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MORPHOLOGICAL STUDIES ON THE RETE MIRABILE EPIDURALE IN THE CALF

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The rete mirabile epidurale consisted of a compact network of interlacing, freely anastomosing arteries, and was distinguished into two parts: a chief part, and an anterior V-shaped extension. The chief part, lying in the circular sinus, was composed of two lobes connecting to the anterior and posterior communicating rami. The anterior V-shaped extension lay in the optic foramen. The rete received its blood supply from the maxillary artery via the proximal rete branch and the distal rete branches, from the basi-occipital arterial plexus, and from the internal carotid artery, which was poorly developed in the calves used. The arteries rising from the rete were the cerebral carotid artery and the internal ophthalmic artery.

The circular sinus received its venous blood from the facial portion, the cornual processus, and the orbital and nasal cavities, which were the main source of its blood supply. The blood in the circular sinus was drained into the basilar venous plexus and into four emissary veins through the foramen lacerum, the foramen orbitorotundum, the foramen ovale, or the small foramen of the hypophyseal fossa.

The arteries were histologically observed in the chief part of the rete. These arteries were usually of the muscular type showing an ordinary histology; however, some of the arteries showed intimal cushions or a sclerotic change. All of the calves used in the present histological observation were less than 13 weeks old, but sclerotic changes were found in about 5% of the arteries in the rete. The cerebral carotid arteries also showed the sclerotic change, which was found in about 65% of the arteries.

INTRODUCTION

According to COLE ('44), the rete mirabile epidurale was discovered by HEROPHILUS, but GALEN (A. D. 130-200) gave us its first description. The rete mirabile epidurale, a structure peculiar to artiodactyls, consists of a compact network of intertwined, freely anastomosing arteries.

The brain of submammalian vertebrates is supplied only by the paired

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internal carotid arteries; the brain of most mammals is supplied by the paired vertebral arteries in addition to paired internal carotid arteries. This shift in blood supply to the brain occurs in the transition from the submammalian vertebrates to the mammals, and might well be called "the mammalian shift" (GILLILAN '72). LAWRENCE & REWELL ('48), TANDLER (1899) and VIAMONTE et al. ('68), however, described an exception to the brain-blood supply with the presence of the rete mirabile and the degeneration of the internal carotid artery in *Cetacea*, *Felis* and *Artiodactyla*.

The present study was undertaken to describe the structure of the rete mirabile epidurale, the sinus dura mater, and the venous system, which are related to the rete in the calf, a member of *Artiodactyla*.

MATERIALS AND METHODS

The heads of 24 Holstein calves, aged 12 days to 9 months, were obtained.

Of these heads, 3 were injected with neoplene latex 601 A through the cannulated common carotid artery. Seven calf heads were injected with methyl methacrylate colored by oil black or oil red through the cannulated common carotid artery, and/or the external jugular vein using the methods described by TOMONAGA ('61). After the infused resin had set (usually overnight at room temperature), the heads were skinned and placed in a covered bath containing protease for maceration of the soft tissues. The bath was kept at a warm temperature for a few days. Then the resin casts, together with the skeletal structures, were cleaned by placing them under running tap water for several hours. This technique was developed in order to observe the relationship between the injected vascular system and the skeletal structures. After observation, these preparations were again placed in concentrated hydrochloric acid for obtaining the simple resin cast.

Thirteen calves under 13 weeks of age were used for histological observations. Specimens containing the rete mirabile epidurale were fixed in 10% formalin. One head was perfused with 10% formalin through the common carotid artery. The specimens were then embedded in paraffin, sectioned at 8 to 15 μ in thickness, and stained with Crossmon's modification of Mallory's trichrome method, hematoxylin and eosin stain, and Weigert's elastic stain.

The sections of the rete were projected and drawn on tracing paper at a linear magnification of 86 or 94 times in order to calculate the arterial number of each section and to measure the internal diameter of the arteries composing the rete.

Methacrylate vessel casts were used to measure the size of the rete mirabile epidurale and the internal diameter of its afferent and efferent arteries.

