in man. Further, it is found amongst the mammalia that the arterial supply to the orbit may come from many diverse sources—from the stapedia artery as in the marmots, from the occipital artery as in the armadillos, or from the internal maxillary artery as in the dog. The name ophthalmic is, therefore, best not used for these other arteries of supply to the orbit, but may be retained to designate that branch of the parent vessel which gives rise to the central artery of the retina. Tandler names the vessel arising from the internal maxillary artery to supply the orbit in the dog the *orbital artery*. This name is adopted here.

A short distance from its origin the orbital artery gives rise to a primary branch which turns immediately into the orbital fissure through which it runs to join the internal carotid artery in the cavernous sinus. This vessel is named by Ellenberger & Baum, after Bellarminov, the 'internal ophthalmic' artery. This is a complete misnomer, for not only does it suggest non-existent homologies, but it is quite misleading as to the function of the artery. Tandler names this vessel the *anastomotic artery*. It is contributory to, and not a branch of, the internal carotid artery.

The true homologue of the human ophthalmic artery was missed by Ellenberger & Baum. It is a small vessel that arises from the anterior cerebral artery and runs

in company with the optic nerve through the optic foramen into the orbit. This vessel only was named by Tandler the ophthalmic artery. It anastomoses near the bulb with a larger vessel that arises extracranially as a branch of the orbital artery. The anastomosis gives rise to the central artery of the retina. This branch of the orbital artery was given no specific name by Tandler, whilst Ellenberger & Baum appeared to regard it as a branch of the 'internal ophthalmic' artery. The vessel is best regarded as an extracranial parallel of the true ophthalmic artery, since from their union there arises the central artery of the retina. In conformity with recent authors (Sisson & Grossman, 1940; Miller, 1948) the names *internal ophthalmic artery* (for the vessel arising from the anterior cerebral) and *external ophthalmic artery* (for the vessel arising from the orbital artery) will be adopted here.

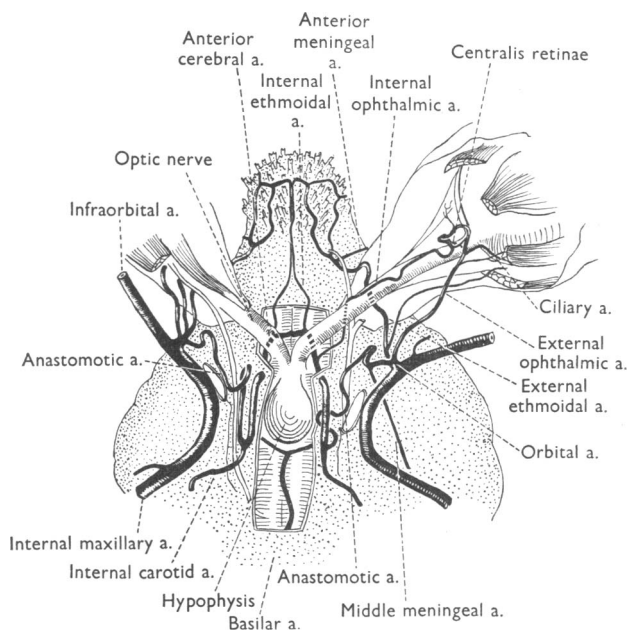


Fig. 4. Dissection of the brain and orbit, with entire cranium removed, to demonstrate the anastomoses between arteries of the orbital complex and intracranial vessels. Ventral aspect.

The third branch of the orbital artery which effects an anastomosis through the cranium is the ethmoidal artery. Ellenberger & Baum supposed this vessel to be homologous with the posterior ethmoidal artery of human anatomy, but Davis & Story (1943) have shown that in the dog the vessel supplies both the anterior and posterior groups of ethmoidal cells. Following the nomenclature of the latter authors it is here called the *external ethmoidal artery*, and the branch of the anterior cerebral artery with which it anastomoses the *internal ethmoidal artery*. Ellenberger & Baum had observed this vessel and named it the anterior ethmoidal artery; it appears, however, that this vessel is peculiar to the carnivores and has no homologue in man.

It may be noted that in the cat the orbital artery is not formed, but Davis & Story retain the name 'orbital complex' for the group of vessels which arises from

the external rete. It is sometimes unformed in the dog, too, when the arteries of the complex arise directly from the internal maxillary artery. Under these circumstances the anastomotic artery and the external ophthalmic artery frequently form a common trunk at their origin, and the external ethmoidal artery and muscle rami do likewise. These varying conditions are shown in Figs. 4-6.

