Carotid Arterial Supply of the Feline Brain
APPLICATIONS TO THE STUDY OF REGIONAL CEREBRAL ISCHEMIA

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Abstract:
- A study of the supply to the feline brain by the carotid-middle cerebral arteries was conducted using in vivo transcardiac injection with a mixture of micropaque and carbon black. Modifications in the filling pattern of the arterial vessels were visualized following short-term occlusion of a middle cerebral artery. A modified surgical method to induce occlusion of the M-1 segment of the middle cerebral artery is also described.

Additional Key Words: cat MCA occlusion anatomy middle cerebral artery arterial anastomoses microangiography

Introduction
- The consequences of occluding a middle cerebral artery (MCA) in the cat have been widely studied through dynamic and structural methods in several models of regional cerebral ischemia, or arterial infarction.1,2 The variability in the size and location of the lesions obtained with this model is probably dependent upon the individual variations in the anatomy of the cerebral arteries, caliber and pattern of the anastomotic channels,3 and changes in perfusion pressure;4 the last factor may or may not be dependent upon the previous two.5

The purpose of this communication is to describe and illustrate in detail the carotid arterial system of the cat. Special reference is made to the anastomoses that exist among leptomeningeal arteries and between them and the dural arteries. The anatomy of the M-1 segment of the MCA is carefully described and illustrated, as a background for previous and subsequent studies involving experimental occlusion of this vessel. Finally, some significant modifications to previously described methods of surgical occlusion of the MCA are detailed.5,6

Methods
Seven adult cats weighing 2.7 kg to 3.5 kg were anesthetized with pentobarbital (30 mg per kilogram of body weight, intraperitoneally) and subjected to transcardiac perfusion with a solution of colloidal micropaque mixed with carbon black (40°C),7 after prewashing with a sodium chloride solution (37°C). The injection was performed at a pressure equivalent to the systolic blood pressure of the animal and (40°C),8 after prewashing with a sodium chloride solution (37°C).

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The carotid rete in the cat has two components: (1) extracranial (external), and (2) intracranial (fig. 1). The external part of the rete extends from the foramen rotundum to the optic foramen and receives its blood supply from the internal maxillary artery (IM). Several large-caliber anastomotic arteries arising from the medial side of the external rete pass through...
the orbital fissure into the cavernous sinus, where they unite to form a major trunk which is joined by the distal end of the primitive internal carotid artery (PIC) whose original cervical portion is vestigial in adult cats. The convergence of these vessels forms the relatively large-sized intracranial internal carotid artery (ICA) (fig. 1). A meningeal arterial branch (M) and the inferior hypophyseal (IH) artery originate from the rete before the main trunk of the ICA is formed. A superior hypophyseal artery originates from the ICA either inside the cavernous sinus or immediately after the ICA pierces the dura. The superior hypophyseal (SH) artery establishes an anastomosis with the internal ethmoidal artery (IE) at the chiasmatic region (figs. 1 and 2a and b). This meningeal anastomotic branch of the SH is usually unilateral but two out of seven cats showed bilateral branching. After giving off a large posterior communicating artery, the ICA courses around the optic chiasm giving origin to an anterior choroidal artery and a few small branches that supply the anteromedial portion of the pyriform lobe. Then, the ophthalmic artery originates; its size varies from a trace to 100 μ in outer diameter. In one-half of the animals studied by us, the ophthalmic artery was not visible. Near its bifurcation, the ICA gives rise to several branches that supply the anterior hypothalamic region (figs. 2a and b).

Usually, as a first branch, the anterior cerebral artery (ACA) gives off a perforating (striate) branch that corresponds to the Heubner artery of the human brain (figs. 2a and b). The anterior communicating artery, as it exists in humans, was absent in the animals studied but an anastomosis between the ACA and a branch of the contralateral ICA was seen in some animals. A large anastomotic vessel between the ACA and the internal ethmoidal artery was observed on the medial surface of the olfactory bulb (figs. 1 and 2a and b).
CAROTID ARTERIAL SUPPLY OF THE FELINE BRAIN

3). Such anastomosis is usually unilateral but some small branches establish a bilateral connection. The ACA gives off a major branch that supplies the falx and the dura covering the frontal convexity. In addition, the ACA has a group of branches that connect it with the ethmoidal plexus (fig. 3).