RESULTS

1 Macroscopical findings

The rete mirabile epidurale consisted of a tightly packed network of interlacing, freely anastomosing arteries and was distinguished into two parts: a chief part and an anterior V-shaped extension.

The chief part was composed of two lobes connected by anterior and posterior communicating rami. The lobes were located at either side of the hypophysis in the circular sinus (fig. 1). On the methacrylate resin cast, the lobes was approximately 32.8 mm in length, about 13.3 mm in height, and 10.3 mm at the greatest width. The chief part was 28.2 mm at its widest part. There were few variations in the lobe measurements. There were variations in regard to the complication of the anterior and posterior communicating rami. The posterior communicating rami always included a large artery (fig. 2).

The anterior V-shaped extension lying along the ventral aspect of the optic nerves and the optic chiasma consisted of a small network of interlacing arteries (figs. 1 & 3). This rete was supplied by vessels from the anterior communicating rami and the distal rete branches.

The rete mirabile epidurale received its afferent blood supply from the maxillary artery via the proximal and distal rete branches, from the basi-occipital arterial plexus, and from the internal carotid artery.

The proximal rete branch arose opposite the origin of the buccinator artery from the maxillary artery (fig. 4). It was approximately 2.0 mm in diameter. The proximal rete branch gave off fine branches to the distal rete branches, then curved backward and entered into the postero-lateral border of the rete through the foramen ovale.

The distal rete branches arose from the maxillary artery just after the origin of the external ophthalmic artery; these also arose from the external ophthalmic artery in some cases (figs. 3 & 4). The number of branches was 4.9 on an average, 1 to 4 from the maxillary artery, and 0 to 3 from the external ophthalmic artery. Coursing caudad and mediad along the ventral and dorsal aspect of the cranial nerves, the branches passed through the foramen orbitorotundum, and then entered the antero-lateral border of the rete. The fine branches of the distal rete branches connected with the anterior V-shaped extension in the orbit (figs. 1 & 4).

The basi-occipital arterial plexus was a plane network and lay in the basilar venous plexus on the basi-occipital bone. The plexus received the vertebral artery and condylar artery and ran forward to join with the posterior part of the lobes and/or posterior communicating rami (figs. 1 & 5).

The internal carotid artery arose from the common carotid artery, entered into the cranial cavity through the foramen jugulare, formed a loop bending ventrally, which was also characteristic of the internal carotid artery in other mammals, and then entered the posterior part of the lobes (fig. 2). The internal carotid artery anastomosed with the arteries constituting the rete, but was recognized as running easily forward within the rete. The artery became larger when running forward to continue the cerebral carotid artery.

The cerebral carotid artery was a main efferent artery of the rete and was about 2.6 mm in diameter. It went out the circular sinus along the hypophyseal stalk.

The internal ophthalmic artery was seen arising from one arm of the anterior V-shaped extension on each side and ran forward to the orbit (fig. 3). This artery was fine in structure (about 0.7 mm).

The rete received its blood supply from the preceding four routes. The ratio of the blood supply to the rete can be presumed from the diameter of each vessel cast of the afferent arteries; the distal rete branches occupied 49%; the proximal rete branch 25%; the basi-occipital arterial plexus 20%; and the internal carotid artery 6% of the blood for the rete. Three quarters of the blood was supplied by the maxillary artery.

The cavernous sinuses lying on the basi-sphenoidal bone were communicated by means of the anterior and posterior intercavernous sinus on the anterior and posterior of the hypophysis, and, as a whole, the circular sinus was formed. The cavernous sinus communicated rostrally with the orbital venous plexus through the foramen orbitotundum. The orbital venous plexus formed a coneshaped network which surround the eye with the apex of the cone leading into the cavernous sinus, and received its blood from the facial portion, the cornual processus, and the nasal cavity. The main sources of blood supply to the orbital venous plexus were the lateral and dorsal nasal veins via the naso-frontal vein and the supraorbital vein; however the nasal blood was drained not only into the naso-frontal vein, but also into the facial vein and directly to the external jugular vein. The blood in the circular sinus was drained into the basilar venous plexus and into four emissary veins through the foramen lacerum, the foramen orbitotundum, the foramen ovale, and the small foramen at the hypophyseal fossa. These four emissary veins united with the pterygoid plexus. The basilar venous plexus lying on the basi-occipital bone was a coarse plexus in which the basi-occipital arterial plexus lay. The anterior V-shaped extension was twisted in the venous plexus in the optic foramen.