The anastomotic artery. The anastomotic artery is the largest single anastomosis between intracranial and extracranial vessels. Only 1 or 2 mm. of its length are visible outside the cranium, and for the greater part of its course it runs within the cavernous sinus, or that extension of the cavernous sinus which protrudes through the orbital fissure to be joined by the orbital venous sinuses. In Figs. 1 and 4 the anastomotic artery is depicted as a simple vessel running between orbital and internal carotid arteries (a condition found in some specimens), but typically the anastomotic artery receives a second contributory vessel within the cavernous sinus. This is the middle meningeal anastomotic ramus. The dual origin of the anastomotic artery is shown in Fig. 5*a*, where the two vessels contributing to the anastomosis are of equal calibre, whilst that of their union is conspicuously larger. The condition most frequently found is that in which the middle meningeal ramus is smaller in calibre than the orbital ramus (Fig. 5*b*). During the careful dissection of fourteen heads this condition was noted on both sides in seven of them; moreover, in a cursory examination of the region in many other heads dissected for other purposes this condition appeared most frequently. The other seven heads all showed some different variation. Dog 366 (Fig. 5*c*) is a variant of one extreme. The middle meningeal anastomotic contribution was not found on either side, whilst the orbital anastomosis was a large vessel. Between this and the condition of equality found in dog D7 (Fig. 5*a*) are all gradations, as seen on the right side of dog 309 (Fig. 5*d*), for example, and the left side of dog 352 (Fig. 5*e*). The right side of dog 352, however, exhibits the other extreme, where the middle meningeal anastomosis dominates and the orbital anastomosis is but a vestige. Dog D5 (Fig. 5*f*) had this condition on both sides, in fact, the middle meningeal anastomosis on the left is a tortuous double vessel to each of which the orbital branch contributes a delicate anastomosis. The complex approaches a retiform structure, and on the left side of dog 309, too, the anastomotic artery was formed into an arterial rete (Fig. 5*d*). Two other observations seem worthy of note. In dog 341 the middle meningeal artery of the right side entered the cranium by a separate foramen spinosum, but despite this, the internal maxillary artery still gave rise to a small vessel in the alisphenoid canal, which, passing through the foramen ovale, ran to unite with the anastomotic artery. In dog 353 (Fig. 4) there was an anomalous condition on the left side, the middle meningeal artery itself arising from the anastomotic artery instead of contributing to it.

In the cat, as Davis & Story have shown, the anastomotic artery is the largest artery of supply to the circle of Willis, and the fact that it plays such an important role in supplying the cerebral structures in one family of the Carnivora, suggests that it may be of importance in other families in which it is present. The misnomer of 'ophthalmic' artery has, perhaps, tended to disguise its function. That the anastomotic artery does make a contribution to the cerebral circulation in the dog is substantiated by the simple morphological observation that the internal carotid

