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A neurosurgical view of anatomical variations of the distal anterior cerebral artery: an anatomical study

HASAN C. UGUR, M.D., PH.D., GOKMEN KAHILOGULLARI, M.D., ALI FIRAT ESMER, M.D., AHAN COMERT, M.D., AYSUN B. ODABASI, M.D., IBRAHIM TEKDEMIR, M.D., ALAITTIN ELHAN, D.V.M., AND YUCEL KANPOLAT, M.D.

Departments of Neurosurgery and Anatomy, Ankara University School of Medicine; and Forensic Medicine Institution, Ankara, Turkey

Object. The vascularization pattern of the anatomy of the distal anterior cerebral artery (ACA) remains a subject of debate. These authors provide detailed information about the distal ACA and shed light on issues concerning it that have not previously been adequately discussed.

Methods. Fifty adult human brains (100 hemispheres) were obtained in routine autopsies. Cerebral arteries were separately cannulated and injected with latex. The vascularization patterns of the cortical branches and the variations of the arteries were investigated. The authors found that the distal ACA supplied all the inner surfaces of the frontal and parietal lobes and a median of one third of the outer surfaces. The origin of the arteries from the main trunk and their exit angles affected the vascularization patterns of the hemispheres. The authors redefine controversial terminology regarding the callosomarginal artery.

Conclusions. In each hemisphere, the vascularization pattern of the distal ACA is different to a greater or lesser extent. An awareness of this fact will contribute significantly to surgical interventions.

KEY WORDS • **distal anterior** • **cerebral artery** • **callosomarginal artery** • **pericallosal artery** • **vascular anatomy** • **brain** • **cadaver**

MANY classifications have been proposed for the sections of the ACA. The part between the bifurcation of the internal carotid artery and the ACoA has been called the A_1 segment or the proximal ACA, whereas the section after the ACoA has been called the distal ACA. The latter has been divided into four parts: the A_2 segment, which extends from the ACoA to the rostrum CC; the A_3 segment, which courses from the rostrum CC to the point at which the artery turns sharply to the posterior on the genu of the CC; the A_4 segment, which extends from the point at which the artery turns sharply to the posterior on the genu of the CC to the line where the CC intersects laterally with the coronal suture; and the A_5 segment, which extends from the point at which the CC intersects with the coronal suture to the splenium CC.[5,8,9,11,14,18,19,23–25,27,30,32,36] Although an almost universal agreement exists on the segmentation of the distal ACA, the relationship between the PrCA and the CMA remains debatable. Because the origin of each cortical branch and the diameter of the distal ACA are different in each hemisphere, it is not always possible to define a standard vascularization pattern for the distal ACA (Fig. 1). No substantial information exists on whether the exit angles of the cortical branches from the main trunk affect the vascularization pattern of the hemisphere or on how the arterial diameter influences hemispheric dominance. Our particular aim in undertaking this study was to address the controversial issues that remain regarding the distal ACA.

Abbreviations used in this paper: ACA = anterior cerebral artery; ACoA = anterior communicating artery; AIFA = anterior internal frontal artery; ASA = anterior spinal artery; CC = corpus callosum; CMA = callosomarginal artery; FPA = frontopolar artery; HRA = Heubner recurrent artery; IFA = internal frontal artery; IIPA = inferior internal parietal artery; MIFA = middle internal frontal artery; OFA = orbitofrontal artery; PrCA = pericallosal artery; PIFA = posterior internal frontal artery; PLA = paracentral lobe artery; SIPA = superior internal parietal artery.

Materials and Methods

One hundred cerebral hemispheres from 50 adult cadaveric brains were obtained, a total suitable for statistical analysis. Brains having signs of central nervous system trauma or disease were excluded. Cerebral arteries were separately cannulated and injected with latex. The brains were then fixed in formaldehyde. The dissections were performed using microsurgical instruments and a surgical microscope (Opmi 99; Carl Zeiss, Göttingen, Germany) according to a surgical protocol. All measurements were hand calibrated precisely (0.1 mm). Standard goniometry (precision 1˚) was used in performing angular measurements. The following measurements were obtained: 1) the diameter of the distal ACA at its branches (that is, the HRA, OFA, FPA, IFA, AIFA, MIFA, PIFA, PLA, CMA, SIPA, and IIPA at each of their origins); 2) the angle between the PrCA and the CMA; 3) the point at which the cortical branches exit; and 4) the variations of the distal ACA.