2 Histological findings

The chief part of the rete adjoined the trigeminal nerves, trigeminal ganglions, and abducent nerves on the lateral side. The oculomotor nerves perforated the dura mater at each side of the hypophysis to course inside the cavernous sinus (fig. 6). The unmyelinated nerve bundles and their ganglions were present around the trigeminal nerves and among the arteries composing the rete. The number of arteries in the chief part was about 76 in the section at the level of hypophysis.

The mean and standard deviation of the diameter of these arteries was $244.3 \pm 91.0 \mu$ in samples of 10% formalin immersion fixation, and $404.7 \pm 211.7 \mu$ in samples of 10% formalin perfusion fixation. These arteries were of the muscular type. The adventitia of the arteries was covered by the endothelial cells, which formed the lining of the circular sinus (fig. 7). Some of the arteries showed intimal cushions, which were composed of smooth muscle fibers arranged longitudinally with fine collagenous fibers, and surround by an internal elastic membrane (fig. 8). The walls of a few small arteries contained many closely packed epithelioid cells (fig. 9). Some of the arteries showed a sclerotic change, which was composed of a hyperplastically swollen intima (fig. 10). The hyperplastic reduplication of the internal elastic membrane was also a frequent finding (figs. 11 & 12). The sclerotic change appeared in about 5% of the arteries, which were seen on the cross section through the rete of the hypophyseal level. The cerebral carotid arteries also revealed the sclerotic change 65% of the arteries.

DISCUSSION

The rete mirabile epidurale is present commonly in artiodactyls, but its structure varies among species. In comparison with the retia of the sheep, goat, calf, buffalo, and pig, the anterior V-shaped extension is present only in the calf and the basi-occipital arterial plexus is present in both the calf and buffalo (BAWLWIN ('64), CUMMINGS & HABEL ('65), DANIEL et al. ('53), FINELLI et al. ('67), FLECHSIG & ZINTZSCH ('69), GILLILAN ('73) and NANDA ('75)). In the chief part of the rete, the anterior and posterior communicating rami develop very well in the calf and buffalo. In the pig the anterior communicating ramus is very weak and the posterior communicating ramus develops very well. Only the posterior communicating ramus is present in the sheep and goat.

According to DENNSTEDT ('04), SEIFERLE ('75) and the present results, the anterior and posterior intercavernous sinuses in the calf develop very well and form a circular sinus with the cavernous sinus. The basilar venous plexus is formed caudal to the circular sinus. In the pig the anterior and posterior inter-

cavernous sinuses are both present but the former is very weak. In the sheep and goat the anterior intercavernous sinus is absent and the basilar venous plexus of the sheep, goat, and pig is either absent or does not show a distinct structure, as in the calf. From these findings it appears that the structure of the rete in the calf, sheep, goat, and pig is dependent on the form of the basilar system of the sinus dura mater.

According to the present findings, as well as those of DANIEL et al. ('53), KOCH ('70), NANDA ('75), and STEVEN ('64), the internal ophthalmic artery of the calf breaks off from the anterior V-shaped extension. In the adult cow the artery is approximately the same diameter as it is in the calf, and consequently, is conspicuous (STEVEN '64). With the exception of the cat and man, the origin of the internal ophthalmic artery breaks off from the cerebral carotid artery or the rostral cerebral artery in other domestic animals, such as the sheep, goat, pig, dog, and horse. In the cat the artery breaks off from the external rete. The internal ophthalmic artery in the cat and calf, accordingly, is unique, and may not be ontogenetically identical to the artery of other domestic animals and man.

