Surgical anatomy of the proximal anterior cerebral artery

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The authors present this study of proximal anterior cerebral arteries in the normal human to provide a clearer basis for strategy in aneurysm surgery. They describe patterns of origin of branches, their subarachnoid course, and parenchymal distribution. Branches that originate from the anterior cerebral artery at the internal carotid bifurcation perfuse the genu and contiguous posterior limb of the internal capsule and the rostral thalamus. Proximal 4-mm branches supply the anterior limb of the internal capsule, the neighboring hypothalamus, anteroventral putamen, and pallidum. The remaining anterior cerebral artery proximal to the communicating artery sends branches to the optic chiasm, the adjacent hypothalamus, and the anterior commissure. Heubner's artery arises directly opposite the anterior communicating artery to supply much of the striatum and internal capsule rostral to the anterior commissure. The anterior communicating artery branches supply the fornix, corpus callosum, septal region, and anterior cingulum. The parenchymal distribution of these end arteries may be surmised from the site of origin of named vessels. With this anatomical information one can avoid interruption of blood supply to vital structures when dealing with the anterior cerebral artery and its branches.

KEY WORDS • proximal anterior cerebral artery • anatomy • Heubner's artery • anterior communicating artery • aneurysm surgery • vascular distribution

Surgery that involves the proximal anterior cerebral artery (PACA) has become increasingly aggressive. It is therefore imperative to know the sites of origin, subarachnoid courses, and parenchymal distributions of branches of the PACA to avoid manipulations which might produce severe neurological deficits. The literature is replete with anatomical studies of the PACA, but the accounts are so varied that a definitive understanding of the anatomy of this vessel is impossible.1,2,4,6,12,14,17,19,23,25,28,30,34

Dandy,11 Critchley,9 and Gurdjian, et al.,15,23,32 are among those who have tried to identify the symptoms and provide clinicopathological correlations for deficits attributable to PACA occlusion. They have enumerated syndromes which include personality changes, hemipareses, dysphasias, and loss of consciousness. Reports of PACA clipping in the treatment of anterior communicating artery aneurysms,8,21,27,29,31 include a small but significant proportion of deficits that also include altered states of consciousness, diminished higher intellectual function, and motor pareses. It is difficult to reconcile these signs and symptoms with our present understanding of their neuro-
Materials and Methods

Our data was derived from 20 individuals between the ages of 41 and 83 years who died in the hospital of various causes and had no history of neurological dysfunction. We examined 40 PACA's with a surgical microscope; detailed drawings were made of the sites of origin of the branches, their subarachnoid course, and locus of penetration into the brain. The artery of Heubner, or recurrent artery, was isolated from the remaining PACA and its branches. The parenchymal distribution of the artery of Heubner was delineated by aniline dye infusion in 28 instances, and the distribution of the other PACA branches in 26 instances.

At autopsy, within 24 hours of death, both cervical internal carotid arteries were isolated and perfused with 200 to 400 cc of normal saline. This was followed immediately by perfusion of 300 cc of 10% buffered formalin through each carotid artery. Then the brain was removed and examined for any external evidence of cerebral pathology; if none was found, it was placed in 10% formalin for additional fixation and further investigation.

On the sixth to eighth day after perfusion the brain was removed from the formalin and positioned with the basal surface upward. Segments of the anterior circle of Willis were cannulated with plastic catheters or ligated as shown in Fig. 1. Polyethylene catheters were positioned in the proximal anterior cerebral
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artery and at the origin of Heubner's artery and were isolated from one another by a silk ligature just proximal to the origin of Heubner's artery. Preliminary dissections indicated that a number of branches arose from the anterior cerebral artery at its origin from the internal carotid artery bifurcation. Subsequently, care was taken to include these branches in each injection but to exclude all branches that arise from the middle cerebral, anterior choroidal, and internal carotid arteries. Another ligature isolated one Heubner's artery and the anterior communicating artery and branches from the other artery of Heubner. We injected 2 to 3 cc's of either methylene blue or neutral red in aqueous solution into each catheter so that the two ipsilateral catheters were injected with different colored dyes. Thus, the parenchymal distribution of the artery of Heubner could be compared directly with the distribution of the other PACA branches for each hemisphere.