Results

The mean diameter of the distal ACA at its origin was 2.75 mm (range 2.02–3.75 mm). The HRA originated from

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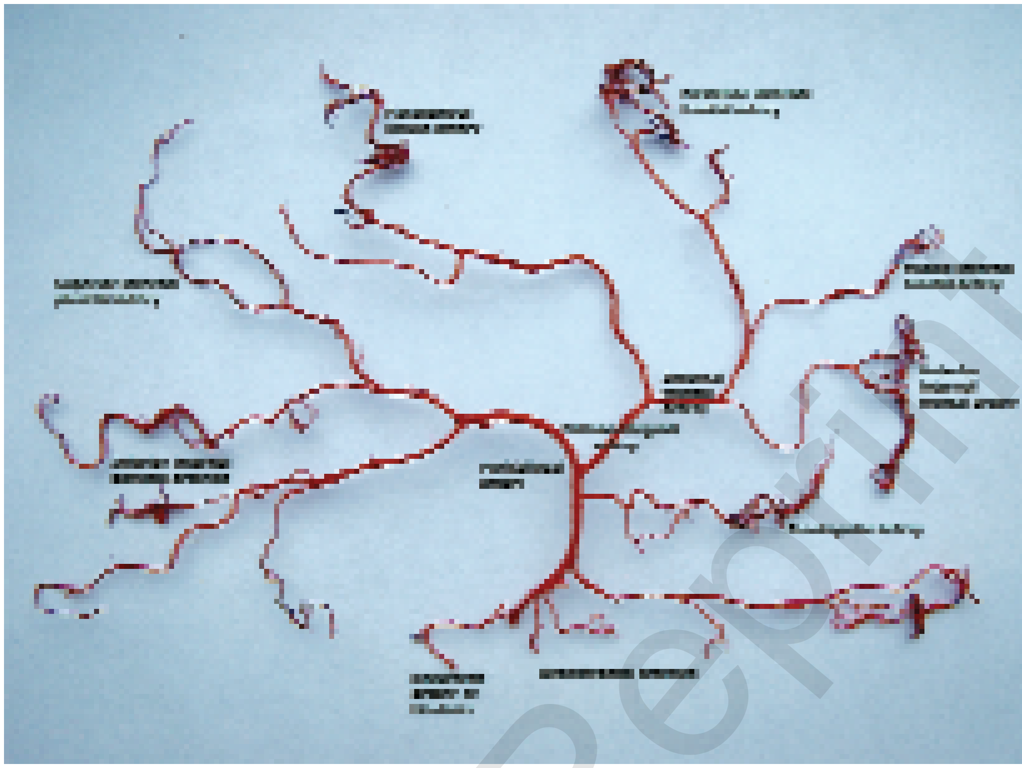

FIG. 1. Photograph showing a standard vascularization pattern of the distal ACA in a hemisphere after the parenchyma has been removed

the distal ACA in 50% of the hemispheres. In 46 hemispheres it originated from the main A_2 trunk; it arose from the OFA in two, from the CMA in one, and from the FPA in one. Two HRAs were detected in 10% of the hemispheres. The OFA was the smallest cortical branch of the distal ACA, and in 64% of the hemispheres it originated from the A_2 segment. The position of the OFA was consistent in all dissected hemispheres. In 42, 16, and 4% of the hemispheres, two, three, and four OFAs were observed, respectively. The FPA was the second cortical branch of the distal ACA. In 72% of the hemispheres it originated from the A_2 segment, in 14% from the IFA, in 9% from the CMA, and in 3% from the AIFA. We observed the FPA in 98% of the dissected hemispheres.