The site of the ICA bifurcation varies from 0.9 to 2.1 mm from the midline (average distance: 1.5 mm). The midline was drawn at the midpoint of a straight line connecting the lateral angles of the right and left anterior perforated substances (figs. 2a and b).

The initial portion of the MCA courses horizontally in a slightly caudal direction (figs. 2a and b). The external diameter of the first segment of the MCA varies from 0.70 to 0.75 mm in the pre-fixed material. The position of the perforators' branching point varies considerably. The site of origin of the first perforator is found anywhere between 3.3 mm and 7.8 mm (average 5.1 mm) from the midline (figs. 2a and b).

The medial striate group in most animals originates from the ACA (equivalent to the Heubner artery). When these are small, one finds that the medial striate group of perforators originates from the MCA proper. The number of main perforators (defined as those more than 80 μ in external diameter) that originates from the MCA varies between two and five. The last ones originate either from the main trunk of the MCA (M-1) or from an MCA branch (M-2), distal to the anterior perforated substance; therefore, in order to reach their point of entrance into the parenchyma, these branches turn back sharply forming a narrow angle with the parent vessel (figs. 2a and b). After branching several times, the majority of these vessels penetrate the cerebral parenchyma through the lateral corner of the anterior perforated substance to form the lateral striate arteries. In the M-1 segment of the MCA one constantly finds only one small cortical branch that supplies the anterolateral part of the pyriform lobe (figs. 2a and b). The origin of this branch is found anywhere between 3.6 mm and 7.5 mm (average: 6 mm) from the midline. In one case we found a branch originating from the ICA and giving off cortical branches that supply the medial and lateral pyriform area and the posterior sylvian gyrus.

In the cat, the MCA irrigates the entire lateral surface of the cerebral hemispheres and the orbital surface lateral to the olfactory tract with the exception of the sigmoid gyrus, the marginal gyrus and the posterior composite gyrus (figs. 4 and 5) where the MCA anastomoses with several branches of the ACA and the PCA. The nomenclature used to designate the feline cerebral gyri is based on that of Crouch.9 The size of the leptomeningeal anastomoses may be up to 130 μ when measured on the outer surface (fig. 5). In addition, numerous smaller connections form a network among individual branches. From this network the cortical penetrating branches originate.

Anastomoses between the MCA and dural arteries were not observed, except for one animal in which a dural artery was seen; this originated from a cortical branch of the MCA over the anterior frontal convexity and measured 100 μ in external diameter.

Following unilateral occlusion of the MCA with a ground Heifetz clip* there was good filling by contrast medium of the main striate branches and the circumferential branches over the hemispheric surfaces (figs. 4 to 6b). The differences in density between the two hemispheres are explained on the basis of poor filling of the fine branches corresponding to the cortical perforators. The long subcortical perforating arteries show essentially the same filling pattern in both hemispheres (fig. 6b). In the material studied by us it was not clear whether distal anastomoses between the medial and lateral group of striated arteries existed.

Discussion

In lower vertebrates, the designation of carotid rete (rete mirabile) is applied primarily to a compact network of freely anastomosing arteries, interlaced with a venous plexus, that are associated with a vestigial or hypoplastic internal carotid artery, such as is found in the cat, sheep, goat, ox and pig.16 17 A true rete mirabile means a network of fine arterial twigs interlaced with venous plexus supplying the circle of Willis from the external carotid artery, as mentioned above. Frequently, the term rete mirabile has been used in a broader sense to designate anastomotic channels between the external carotid artery branches and the leptomeningeal arteries on the surface of the brain.16

The so-called circle of Willis of the arterial tree, which is located at the base of the brain in humans, differs from the feline one in the following aspects.

In the cat, the ophthalmic artery originates from the distal end of the ICA (CI) and supplies the frontoorbital meninges, establishing anastomoses with the ciliary artery. The size of the ophthalmic artery varies considerably and sometimes is completely absent.