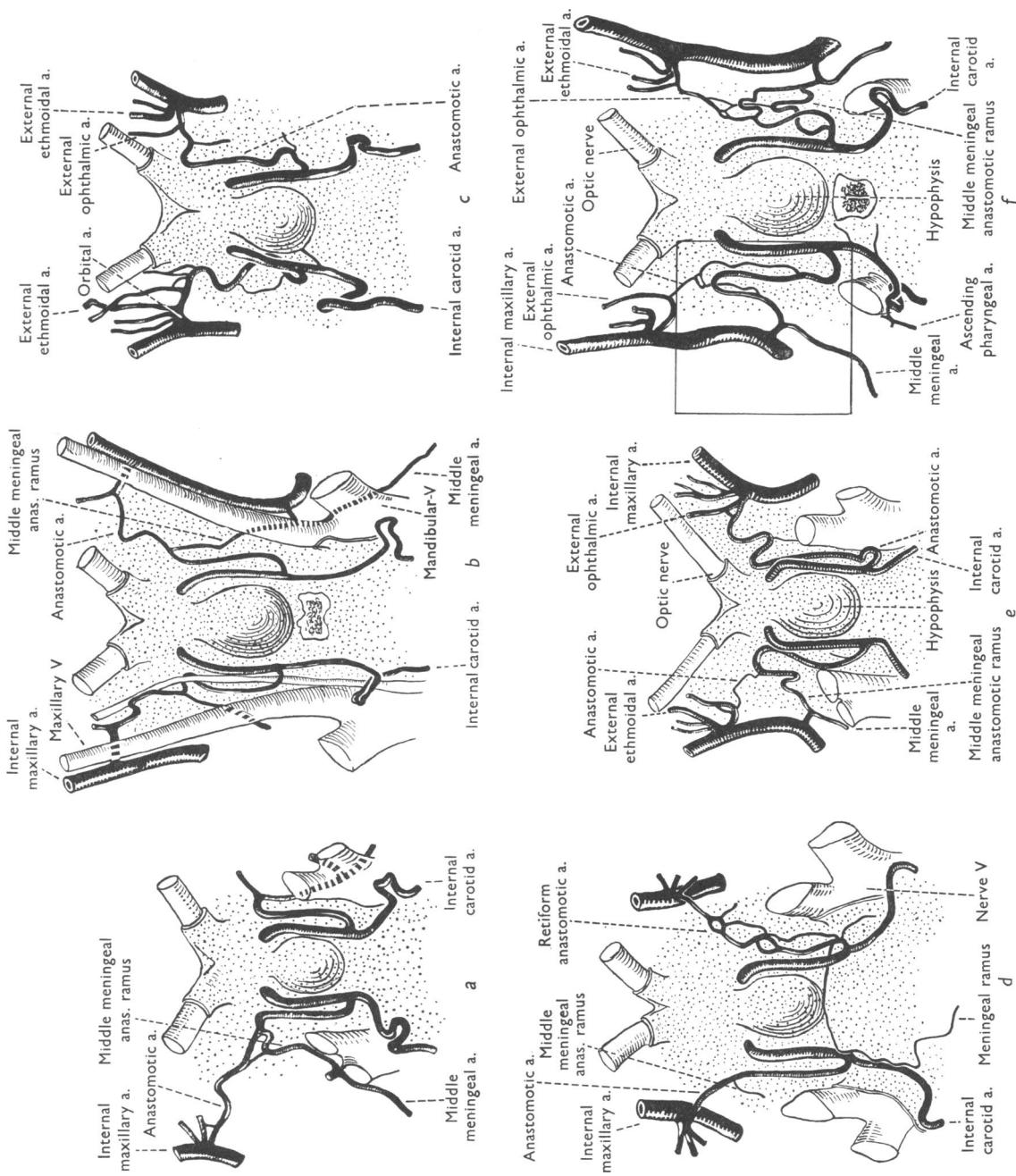


Fig. 5. Dissections of the anastomotic artery to illustrate its variations of form in six dogs. a, dog D7, contributory rami from orbital and middle meningeal arteries of equal calibre; b, dog 367, most frequently occurring form with dominant orbital contribution; c, dog 366; d, dog 369; e, dog 352; f, dog D5; varying degrees of dominance of the contributory vessels, and rete formation.

artery is larger after its junction with the anastomosis than before it. Further, the acute experiments of Bouckaert & Heymans (1935) suggest that the anastomosis normally contributes to the internal carotid flow. They showed that the flow in the anastomotic artery was sufficient, when all other sources of blood supply to the brain had been cut off, to maintain the nervous centres in a fully active state; and they showed, in a chloralosed dog, that when the anastomotic artery was clamped, the pressure in the cephalic end of the internal carotid artery fell considerably, suggesting that the anastomotic artery had been contributing blood to the internal carotid field.