TABLE 1

*Morphometric measurements for arteries studied**

Type of Artery	Presence (%)	Diameter at Origin (mm)*	Most Common Segment of Origin
HRA	50	0.8 (0.5–1)	not applicable
OFA	100	1.13 (0.48–1.85)	A_2
FPA	98	1.41 (0.56–2.50)	A_2
IFA	58	1.73 (0.99–2.52)	A_3
AIFA	100	1.27 (0.48–2.06)	IFA
MIFA	100	1.23 (0.63–1.89)	IFA
PIFA	100	1.33 (0.72–2.09)	CMA
CMA	49† & 34‡	1.91 (1.20–2.96)	A_3
PLA	100	1.40 (0.55–2.02)	CMA
SIPA	88	1.28 (0.69–1.89)	A_4
IIPA	85	1.19 (0.51–1.78)	A_5

* Values are means, with the ranges in parentheses.
† Hemisphere with a typical CMA.
‡ Hemisphere with an atypical CMA.

The IFA originated in 75% of the hemispheres from the A_3 segment, in 15% from the CMA, and in 10% from the A_2 segment. We observed the IFA in 58% of the hemispheres. In 45% of them, it arose as a single trunk and then branched off into the AIFA, MIFA, and PIFA. In 40% of the hemispheres, it branched off into the AIFA and the MIFA, whereas in 15% it branched off into the MIFA and the PIFA. The IFA originated in 53% of the hemispheres from the IFA, in 18% from the CMA, in 15% from the FPA, in 10% from the A_3 segment, and in 4% from the A_2 segment. It was observed as a single trunk in all of the hemispheres. The MIFA originated in 50% of the hemispheres from the IFA; in 25% from the CMA, in 21% from the A_3 segment, and in 4% from the FPA. It was observed as a single trunk in all of the hemispheres. The PIFA originated in 48% of the hemispheres from the CMA, in 32% from the IFA, in 12% from the A_3 segment, in 6% from the PLA, and in 2% from the A_4 segment. It was observed as a single trunk in all the hemispheres.

The mean exit angle of the CMA from the main trunk was 55˚ (range 8–105˚). It originated in 64% of the hemispheres from the A_3 segment, in 18% from the A_2 segment, in 12% from the A_4 segment, and in 6% from the ACoA. In 15% of the hemispheres, the CMA was larger than the PrCA was at the bifurcation, whereas the reverse was true in 60% of the hemispheres. In 25%, the diameters of the PrCA and the CMA were the hemispheres. In 17%, the

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FIG. 2. Photographs of an azygos artery *(asterisk)*, which is visible as it courses to the left hemisphere. *Left*: Before disconnection of the hemispheres. *Right*: After disconnection

CMA was not detected. In 34%, atypical CMAs were observed, whereas in 49% they were typical.

The PLA originated in 66% of the hemispheres from the CMA, in 18% from the A_4 segment, in 12% from the A_3 segment, in 2% from the IFA, and in 2% from the opposite A_4 segment. The PLA was consistent in all the hemispheres dissected. It supplied the internal and medial third of the lateral surface of the premotor, motor, and sensorial cortices. In 9% of the hemispheres, it extended as far as the middle part of the lateral surface of the precentral gyrus.

The SIPA originated in 33% of the hemispheres from the A_4 segment in 30% from the CMA, in 24% from the A_5 segment, in 10% from the PLA, and in 3% from the A_3 segment. We observed the SIPA in 88% of the dissected hemispheres. The IIPA was the terminal branch of the distal ACA. It originated in 75% of the hemispheres from the A_5 segment, in 15% from the SIPA, and in 10% from the A_4 segment. We observed the IIPA in 85% of the dissected hemispheres, and in 2% of them it supplied the medial surface of the occipital lobe.

In our dissections, the PrCA had an interesting relationship with CMAs originating from the ACoA. In six hemispheres in which the CMA originated from the ACoA, the PrCA was observed but in none of the others was it detected. Some of the relevant morphometric measurements are presented in Table 1.

Crossing vessels were detected primarily at the anterior frontal pole, the orbital surface of the frontal lobe, and the splenium CC. In two hemispheres, azygos ASAs were observed (Fig. 2). In one brain, a single ASA was seen. The opposite ASA was aplastic, and there was no ACoA complex. All the internal parts of both hemispheres were supplied by one ACA. An aneurysm was found on the ACA in this brain (Fig. 3).

