The perforating branches of the middle cerebral artery

A microanatomical study

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The perforating branches (PFB's) of the middle cerebral artery (MCA) were studied in 34 unfixed brain hemispheres which were injected with a polyester resin and dissected under the operating microscope. Five hundred and eight vessels were identified and their site of origin, branching pattern, outer diameter (OD), and length recorded. Four hundred and two PFB's (79%) originated from the main trunk of the MCA before its division; the remaining 106 vessels (21%) had their origin from branches of the MCA as follows: superior trunk, 43 vessels (8.5%); inferior trunk, 30 vessels (6%); middle trunk, four vessels (0.8%); early temporal branch, 27 vessels (5.3%); and early frontal branch, two vessels (0.4%). The number of PFB's in each hemisphere varied from five to 29 (mean 14.9 ± 0.7 vessels). The great majority of PFB's (96%) originated along the proximal 17 mm of the MCA. The PFB's arising in the first 10 mm had a mean OD of 0.35 ± 0.01 mm and a mean length of 9.25 ± 0.19 mm, and those arising from the second 10 mm had a mean OD of 0.47 ± 0.02 mm and a mean length of 16.67 ± 1.4 mm. A clear distinction between a medial and lateral group of PFB's was present in only 14 hemispheres (41%). In nine hemispheres (26%), perforating vessels from the anterior cerebral artery (A1 segment) and from the recurrent artery of Heubner replaced the medial group of PFB's of the MCA. In one case this group originated in an accessory MCA. In three hemispheres (9%) a small anastomosis (OD 0.2 mm) was seen between a PFB of the recurrent artery of Heubner and one of the MCA. From a total of 508 PFB's, 255 vessels (50%) originated as single vessels, while 253 vessels (50%) originated as branches of common stems. The OD of the single vessels ranged from 0.1 mm to 1.1 mm (mean 0.39 ± 0.02 mm), and the length from 3 to 20 mm (mean 10.8 ± 0.2 mm). The common stems ranged in OD from 0.6 to 1.8 mm (mean 0.87 ± 0.04 mm), and in length from 1 to 15 mm (mean 4.1 ± 0.4 mm).

The clinical application of these anatomical data to the management of aneurysms and arteriovenous malformations of the MCA, and in the field of interventional neuroradiology is described. The most frequent pathological entities involving the perforating vessels are also discussed.

KEY WORDS * cerebral arteries * middle cerebral artery * cerebrovascular disease * microsurgery * anatomical study * interventional neuroradiology

Although the perforating branches (PFB's) of the middle cerebral artery (MCA) were described by early anatomists,17 and their role in the pathogenesis of intracerebral hemorrhage has been emphasized by Charcot and Bouchard,11 the surgical significance of these vessels became apparent only with the introduction of the operating microscope and the development of interventional neuroradiology. The surgeon operating on aneurysms or performing vascular reconstruction procedures in the proximal segments of the MCA should be aware of the origin and course of the perforating vessels so as to avoid accidentally damaging or clipping them, which may result in severe neurological deficit.

Recently, microsurgical techniques have been used to successfully remove deep-seated arteriovenous malformations (AVM's) fed by PFB's of the MCA.3,23,35 Superselective catheterization and embolization of these vessels have also been reported.7 To utilize these new therapeutic approaches for deep-seated AVM's, knowledge of the microanatomy of the PFB's of the MCA is essential.

In this anatomical study, we used unfixed specimens, intravascular injections, and microsurgical techniques...
closely simulating in vivo conditions. These measures allowed for exquisite dissection, precise measurements of vessel length and diameter, and excellent visualization of the course and relationship of the perforating vessels to surrounding anatomical structures.

**Materials and Methods**

Seventeen unfixed human brains were obtained from routine autopsies of adults (mean age 42 ± 2.6 years) without signs of central nervous system pathology. The brains, removed from the skull 4 to 8 hours post mortem, were immediately immersed in Ringer's solution. The internal carotid arteries were cannulated with a No. 18 polyethylene catheter, and both posterior communicating arteries were ligated near their origin. The vessels were flushed with 300 cc of normal saline under controlled manual pressure. Unsaturated polyester resin was prepared with a mixture of monomer (40% to 45% styrene), catalyst (methyl-ethyl ketone peroxide), and red pigmented resin (cadmium compounds in an ethyl hexanol vehicle) in a 10:1:1 ratio.* The preparation was injected manually until good arterial filling was evident, and the brains were left undisturbed in Ringer's solution at 4°C during the hardening process. Two to 3 hours after injection, the specimens were ready for examination. The brains were placed upside down to expose their ventral surface, the frontal lobes nearest the examiner. Self-retaining retractors were used to open the medial end of the Sylvian fissure, exposing the proximal MCA and its perforating branches, and the brains were examined under the operating microscope. We recorded the length and pattern of division of the MCA, as well as the number, site of origin, pattern of branching, outer diameter (OD), and length of the perforating vessels.