Following aniline dye infusion, we carefully dissected the branches that arise from the PACA with the aid of the surgical microscope. We took particular care to denote the relative size of any branch, its site of origin along the PACA, its approximate subarachnoid course, and the locus of penetration of its ramifications into the brain substance. We then cut serial coronal sections approximately 7-mm thick and outlined the maximum distribution of dye within the parenchyma on drawings of representative sections. Data were collated from these drawings.

**Results**

Analysis of each surface of the coronal sections revealed less than 1.5 mm of extravascular diffusion of dye from any grossly discernible vessel. Histological sections from nuclear gray and capsular white matter that had been maximally stained with either of the dyes failed to show filling of any vessel smaller than 20 μ. Frequently the perivascular space was found flooded with dye and the vessel within the space appeared collapsed. This suggested that the partially fixed vessel had ruptured, which allowed dye to spread through the perivascular space. This space is known to terminate in the precapillary arteriolar region. No discernible venous structure was found with dye in its lumen or perivascular space. These findings suggest that the injected solutions had not passed through the capillaries into the venous system, and that the extravascular spread of the dyes was not great enough to distort the estimate of the arterial distribution of the PACA branches.

**Proximal Anterior Cerebral Artery Branches**

A group of three to six branches arose from the region of the PACA (Fig. 2). In no instance could any of these vessels be construed to be the anterior choroidal artery, which in every instance arose more proximally on the internal carotid artery. The locus on the anterior perforate substance and optic tract within which these most proximal branches penetrated the brain substance is shown in Fig. 2. This finding was consistent in over 80% of the vessels examined.

Figure 3 shows the site of origin on the PACA of five to nine branches. The branches which arose most distally were very fine or hair-like and supplied only the arterial plexus.
on the superior surface of the optic nerve and contiguous chiasm. The more proximal vessels penetrated the brain by way of the anterior perforate substance and optic tract (Fig. 3). We have observed long branches penetrating the optic tract and traversing this structure without branching to perfuse the hypothalamus and paraolfactory structures.

Maximum and minimum parenchymal distributions of these branches are depicted in the serial coronal sections in Fig. 4. In 96% of the instances studied (Fig. 4, second section), branches of the PACA perfused the medial third of the anterior commissure and pallidum and posterior medial paraolfactory nuclei. Structures anterior to this commissure, such as the most medial inferior aspect of the caudate caput and putamen, anterior paraolfactory nuclei, and portions of the anterior limb of the internal capsule, were perfused in about 70% of the instances studied.

We observed branches from the most proximal group of vessels arising at the carotid bifurcation to perfuse the genu and contiguous posterior limb of the internal capsule in nearly 80% of the specimens. The globus

Fig. 3. Cross-hatching on the anterior cerebral artery (ACA) and on the anterior perforate substance (APS) and optic structures (OS) represents the sites of origin and penetration into the brain, respectively, of the distal group of anterior cerebral artery branches. Branches arising from the distal third of the ACA were invariably small and contributed only to the arterial plexus of the optic nerve, chiasm, and tract.

Fig. 4. Upper to lower are drawings of four coronal sections progressing from anterior to posterior. The stippled area represents the perfusion bed of the proximal group and cross-hatching the perfusion bed of the distal group of PACA branches depicted in Figs. 2 and 3. The left hemispheric distribution represents a maximal perfusion volume while that on the right represents a minimal perfusion volume. The second section has been cut through the anterior commissure; therefore much of the anterior pallidum, hypothalamus genu, and contiguous portion of the posterior limb of the internal capsule, and even the most rostral portion of the anterior thalamus receive some blood supply from the most proximal branches of the anterior cerebral artery.
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pallidus at the level of the genu of the internal capsule was likewise perfused in 80%. Although no other author since Duret has described perfusion of any part of the thalamus by perforating branches from the anterior circle of Willis, we observed perfusion of portions of the anterior nucleus of the thalamus in 68% and part or all of the hypothalamus anterior to the mammillary bodies in 56% of the instances examined.