Discussion

Although the distal ACA seems to have a simpler structure than other cerebral arteries, it has more variations than the middle cerebral artery, which is known for its complex structure. Rhoton[27] deems the PrCA to be the primary artery advancing after the ACoA and the extension of the A_1 segment. Despite being the thickest branch of the PrCA, the CMA has not been found suitable for classification as the extension of the A_1 segment because it is not always present. On the other hand, some authors have claimed that the PrCA comes into existence after its bifurcation point with the CMA, and taking the width of these arteries and the size of the area they supply into consideration, the main or dominant branch should be determined.[6,11,25,30,33] In addition to the controversies over the relationships and anatomical characteristics of these two arteries, there is no classic and/ or standard definition of the CMA. Moscow and colleagues[19] reported that the CMA produced two or more cortical branches on its course within or on the edge of the cingulate sulcus. The work of Ono, et al.,[22] demonstrated the classic structure of the cingulate sulcus in only 60% of hemispheres studied, which indicates the lack of a standard in defining the CMA. A classification method that could provide standardization and eliminate present controversies is required for a sound definition of the CMA. A perusal of the literature reveals disparate rates, such as 40 and 85%, for the presence of the CMA.[11,29] This lack of consistency substantiates the position of authors who believe the artery cannot be classified because it is not always present. Hence, considering the studies conducted to date and discussions evolving around this issue, it appears that the CMA should not be classified on the basis of its origin, its diameter at the origin, the areas it supplies, or its cortical branches. An artery originating from the A_4 segment, coursing in the cingulate sulcus, and producing cortical branches was defined as a cortical branch arising from the PrCA and producing the PLA and the SIPA by one researcher, whereas another researcher defined it as a CMA originating from the A_4 segment. According to the definition of Moscow and colleagues, the cortical artery identified in the hemisphere pictured in Fig. 4 *upper left* enters and advances in the cingulate sulcus while producing cortical branches. The artery

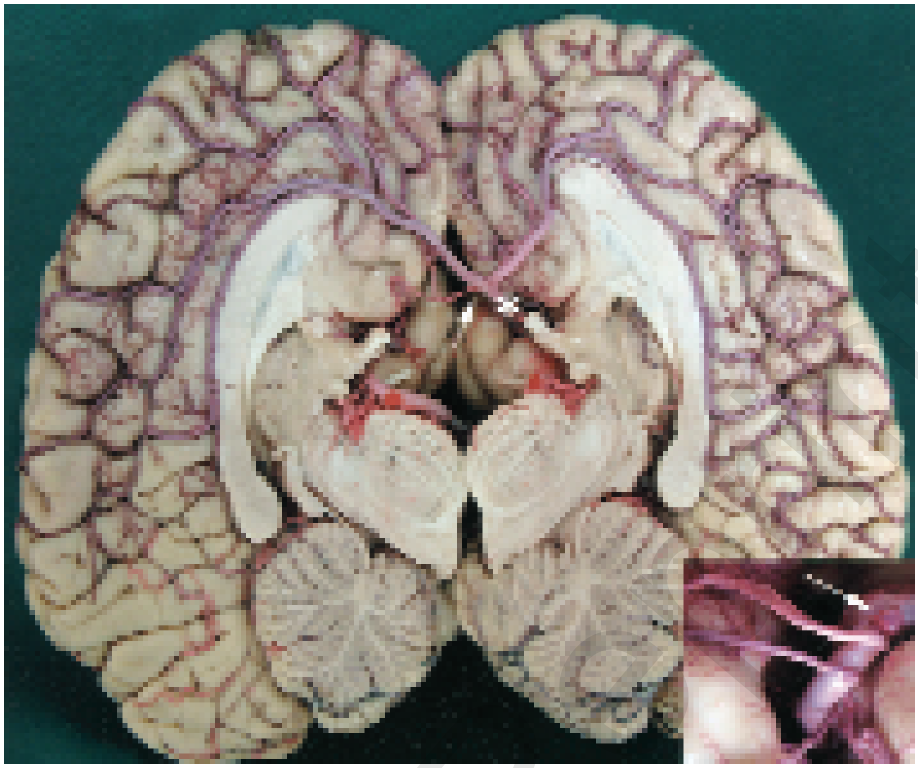

FIG. 3. Photograph of a brain supplied by one ACA *(asterisk)* without constituting a communicating artery complex. An aneurysm *(arrow)* is present. *Inset* shows another view of the aneurysm.