We considered all vessels arising from the MCA and penetrating the brain substance through the anterior perforated space as PFB's of the MCA. The boundaries of the anterior perforated space were the olfactory trigone and striae (rostral), the optic tract and the diagonal band of Broca (caudal), the optic chiasm (medial), and the limen insulae (lateral).

The main trunk of the MCA is that portion of the artery situated between the origin at the internal carotid artery bifurcation and its division, which we called the main division. The arteries resulting from this main division are the secondary trunks which were named superior, middle, or inferior, depending on the manner in which the main trunk of the MCA divides. The cortical branches arising from the main trunk of the MCA were called "early branches;" they may be early temporal branches or early frontal branches, depending upon their territory of distribution.

**Anatomical Observations**

The main trunk of the MCA had an average length of 15.8 ± 0.9 mm and bifurcated in 71% of specimens, trifurcated in 20%, and quadrifurcated in 9%. A total of 508 PFB's of the MCA were examined in the 34 hemispheres studied. The number of PFB’s in each hemisphere varied from five to 29 (mean 14.9 ± 0.1 vessels).

**Site of Origin**

The main trunk of the MCA, before the main division, gave rise to 402 (79%) PFB’s. The remaining 106 vessels (21%) had their origin as follows: superior trunk,
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FIG. 3. Medial and lateral groups of perforating branches of the middle cerebral artery (MCA), basal view. In this specimen, a clear distinction between medial (MPFB's) and lateral (LPFB's) groups of perforating vessels can be seen. A clear distinction between these two groups was present in only 14 of 34 hemispheres (41%). Several of the MPFB's arise from a common stem (C.S.). The LPFB's follow a recurrent course to reach the anterior perforated space (APS). MCA (M1) = M1 segment of the MCA. DMCV = deep middle cerebral vein.

43 vessels (8.5%); inferior trunk, 30 vessels (6%); middle trunk, four vessels (0.8%); early temporal branch, 27 vessels (5.3%); and early frontal branch, two vessels (0.4%) (Fig. 1). The PFB's of the MCA arose from the superior wall of the parent vessel at different points without forming a distinct line. The angle of origin was variable for the medial perforating vessels and usually acute for the lateral PFB's, which followed a recurrent course to reach the anterior perforated space.

The great majority (96%) of the PFB's originated along the proximal 17 mm of the MCA (Fig. 2). A clear distinction between a medial and lateral group of PFB's was present in only 14 hemispheres (41%) (Fig. 3). In nine hemispheres (26%), perforating vessels from the anterior cerebral artery (A1 segment) and from the recurrent artery of Heubner replaced the medial group of PFB's of the MCA. In one case this group had its origin in an accessory MCA.

Pattern of Branching

Of a total of 508 PFB's, 255 (50%) originated as single vessels, and 253 (50%) originated as branches of common stems (Fig. 4). These 51 common stems gave origin to two vessels in 17 cases, three vessels in six cases, four vessels in five cases, five vessels in four cases, six vessels in five cases, seven vessels in four cases, eight vessels in two cases, 10 vessels in five cases, 12 vessels in two cases, and 13 vessels in one case.

Outer Diameter and Length

The use of intravascular injection and magnification allowed us to perform accurate measurements in the small vessels (with an OD greater than 100 μ) and to differentiate them from arachnoid strands. The OD of the single vessels ranged from 0.1 mm to 1.1 mm (mean 0.39 ± 0.02 mm), and they ranged in length from 3 to 20 mm (mean 10.8 ± 0.2 mm). The common stems ranged in OD from 0.6 to 1.8 mm (mean 0.87 ± 0.04 mm), and in length from 1 to 15 mm (mean 4.1 ± 0.4 mm). The caliber of the single PFB's and of those originating in common stems remained the same through their subarachnoid course from their origin to their locus of penetration in the anterior perforated space. To compare the measurements of the medial and lateral PFB's, we considered the proximal 20 mm of the MCA in two halves: the perforating vessels arising in the first 10 mm had a mean OD of 0.35 ± 0.01 mm and a mean length of 9.25 ± 0.19 mm, and those arising in the second 10 mm had a mean OD of 0.47 ± 0.02 mm and a mean length of 16.67 ± 1.4 mm.