The sclerotic changes were observed in the arteries of the rete in spite of the calves' young ages. FINELLI et al. ('67) also found that sclerotic changes occurred in the arteries of the buffalo rete. Studies on the development of the rete have been done on the pig (TANDLER '06) and sheep (BALANKULA '54). According to TANDLER ('06), the rete of the pig originates from the internal carotid arteries. In the following formation of the rete in the pig the internal carotid arteries are obliterated, and the rete has new afferent arteries, an ascending pharyngeal artery, and rete branches of the maxillary artery. It is suggested that the development of the rete in the calf is similar to that in the pig. During rete development the blood supply to the rete through the internal carotid artery may decrease gradually. Such a shift of the blood stream may cause the sclerotic changes because of the passing obliterating phenomenon in some arteries of the rete related to the internal carotid artery.

While blood is supplied to submammalian vertebrates only by the paired internal carotid arteries, mammalian brains receive blood from the vertebral-basilar arterial system in addition to the paired internal carotid arteries. In artiodactyls, however, a highly specialized plexus, rete mirabile epidurale, other than the internal carotid artery and the vertebral-basilar arterial system, constitutes the major arterial route to the brain. There is general acceptance that the rete has some functional significance in relation to the cerebral circulation. Many authors agree that the complex, voluminous route and presence of intimal cushions in the arterial plexus of the rete mirabile epidurale is able mechanically

to change the hemodynamics of the circulation.

According to TAYLER ('66), however, the horns of goats selectively control the temperature of the brain via an exchange of heat between the arterial blood of the rete and the cooled venous blood returning from the horns into the cavernous sinus. From a study on the influence of the nasal mucosa and the rete mirabile epidurale upon hypothalamic temperature in sheep, BAKER & HAYWARD ('68) concluded that venous blood returning from the nasal mucosa and the skin of the head to the cavernous sinus cools the arterial blood in the rete, and that this is an important factor in the maintenance of hypothalamic temperature in the wool-covered, longnosed, panting sheep.

Our results show that a close connection exists between the structure of the rete and the sinus dura mater, and that in addition, the main source of blood supply to the cavernous sinus in the calf is the nasal venous blood. The nasal mucous membrane in the calf shows the highest degree of vascular complexity and plays a role in heat regulation, as well as air conditioning (SCOTT '54). Accordingly, the writers suggest that the rete mirabile epidurale also selectively controls the brain temperature.

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EXPLANATION OF PLATES

Abbreviation of figures :

BO-Basi-occipital arterial plexus, CC-Cerebral carotid artery, DR-Distal rete branches, EO-External ophthalmic artery, H-Hypophysis, IC-Internal carotid artery, IO-Internal ophthalmic artery, M-Maxillary artery, PR-Proximal rete branch, Vext-Anterior V-shaped extension, III-Oculomotor nerve, V-Trigeminal nerve, VI-Abducent nerve

PLATE I

- Fig. 1 Ventral view of latex cast showing rete mirabile epidurale and its afferent and efferent arteries Approx. $\times 1.2$
- Fig. 2 Dorsal view of latex cast showing a large artery (\rightarrow) of the posterior communicating rami Approx. $\times 3$
- Fig. 3 Dorsal view of latex cast showing anterior V-shaped extension, distal rete branches, and the internal ophthalmic artery Anterior V-shaped extension was normally V-shaped, but this specimen had been spread out for display. Approx. $\times 2$