arising from the region of this cortical artery matches the definition of a CMA. Given these factors, how can the presence of a CMA in this hemisphere be defined? It is not easy to declare that those claiming the presence of two CMAs or those referring to the second branch as a cortical branch of the PrCA are producing either valid or incorrect definitions. Therefore, we propose a new way to define CMAs according to whether a hemisphere has no CMAs, an atypical one, or a typical one.

Hemispheres With No CMAs

In our study, four common basic features were noted in this type of hemisphere. One such characteristic was the absence of a marked artery within the cingulate sulcus, as described by Moscow and colleagues.[19] The second characteristic was that all cortical branches arose from the PrCA at a right angle and, without following a tortuous course, directly reached the cortex they supplied. Almost identical distances between the cortical branches that arose from the PrCA was the third characteristic. The fourth was that these cortical branches had nearly identical diameters (Fig. 4 *upper right*).

Hemispheres With Atypical CMAs

One of the common features of this type of hemisphere was the lack of a long course where the arteries entered the cingulate sulcus (Fig. 4 *lower left*). Furthermore, this type of hemisphere was mostly devoid of an uninterrupted cingulate sulcus. The CMAs often originated from the A_3 segment; thus, they can often be mistaken for IFAs. Unlike IFAs, however, the CMAs reached as far as the paracentral lobule behind the superior frontal gyrus. They did not have a pronounced path parallel to the PrCA and had smaller diameters. After diverting from the PrCA, the CMAs produced a thick trunk composed of the MIFA and the PIFA and a thinner trunk running to the paracentral lobule. Another cortical branch originated from the PrCA and advanced directly to the paracentral lobule. Similarly, the FPA and IFA arose in these hemispheres from a location proximal to the CMA in a single or thick trunk. There was no significant distance between the branches arising from the PrCA. There may be two symmetrical CMAs occurring in the same hemisphere (Fig. 4 *upper left)*.

Hemispheres With Typical CMAs

The distinguishing feature of these hemispheres was the relatively longer course of the CMA entering the cingulate sulcus, which runs parallel to the PrCA (Fig. 4 *lower right*). The CMA originated from the A_2 segment less frequently than it did from the A_3 segment. Most of the cortical branches arose from the CMA. Furthermore, there were no significant differences between the diameters of the CMA and the PrCA.

Although the HRA has been reported to arise from the A_2 segment,[1,7,25] less frequently it has been noted to arise from its cortical branches.[18] In our dissections, we found that it arose from the OFA at a rate of 2%, from the CMA at a rate of 1%, and from the FPA at a rate of 1%. In addition, in 10% of the dissections, two HRAs originating from the A_2 segment were detected. Without a doubt, awareness of this type