The branches which perfused these structures arose from the most proximal 2 to 3 mm of the anterior cerebral artery. We believe that the above percentages are underestimates of the true incidence of perfusion, for in many cases at the time of arterial dissection relatively large proximally originating branches have been found unperfused. These vessels were anatomically patent but had been kinked or occluded by trapped air bubbles at the time of perfusion.

Recurrent Artery of Heubner

Heubner's artery was seen to arise as a single vessel across from the anterior communicating artery at the junction of the anterior cerebral and the pericallosal arteries in 55% of the instances studied. In 35% it originated within the first 1.5 mm of the distal anterior cerebral artery (Fig. 5). At both of these sites it arose from the lateral aspect of the first order vessel. In most instances it was directed immediately backward against the superolateral aspect of the PACA. Often it was invested in the adventitia of that vessel for as much as 6 to 7 mm before proceeding at an acute angle from the anterior cerebral artery, and coursing freely through the subarachnoid space to penetrate the brain as four to seven branches at the base of the lateral and medial olfactory striae. The adherence of Heubner's artery to the anterior cerebral artery initially is so complete that at first glance even under the microscope its true origin is obscured. It appears to be arising from the middle third of the proximal anterior cerebral artery at the point where it leaves the adventitia to course through the subarachnoid space. Inadvertent occlusion of this vessel may easily occur if a clip is applied to the anterior cerebral artery within 5 mm of the exit point of the communicating artery because the origin and initial course of Heubner's artery are so obscured by the investing adventitia of the anterior cerebral artery. At the usual distal site of origin a small artery was frequently seen that arose just proximal and adjacent to Heubner's artery and disappeared into the brain in the anteromesial region of the anterior perforate substance.

Figure 6 depicts the maximum and minimum parenchymal distributions of Heubner's artery. The anterior posterior extent of perfusion was the tip of the lateral ventricle anterior to the anterior commissure posteriorly in 92% of instances studied, while perfusion of any structure posterior to the anterior commissure was seen in only 15%. While the inferior half of the striatum with the interposed anterior limb of the internal capsule was consistently perfused, in over 50% of the cases the entire anterior striatum was perfused by the artery of Heubner and PACA. As seen in Fig. 6, at the level of the...
anterior commissure the artery of Heubner had relinquished the periventricular region including the caudate nucleus to other branches of the anterior cerebral, anterior communicating, or middle cerebral arteries, and continued to perfuse only the putamen inferiorly and the anterior commissure laterally.

Anterior Communicating Artery Branches

The anterior communicating artery has been described as having no branches in humans or inconsistently possessing a single callosal branch. Yet, we have observed no fewer than three branches arising from the anterior communicating artery in all 19 cases where this was present. In one instance both PACA's came together to form a single pericallosal artery, the configuration usually found in lower primates. An anterior communicating artery branch with a luminal diameter as great as either pericallosal artery was noted in two of the remaining 19 brains, or an incidence of 10%. This vessel has been called the “arteria termatica” of Wilder, or...
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median artery of the corpus callosum, and an incidence of from 3.3% to 20% has been reported in autopsy series. The largest of the three branches underwent frequent ramifications to septal and median paraolfactory nuclei before entering the corpus callosum and cingulum. The lesser two branches perforated the superior aspect of the chiasm and both optic nerves, and sent branches to the septal and paraolfactory tissue as shown in Fig. 7.

As depicted in Fig. 8, the communicating artery branches perfused the septum pellucidum, corpus callosum, columns of the fornix, lamina terminalis, and to a lesser extent the most mesial paraolfactory structures and most anterior hypothalamus. In the early perfusions, ligation of the anterior communicating artery to separate the right and left Heubner's artery circulations often kinked some or all of the communicating artery branches and prevented their perfusion. In the instances where the anterior communicating artery ligation was omitted, perfusion of a large part of the anterior cingulum was frequently noted. A numerical estimate of the frequency of perfusion of these structures would be meaningless because of the vagaries of perfusion of this vessel with the earlier technique employed.