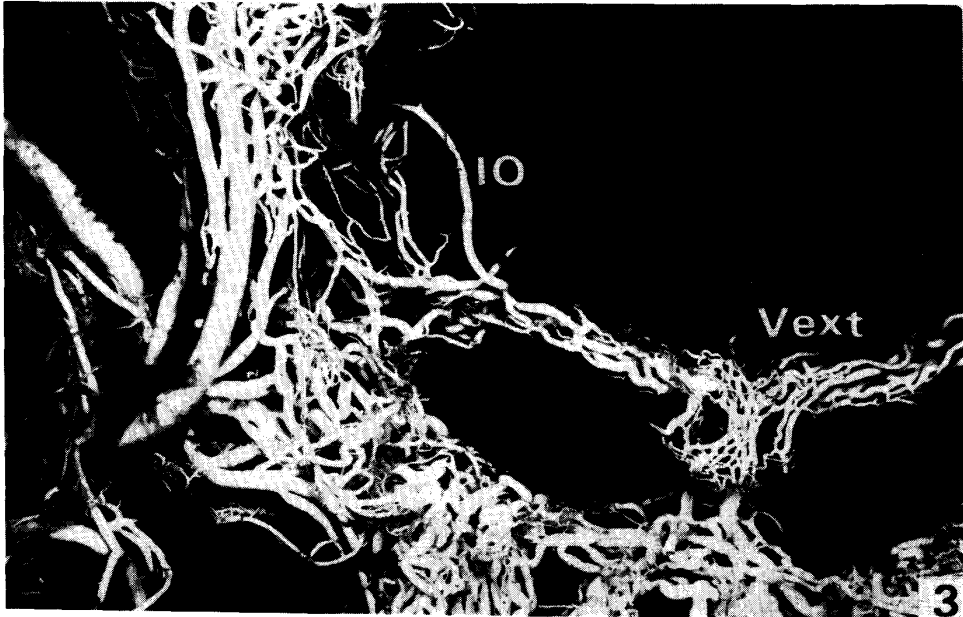
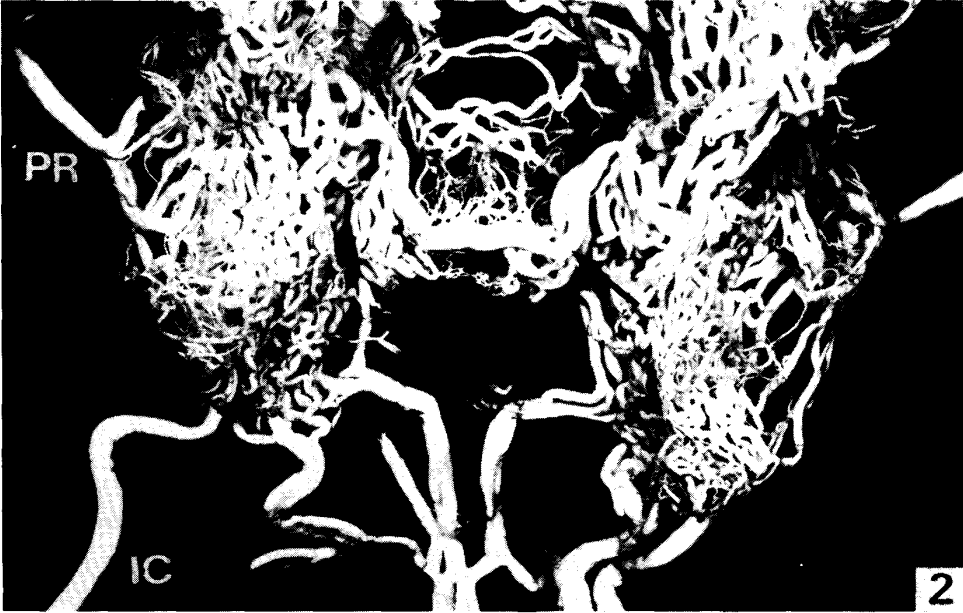
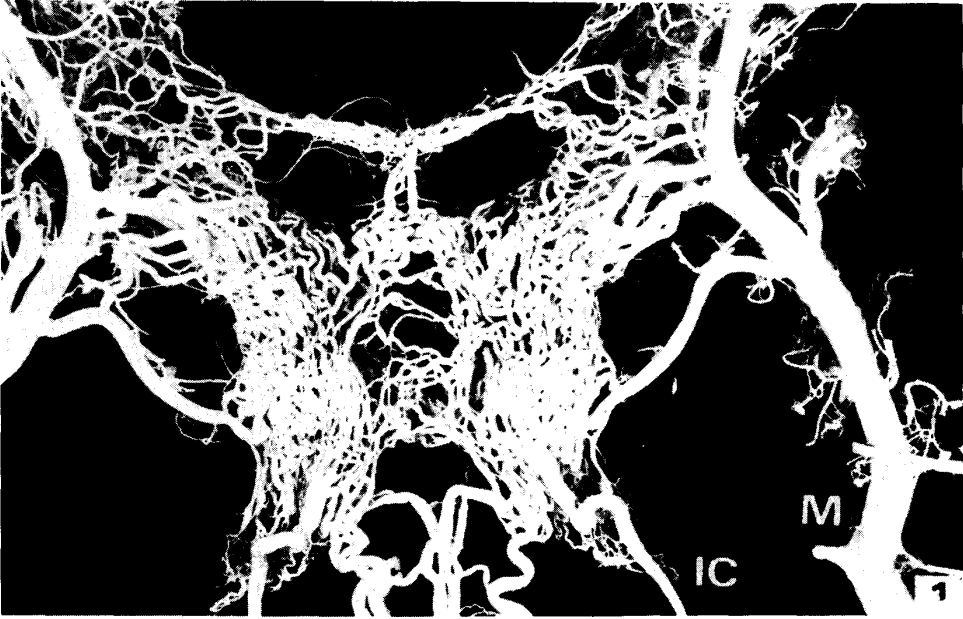