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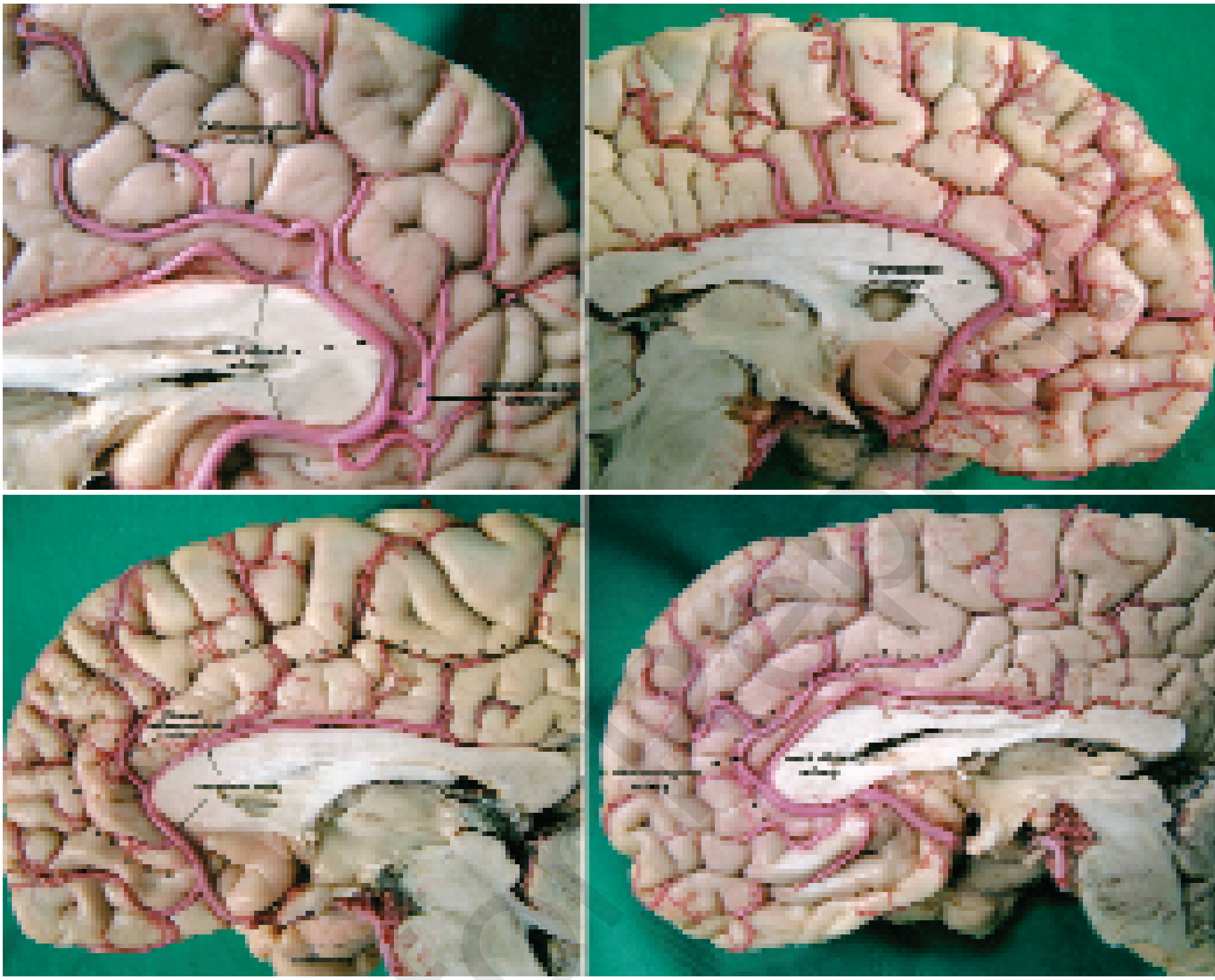

FIG. 4. *Upper Left* and *Right*: Photographs of an atypical hemisphere with two symmetrical CMAs and a hemisphere with no CMA, respectively (*arrowheads* indicate the cingulate sulcus). In the latter, cortical branches from the A_4 segment of the distal ACA have surrounded the medial part of the precentral gyrus. *Lower Left* and *Right:* Photographs of hemispheres containing atypical and typical CMAs, respectively. *Arrowheads* indicate an interrupted cingulate sulcus in the former and a cingulate sulcus in the latter.

of variation will provide great benefits in surgical interventions taking place in the area supplied by the HRA.

The OFA was observed in all hemispheres. Although it is reported to originate most frequently from the A_2 segment and the FPA;[25] in our study it was also detected arising from the IFA and the CMA. Furthermore, it arose from the A_1 segment at a rate of 1%. More than one branch of the OFA supplied the orbitofrontal gyrus; thus, in arterial occlusion, the orbitofrontal gyrus seems to carry fewer risks for ischemia. The FPA usually arose directly from the A_2 segment.

The IFA was one of the most variable branches of the distal ACA. Although all three frontal arteries sometimes arose from a single IFA, on occasion they originated from the CMA as well. In some hemispheres, they also arose in groups of two from the other cortical branches or individually from the A_2 segment.