Perforating Branches of Recurrent Artery of Heubner

The terminal branches of the recurrent artery of Heubner (RAH) replaced the medial group of PFB's of the MCA in five cases (15%). When they were present together, the branches of the RAH maintained a superior position in relation to the perforating vessels of the MCA (Fig. 5). In three cases (9%), a small anastomotic vessel (OD 0.2 mm) was found between the RAH and a PFB of the MCA (Fig. 6). In one case a fenestration of the MCA split the proximal 4 mm of the main trunk into two vessels of similar size (OD 2.5 mm). No perforating branches were found arising at the level of the fenestration.
FIG. 5. Recurrent artery of Heubner and medial perforators of the middle cerebral artery (MCA), basal view. The terminal branches of the recurrent artery of Heubner maintained a superior position in relation to the perforating branches of the MCA. APS = anterior perforated space; DMCV = deep middle cerebral vein; MCA (M1) = M1 segment of the MCA; MPFB's = medial perforating branches; RAHc = recurrent artery of Heubner complex; TL = temporal lobe.

FIG. 6. Anastomosis in the anterior perforated space (APS), basal view. A natural anastomosis (Anast) between the recurrent artery of Heubner complex (RAHc) (branch of the anterior cerebral artery) and a perforating branch of the middle cerebral artery (MCA) was found in only three hemispheres (19%). In these specimens the recurrent artery of Heubner divided into several branches which replaced the medial group of perforators of the MCA. DMCV = deep middle cerebral vein; ICA = internal carotid artery; LPFB’s = lateral perforating branches of the MCA; MCA (M1) = M1 segment of the MCA; OLF. Br. = olfactory branch of the recurrent artery of Heubner.

FIG. 7. The lateral perforating branches (LPFB's) of the middle cerebral artery (MCA), basal view. This figure shows two large lateral perforators probably related to “Charcot's artery of the cerebral hemorrhage.” A medial group of small perforating vessels (MPFB's) arising from the main trunk of the MCA penetrates the anterior perforated space (APS) inferiorly to the recurrent artery of Heubner (RAH); MCA (M1) = M1 segment of the MCA.

Discussion

The first detailed anatomical study of the perforating branches of the MCA was performed by Duret at the end of the last century. The work of Duret reflected the interest that arose with the discovery by Charcot and Bouchard of the presence of miliary aneurysms along those vessels and their role in the pathogenesis of intracerebral hemorrhage. Duret injected his specimens with gelatin colored with carmine and found that the perforating vessels originated mainly in the proximal 20 mm of the MCA, measured 0.25 to 1 mm in diameter, and penetrated the anterior perforated space in a transverse plane in front of the mamillary bodies. He also divided the perforators of the MCA into medial and lateral groups. Among the lateral group, there was always an artery of large diameter which coursed along the base of the lenticular nucleus and supplied the caudate nucleus after crossing the upper portion of the internal capsule. Charcot called this “the artery of the cerebral hemorrhage” (Fig. 7).

After these pioneering studies, the anatomy of the PFB's of the MCA, also called the “lenticulostriate arteries,” “arteries of the corpus striatum,” or “striatal branches,” was described by several authors and is mentioned in Table 1. Intravascular injections were used to visualize the vessels easily, to follow their course, and to study their distribution. The number of perforating vessels, their size, and their angle of origin from the parent vessel varied in the different studies. Most of this work was based on gross dissections, and performed in fixed specimens rather than in specimens that would more accurately define the vascular parameters seen at surgery. By using unfixed specimens and intravascular injection tech-
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TABLE 1
Summary of anatomical studies on perforating branches (PFB's) of the MCA*