PLATE II

- Fig. 4 Ventral view of latex cast showing proximal and distal rete branches Approx. $\times 1.3$
- Fig. 5 Dorsal view of latex cast showing basi-occipital arterial plexus Approx. $\times 1.5$
- Fig. 6 This section is cut at the level of hypophyseal stalk.
H-E $\times 4$

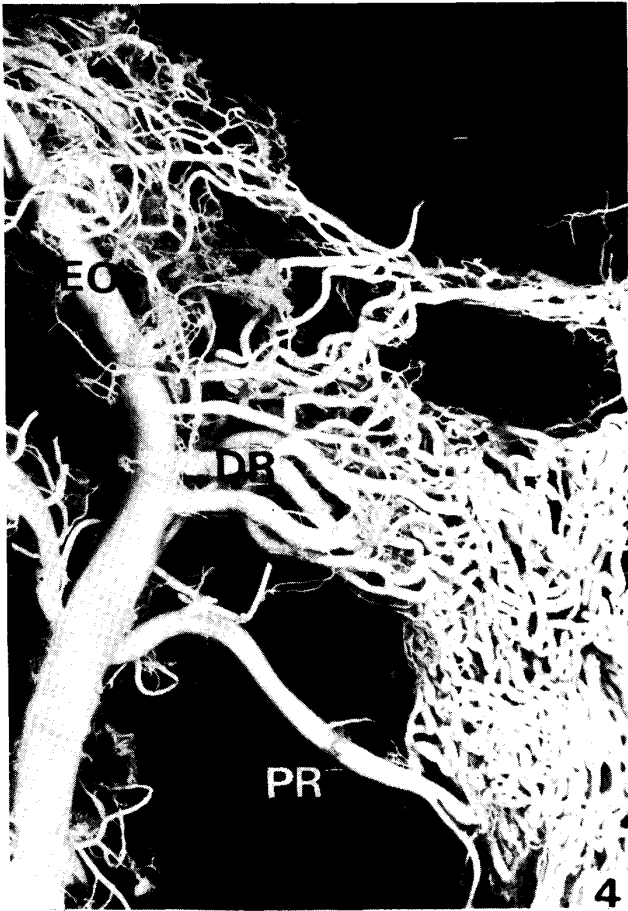


PLATE III

- Fig. 7 Artery commonly observed in the rete is a muscular type and has an internal elastic membrane. Weigert $\times 90$
- Fig. 8 Artery with intimal cushion Weigert $\times 90$
- Fig. 9 Thick-walled artery containing many epithelioid cells
H-E $\times 330$
- Fig. 10 Artery showing sclerotic change
Note hyperplastically swollen intima. Weigert $\times 90$
- Fig. 11 Artery showing sclerotic change
Note hyperplastic reduplication of internal elastic membrane.
Weigert $\times 350$
- Fig. 12 Artery showing high degree of sclerotic change
Weigert $\times 100$