We have reoriented the anterior portion of the circle of Willis in Fig. 9 so that the superior aspect of the arteries may be seen. All the branches of the PACA arose from the superior aspect of the artery, except Heubner's artery which arose laterally, and the most proximal branch at the bifurcation of the internal carotid artery which arose posteriorly. The median length of the proximal anterior cerebral artery was 13 mm and the average number of branches was 11, excluding Heubner's artery and the branches off the anterior communicating artery. These branches were not randomly dispersed along the vessel. An average of seven branches appeared in the first 5 mm. We have seen no more than three branches arising from the most distal 5 mm and these were always hair-

Fig. 9. Diagram of dorsal surface of anterior circle of Willis. With the exception of the artery of Heubner (AH) which arises from the lateral aspect of the anterior cerebral artery (ACA) and the most proximal branch which arises from the posterior surface of the internal carotid artery bifurcation, all the other tributaries of the proximal anterior cerebral artery arise from its own dorsal surface. The branches that perfuse the genu and contiguous portion of the posterior limb of the internal capsule, the medial globus pallidum, the hypothalamus, and the most rostral part of the thalamus originate within 3 to 4 mm of the exit point of the proximal anterior cerebral artery. The intimate relationship of the recurrent artery of Heubner to the proximal anterior cerebral artery is also shown.

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like and contributed to the anastomotic plexus on the surface of the optic chiasm.

Discussion

Injection of intracranial arteries has been the most popular technique used to determine the parenchymal distribution of these vessels. Gillilan has provided a brief and inclusive historical account of intracranial vascular injection studies. Concern that potential cerebral arterial, arteriovenous, and capillary anastomoses would produce erroneously larger estimates of physiological perfusion territories of individual arteries has fostered many of the technical modifications developed in these investigations. Cobb, Lazorthes, et al., and Van den Bergh and Vander Eecken presented arguments in favor of arterial and capillary anastomoses. Studies by Heubner, Alexander that were carried out without concern for any anastomoses yielded results which suggested that such concerns are out of proportion to the extent of the problem. Most authors concede that arterial and capillary anastomoses are least functional in the basal ganglia and diencephalon, and are predominantly capillary anastomoses in this region. As we were unable to demonstrate any capillary filling in histological sections, it appears that the perfusion territory of the proximal anterior cerebral artery has been reliably shown with this technique.

Conflicting descriptions of the PACA and its parenchymal perfusion distribution have led to confusion about the significance of its small perforating branches. What is lacking in previous studies and is so important to the surgeon is a precise description of the origin and extent of branches perfused in any injection. By use of low viscosity dyes and perfusion of the most proximal branches of the anterior cerebral artery, we have delineated a significantly greater perfusion territory for this vessel than was previously demonstrated. Moreover, we have described a remarkable constancy in the pattern of origin of PACA branches with their subarachnoid course and parenchymal distribution. This finding is not only an academic extension of Hilton's and Shellshears' concept of functional vascular distribution, but is of clinical significance for several reasons.

Heubner's artery supplies the most anterior striatum and anterior limb of the internal capsule. For that reason, it is probably not a vessel responsible for hemiparesis. Second, branches that arise from the most proximal portion of the anterior cerebral artery and the internal carotid bifurcation consistently perfuse the genu and contiguous posterior limb of the internal capsule, the rostral thalamus, and much of the hypothalamus. Aneurysms, arterial emboli, or surgical manipulation of the anterior cerebral artery in this region could readily produce a hemiparesis with brachial preponderance and produce significant personality changes; disturbance of the vessels in this region seems more likely to produce such deficits than disturbance of the artery of Heubner. Third, there has been little mention of the branches of the anterior communicating artery in previous accounts. We have noted three prominent branches that arise from this vessel and supply the fornix, septal nuclei, corpus callosum, and anterior cingulum, prominent structures in the limbic system. This finding may explain the high proportion of permanent personality changes which occur in people with ruptured berry aneurysms of this vessel.

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