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Gross Dissec.</th>
<th>Micro Dissec.</th>
<th>Injection</th>
<th>No. of Brains</th>
<th>Specimen</th>
<th>Anatomical Data on PFB's</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duret, 1873</td>
<td>+</td>
<td>-</td>
<td>gelatin &amp; carmine</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Beevor, 1907</td>
<td>+</td>
<td>-</td>
<td>gelatin &amp; soluble colors</td>
<td>87</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Shellshear, 1920</td>
<td>+</td>
<td>-</td>
<td>gelatin &amp; soluble colors</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Abbie, 1934</td>
<td>-</td>
<td>+</td>
<td>india ink</td>
<td>40</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Alexander, 1942</td>
<td>+</td>
<td>in 6 hemis</td>
<td>india ink</td>
<td>40</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Kaplan, et al., 1954</td>
<td>+</td>
<td>-</td>
<td>radiopaque material</td>
<td>125</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Herman, et al., 1963</td>
<td>NA</td>
<td>NA</td>
<td>gelatin &amp; india ink</td>
<td>20</td>
<td>1 wk</td>
<td>no</td>
</tr>
<tr>
<td>Westberg, 1963</td>
<td>+</td>
<td>-</td>
<td>plastic polymer</td>
<td>17</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Jain, 1964</td>
<td>+</td>
<td>-</td>
<td>resin &amp; red lead in 20 hemis</td>
<td>300</td>
<td>60 hemis</td>
<td>540 hemis</td>
</tr>
<tr>
<td>Kaplan, &amp; Ford, 1965 &amp; 1966</td>
<td>+</td>
<td>-</td>
<td>radiopaque material</td>
<td>NA</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>Salamon, et al., 1966</td>
<td>NA</td>
<td>NA</td>
<td>gelatin &amp; red lead in 50 angios</td>
<td>10</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Gillilan, 1968</td>
<td>+</td>
<td>-</td>
<td>plastic, gelatin &amp; india ink, latex</td>
<td>50</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Stephens &amp; Stiwell, 1969</td>
<td>+</td>
<td>-</td>
<td>acrylic, barium sulphate</td>
<td>43</td>
<td>1 wk &amp; 2 mos</td>
<td>no</td>
</tr>
<tr>
<td>Kodama &amp; Suzuki, 1974</td>
<td>NA</td>
<td>NA</td>
<td>micropaque gel solution</td>
<td>34</td>
<td>&gt; 3 wks</td>
<td>no</td>
</tr>
<tr>
<td>Grand, 1980</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>18</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Umansky, et al., 1985</td>
<td>-</td>
<td>+</td>
<td>polyester, tinted resin</td>
<td>17</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>

* MCA = middle cerebral artery; NA = not available or not reported; + = performed; – = not performed; hemis = hemispheres; angios = angiograms; APS = anterior perforated space; SV = single vessels; CS = common stems; RAH = recurrent artery of Heubner. Specimens described by Salamon, et al.33 were also studied radiographically.

niques, we attempted to duplicate the typical surgical situation, and our study may provide more detailed information regarding the anatomy of the perforators of the MCA.

We found that the number of perforating vessels of the MCA in each hemisphere (mean 14.9 ± 0.1 vessels) was greater than the number reported in previous studies (Table 1). The larger number was found in those specimens in which the PFB's arose from the MCA along the whole length of its main trunk. In those hemispheres in which the medial perforators were replaced by branches originating in the A1 segment of the anterior cerebral artery, or in the RAH (26%), there were fewer PFB's arising from the MCA.

Traditionally, the PFB's of the MCA have been described as arising in two well defined groups: a medial group, made up of small vessels, and a lateral group of larger vessels. In our study, a clear distinction between
TABLE 2
Areas supplied by the perforating branches of the MCA*

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Caudate Nucleus</th>
<th>Globus Pallidum</th>
<th>Putamen</th>
<th>Internal Capsule</th>
<th>Thalamus</th>
<th>Claustrum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head</td>
<td>Body</td>
<td>Tail</td>
<td>Medial</td>
<td>Lateral</td>
<td>Anterior</td>
</tr>
<tr>
<td>Duret, 1873</td>
<td>partially</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>dorsolateral</td>
</tr>
<tr>
<td>Beevor, 1970</td>
<td>dorsal half</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Shellshear, 1920</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Alexander, 1920</td>
<td>posterodorsal</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Herman, * et al.* 1963</td>
<td>partially</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Kaplan &amp; Ford, 1966</td>
<td>partially</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Gillilan, 1968</td>
<td>dorsolateral</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Stephens &amp; Stilwell, 1969</td>
<td>posterodorsal</td>
<td>+</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

* MCA = middle cerebral artery; NA = not available; + = area supplied; − = area not supplied.

There is no uniform agreement in the literature regarding the angle of origin of the PFB's arising from the MCA. Earlier studies described the origin of these vessels as being at right angles to the parent artery (Table 1). In 1920, Shellshear was the first to describe the acute angle of origin of the lateral perforators. Herman, * et al.* suggested that these findings were fixation artifacts and reaffirmed the concept of a right angle of origin. In our dissections, the lateral PFB's, which followed a recurrent course to reach their points of penetration in the anterior perforated space, had an acute angle of origin, and the more lateral the origin, the more acute the angle (Fig. 3). The medial PFB's originated closer to their points of penetration in the anterior perforated space, pursued an irregular and tangled course, and had a more varied angle of origin with no uniform pattern (Fig. 5). An apparent right angle of origin may be produced by stretching the perforating vessels when the main trunk of the MCA is elevated to visualize their point of take-off. Jain and Kodama and Suzuki found that the angle of origin of PFB's arising from the MCA varied with the age of the individual, with differences being seen in brains of fetuses, children, and adults.