When the area supplied by the PLA as well as its origin and course are considered, it would not be wrong to describe it as the most regular branch of the distal ACA with the least number of variations. The most significant feature of the IIPA is that frequently it was the terminal branch of the distal ACA. The SIPA, on the other hand, mostly arose from the PrCA, and sometimes from the CMA or the PLA. It should be noted that the IIPA can reach the occipital region. Arteries coursing downward around the splenium CC and reaching the epiphysis were also observed.

The precallosal artery and the CMA were frequently found together (a conjunction not mentioned previously in the literature), and they had proximal origins as well (Fig. 5). Atrophic PrCAs in these hemispheres were insufficient in supplying the CC, which was compensated for by the PrCA. This strong coexistence has not been mentioned in the literature.

A rare variation of the single A_2, which feeds both hemispheres by only one branch, has been previously described. These cases have been termed "unpaired," "arteria terma-

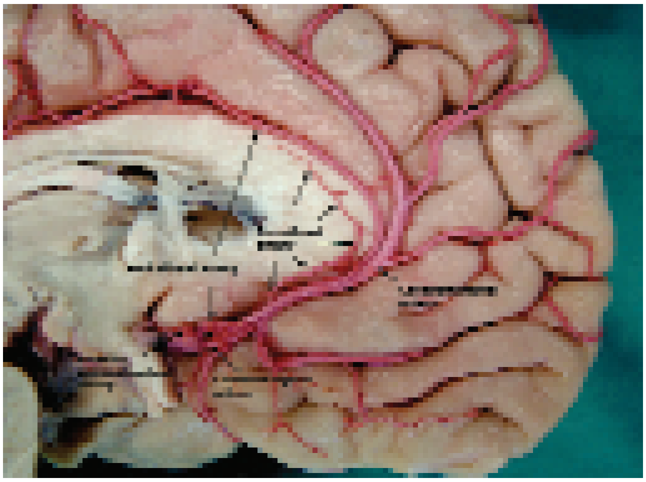

FIG. 5. Photograph showing the presence of a PrCA with a proximally originating CMA.

tica," and, more commonly, "arteria pericallosa azygos." The literature contains studies pointing to a high risk of aneurysm in such cases.[13,27,31,36,37] In our dissections, we observed azygos anterior cerebral arteries in two hemispheres (Fig. 2).

To date, a vascularization pattern supplying both hemispheres alone with no communicating artery formation and only one ACA has never been described. In such a brain, an aneurysm formation was discovered proximal to the artery (Fig. 3). It seems necessary to be aware to be mandatory to be aware of the anatomy and variations of the distal ACA so that confident surgical and endovascular interventions can be performed.[3,4,9,10,14–17,20,21,26,28,35,38]

Another unaddressed issue concerns the manner in which the angles of the cortical arteries arising from the PrCA affect the vascularization pattern. The measurement of the angle between the PrCA and the CMA in particular provided valuable information about the hemisphere. For example, in CMAs with proximal origin, there was usually a narrow angle between the PrCA and the CMA, and the internal surfaces of such hemispheres were significantly supplied by the CMA. At the A_3 level, where bifurcation mostly occurred as the angle grew, the dominance was in favor of the PrCA. Although the CMA was previously reported as present in only 50% of angiography sessions,[23] cautious preoperative angle measurements on the angiography when intervening in this area may provide better interpretations of the vascularization pattern of the gyri.

Conclusions

The vascularization pattern and variations of the distal ACA were investigated in 100 hemispheres. The origin of the arteries from the main trunk and the exit angles affected the vascularization pattern found in the hemispheres. We propose a new way to define CMAs according to whether a hemisphere has no CMA, an atypical one, or a typical one. In each hemisphere, the vascularization pattern of the distal ACA differs to a greater or lesser extent. Awareness of this fact will contribute greatly to surgical interventions.

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Address reprint requests to: Hasan C. Ugur, M.D, Ph.D, Department of Neurosurgery, Ankara University, 06100 Sihiye, Ankara, Turkey. email: hasanugur2001@hotmail.com.

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