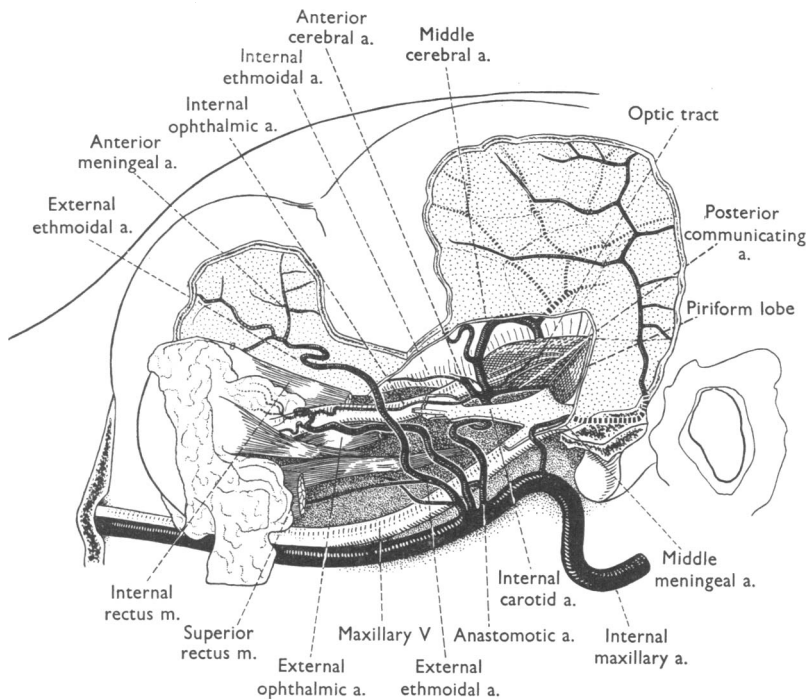


Fig. 6. Dissection of the orbit and base of the brain, lateral aspect, to demonstrate the ophthalmic anastomosis and the origin of the internal ophthalmic and internal ethmoidal arteries from the anterior cerebral artery beyond the division of the internal carotid.

The ophthalmic anastomosis. This anastomosis differs from those already described in that it is not one through which external carotid blood is likely to gain access to intracranial structures. Rather, it is a route by which the internal carotid may make a small contribution to the blood supply to the eye. The internal ophthalmic artery is a small vessel which arises from the anterior cerebral artery a short distance beyond the division of the internal carotid (Fig. 6). For the first third of its course it occupies a position lateral to the optic nerve and passes with it through the optic foramen into the orbit. Here it becomes closely applied to the nerve, which it crosses dorsally, to run along its antero-dorsal side. The external ophthalmic artery is one of the orbital complex of vessels and is usually associated with the anastomotic artery at its origin. It pierces the periorbita and passes between the retractor oculi muscles

to assume a position close to the optic nerve. It becomes closely applied to the optic nerve a few millimetres from the bulbous and there anastomoses with the smaller internal ophthalmic artery. During this course it gives rise to rami to the retractor muscles, and a ciliary artery may be given off before the anastomosis with the internal ophthalmic artery is effected.

The central artery of the retina is difficult to detect by dissection, but by making serial sections through the region of the optic nerve and optic disc it has been possible to confirm Tandler's statement that the artery arises from the anastomosis formed by the internal and external ophthalmic arteries.

The ethmoidal anastomosis. For the greater part of its length outside the skull the external ethmoidal artery runs within the periorbita, from which it emerges to pass immediately through the ethmoidal foramen of the frontal bone and gain the ethmoidal fossa of the cranial cavity. Here it divides into three branches, the anterior meningeal artery and a dorsal and ventral ramus (Fig. 4). These latter vessels anastomose again more anteriorly, and the rete is joined by a contribution from the internal ethmoidal artery. The internal ethmoidal artery arises from the anterior cerebral artery distal to the origin of the internal ophthalmic artery and runs antero-medially until it meets its fellow from the other side (Figs. 4 and 6). The two vessels run forward close together, within the dura at the base of the falx cerebri, until they reach the cribriform plate where they diverge to anastomose with the vessels of their respective sides.

The ethmoidal anastomosis, like the ophthalmic anastomosis, is not one which forms a contributory channel to the cerebral blood supply. The external ethmoidal artery may carry blood of external carotid origin to the olfactory bulbs, but it is extremely unlikely, unless the normal circulation had been extensively interfered with, that blood carried by the external ethmoidal artery could return via the internal vessel to reach the circle of Willis.

DISCUSSION

A consideration of the carotid distribution from the point of view of the anastomoses between extracranial and intracranial arteries has a systematic, as well as a functional, justification. Davis & Story (1943) have observed that within different families of the Order Carnivora the carotid circulation shows divergent forms of specialization such that either the internal or external carotid arteries may become the main source of supply to the brain. In the cat the internal carotid artery has become completely vestigial and carries no blood, the ascending pharyngeal and internal maxillary arteries acting as alternative contributors to the circle of Willis. The opposite extreme is represented in the bears in which there are no interconnections of importance between the intracranial and extracranial vessels. The dog occupies an intermediate position, but the present observations suggest that, so far as these vessels are concerned, it exhibits closer parallels with certain members of the Aeluroidea than Davis & Story had supposed.