The microanatomical knowledge of the size, angle of origin, and pattern of branching of the perforating vessels has practical implications in interventional neuroradiology. Since 1872, when Cohnheim theorized that infarcts could occur only where there was no anastomosis between arteries, the idea of "end arteries" has persisted and has been applied to the perforating arteries of the brain. In 1966, Kaplan and Ford mentioned the existence of extracerebral anastomoses among the PFB's of the anterior cerebral artery, the RAH, and the PFB's of the MCA. More recently, Kodama and Suzuki performed microangiographic studies on the brains of fetuses, children, and adults. They demonstrated the existence of anastomosis among the PFB's of the MCA themselves and with the medullary arteries. In our dissections we found a small anastomotic vessel (OD 0.2 mm) between the RAH and a PFB of the MCA in three hemispheres (9%). The areas supplied by the PFB's of the MCA have been described by several authors and are mentioned in Table 2.
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in Table 2. These areas include the body of the caudate nucleus, the dorsal aspect of its head, the lateral segment of the globus pallidus, the dorsal half of the internal capsule, and most of the putamen. Contrary to Duret's description of a lenticulo-optic artery, the PFB's of the MCA did not contribute to the vascularization of the thalamus in most of the studies. Westberg, in an investigation performed on 100 normal cerebral angiograms, and 20 angiograms in cadavers, found that a "state of balance" exists between the distribution of the branches from the RAH and the PFB's of the MCA. If the former artery is small, the branches from the MCA predominate in number and area of distribution, whereas if the latter are few and small, the branches of the RAH are more prominent. In our study we found nine hemispheres (26%) in which PFB's from the anterior cerebral artery (A segment) and from the RAH replaced the medial PFB's of the MCA. The existence of this state of balance between the PFB's of the anterior cerebral artery and those of the MCA and the possibility of anastomotic channels joining these two systems may have clinical significance, giving rise to a different symptomatology in cases of vascular occlusion.

Prior to the introduction of computerized tomography, the angiographic characteristics of PFB's of the MCA interested neuroradiologists. The displacement of those vessels was an important guide in the localization of deep-seated space-occupying lesions. Abnormalities of the perforating vessels, such as tortuosity, elongation, dilatation, and microaneurysms, have been demonstrated in patients with cerebrovascular disease by means of magnification serial cerebral angiography. In the early 1970's, Molcho, et al., and Hilal, et al., were able to catheterize the MCA and a striate vessel, respectively, using a magnetically guided catheter. More recently, Berenstein reported a case of a bilateral deep-seated AVM treated by selective catheterization and embolization of the PFB's of the MCA.

For the neurosurgeon dealing with an MCA aneurysm, the preoperative angiographic localization of the main division of the artery has practical implications. Most saccular aneurysms are located near this division and in close proximity to the most lateral perforating vessels. Although the PFB's are angiographically visible, the recurrent course of the lateral perforators along their parent vessels may give the false impression that they arise more medially than is actually true. In our study, the main divisions of the MCA occurred at 15.6 ± 0.9 mm from the origin of the artery, and 96% of the PFB's originated along the proximal 17 mm of the MCA (Fig. 2). In cases of early division (less than 10 mm from the origin of the MCA), there is a high probability that the PFB's will be found close to the aneurysm, while in cases of late division (more than 20 mm from the MCA origin), the take-off of most of the perforating vessels will be found medial to the origin of the aneurysm.

In planning an embolectomy or endarterectomy of the main trunk of the MCA, the presence of the perforating vessels is an important factor in determining the feasibility of the procedure and the proper placement of the temporary clips. Acute reduction or suppression of the blood flow through these vessels may produce severe neurological deficits.

Experimental models have been developed in which the selective occlusion of the lateral perforating branches of the MCA resulted in an infarction in the region of the basal ganglia and internal capsule, followed by well defined clinical and radiological findings. The similarity of these models to the clinical situation of lacunar infarcts, as well as their reproducibility, make them a valuable tool in the study of focal cerebral ischemia.

Arteriovenous malformations involving the basal ganglia and internal capsule, which account for 8% to 18% of all AVM's in different series, still represent a therapeutic challenge even in the most sophisticated neurosurgical centers. Before the introduction of the operating microscope, isolated cases had been reported of surgical removal of AVM's from the head of the caudate nucleus. More recently, the addition of microsurgical techniques has extended the indications for operation to include AVM's that before would have been considered inoperable, such as those involving the capsulolenticular area.

Better knowledge of the normal microvascular anatomy of the area will help both the neurosurgeon and the neuroradiologist to understand and to treat the vascular pathology of this complex region.

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References


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