The anterior communicating artery does not exist in the cat, and this is in agreement with Hiflimann, although others have described one.10 11

There are several varieties of anastomoses between the intradural vessels and the meningeal vessels. (1) The falx and the dura over the frontal convexity are supplied by branches of the ACA, which anastomose directly with the internal ethmoidal artery and indirectly with the external ethmoidal artery, via the ethmoidal plexus. At the latter, the right and left ACA join one another, although in some cats both ACAs are connected directly via the internal ethmoidal artery. (2) Anastomoses between the internal ethmoidal and the superior hypophyseal artery are found constantly. (3) There is an inconstant dural branch which originates in MCA branches. Such was

*The tip of the Heifetz clip was ground triangularly to make its application easy and safe.
Ventral view of the cat brain. Arterial system is filled with colloidal micropaque solution mixed with carbon black through the heart IC: internal carotid artery, IE: internal ethmoidal artery, LS: lateral striate arteries, MC: middle cerebral artery, MS: medial striate arteries (Heubner's artery), SH: superior hypophyseal artery. *Cut end of the SH connecting with the IE at * mark in figure I.
CAROTID ARTERIAL SUPPLY OF THE FELINE BRAIN

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found in one animal, although its caliber was small. Anastomoses between the anterior cerebral artery and the middle cerebral artery as well as between the middle cerebral artery and the posterior cerebral artery are abundant over the sigmoid gyrus, the marginal gyrus, and the posterior composite gyrus, but they are less abundant between the MCA and the ICA branches over the pyriform lobe. The potential for efficient collateral circulation, in the presence of large artery occlusion, is limited to the larger leptomeningeal arteries. In the cat, these are considered to be more than 70 μ in external diameter. The fine leptomeningeal network is inefficient for such a purpose, as previously described in humans by Vander Eecken.  

When one uses the transorbital approach to the MCA, with the modifications described herein, the proximal portion of the MCA is surgically inaccessible due to the near-midline location of the ICA point of bifurcation. The lateral edge of the optic

**FIGURE 3**

FIGUIR3
Dorsal view of the same brain as figure 4; note the size and number of the leptomeningeal collateral channels between ACA and MCA, PCA and MCA. Basic filling pattern of leptomeningeal arterial networks is same on both hemispheres, although the background is pale on the clipped side.

Canal is located approximately 5 mm from the midline, which thus becomes the most proximal site where the MCA could be clipped, using the modified technique previously described. With O'Brien and Waltz's approach, the most proximal site at which the artery can be clipped is 4 mm from the midline, as measured from their illustrations. The presence of a paranasal sinus (ethmoidal sinus) close to the medial

FIGUIR4
Lateral view of the cat brain. Colloidal micropaque solution is perfused through the heart with clip placed on MCA on the side shown. The MCA territory is filled retrogradely via leptomeningeal collateral channels. AS: anterior sylvian gyrus, C: coronal gyrus, ES: eclosylvian gyrus, M: marginal gyrus, PC: posterior composite gyrus, PS: posterior sylvian gyrus, S: sigmoid gyrus, SS: suprasylvian gyrus.
Coronal sections of the same specimen as in figures 4 and 5, illustrating in 6a pallor of the cortex on the right hemisphere. The site of the clip is indicated by an arrow. In 6b, which is a soft tissue x-ray of the specimen, filling of the MCA branches distal to the point of occlusion occurs in a retrograde fashion. The differences in the color density of the two hemispheres are due to lack of filling in some of the short cortical perforators. Note the slight pallor in the lateral half of the caudate nucleus which thus becomes the most peripheral arterial field after occluding the main trunk of the MCA.
half of the optic canal constitutes one more anatomical reason for failing to have access to the initial millimeters of the MCA in the cat, when one uses the transorbital approach. In older cats (over 3.6 kg of body weight) this paranasal sinus extends even more laterally than in younger animals and surrounds the optic canal completely, thus making it impossible to reach the MCA without entering the sinus and increasing the possibility of postoperative infectious complications.

In chronic experiments in which temporary clipping of the MCA is desirable, we have determined that the modifications to the transorbital approach described herein are advantageous, primarily at the time when the clip is to be removed, which is the most difficult part of the surgical procedure. During this maneuver, direct visualization of the blade of the Heifetz clip is essential, in order to avoid damage to the arterial wall and the surrounding structures. The convergent direction of the illumination axis and that of the clip applicator, as previously described, facilitate this maneuver immensely.

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References
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