These authors suggest that the primitive condition of these vessels in the Carnivora was similar to that now found in a genus such as *Bassariscus* in which the anastomotic artery is a simple vessel running between the internal maxillary artery and the internal carotid. Their observations upon a number of orders led them to

conclude that the anastomotic vessel was subject to two opposite evolutionary developments: 'In the Carnivora the anastomotic vessel then presents two opposite evolutionary trends: in the direction of complete suppression in the Arctoidea, and towards extraordinary elaboration in the Aeluroidea.' If this assertion is generally true, then the present observations suggest that the domestic dog, a member of the Superfamily Arctoidea, must be regarded as an exception. Although the form of the anastomotic artery may vary considerably from one individual to another, not only was it present in all the heads examined, but it was usually nearly as large as the internal carotid artery, and in some cases showed a retiform development comparable in complexity with the rete in the aeluroid civet cat, as depicted by Tandler (1899). Again, with respect to the middle meningeal anastomotic ramus, the situation in the dog would appear to be comparable to that typically found amongst the Aeluroidea. In the cat the anastomotic ramus of the middle meningeal is larger than the middle meningeal itself, so that in this species the latter vessel appears to arise as a branch of the former. The middle meningeal artery is thus involved in the general redistribution of carotid blood to reach the circle of Willis via the external carotid field. This change in the role of the middle meningeal artery is evident in the dog too, where the anastomotic ramus is frequently found to be the larger distributory vessel and the meningeal artery appears to arise from it. Thus the suggestion of Davis & Story that this anastomotic ramus of the meningeal artery may characterize the aeluroid carnivores also finds an exception in the dog.

All these developments to alter the pattern of cerebral blood supply reach their extreme condition in the domestic cat where the brain receives blood only from external carotid and vertebral sources. The fact that the carotid system in the dog shows similar, though less advanced, changes, suggests that the importance which is usually attached to the internal carotid artery as supply route to the brain is not commensurate with its functional role. And whilst it is clear that the contribution of carotid blood to the brain is at least as great as that from the vertebral arteries, it is partly the anastomotic arteries, and perhaps the occipital anastomoses, which keep the proportions so adjusted.

SUMMARY

1. The arterial supply to the dog's head has been examined in a series of injected specimens in order to demonstrate the arterial pathways by which the brain may receive a blood supply.

2. Five anastomoses are described: the occipital-vertebral anastomosis, the ascending pharyngeal-internal carotid anastomosis, and the three anastomoses between the internal maxillary artery and intracranial vessels—the anastomotic artery, the ophthalmic anastomosis, and the ethmoidal anastomosis.

3. Of these anastomoses the occipital-vertebral anastomosis and the anastomotic artery are considered to be important routes by which carotid blood might reach the brain. In particular the role of the anastomotic artery is discussed: it is a contributory vessel to the internal carotid flow. The various forms which this artery may assume are described.

4. The similarity between the carotid vascular pattern in the dog and the aeluroid carnivores is discussed.

It is a pleasure to record my thanks to Prof. E. B. Verney for his advice and encouragement throughout the course of this work.

REFERENCES

- BOUCKAERT, J. J. & HEYMANS, C. (1935). On the reflex regulation of the cerebral blood flow and the cerebral vaso-motor tone. *J. Physiol.* **84**, 367-380.
- BRADLEY, O. C. (1948). *Topographical Anatomy of the Dog*, 5th ed. rev. T. Grahame. London: Oliver and Boyd.
- DAVIS, D. D. & STORY, H. E. (1943). The carotid circulation in the domestic cat. *Field Mus. Publ.* (Zool. series), **28**, 1.
- ELLENBERGER, W. & BAUM, H. (1891). *Systematische und topographische Anatomie des Hundes*. Berlin: Paul Parey.
- LEGAIT, E. & RACADOT, J. (1949). Modifications des voies afférentes de la circulation cérébrale au cours du développement chez quelques Mammifères. *C. R. Ass. Anat.* **36**, lix, 444-450.
- MILLER, M. E. (1948). *Guide to the Dissection of the Dog*. New York: Ithaca.
- SISSON, S. & GROSSMAN, J. D. (1940). *The Anatomy of the Domestic Animals*, 3rd ed. Philadelphia: W. B. Saunders.
- TANDLER, J. (1899). Zur vergleichenden Anatomie der Kopfarterien bei den Mammalia. *Denkschr. Akad. Wiss. Wien*, **67**, 677-784.
- VERNEY, E. B. (1947). Croonian Lecture. The antidiuretic hormone and the factors which determine its release. *Proc. Roy. Soc. B*, **135**, 25-106.