Arterial vascularisation of the anterior perforated substance

Sen T, Esmer A F, Acar H I, Karahan S T, Tuccar E

ABSTRACT

Introduction: The arteries of the anterior perforated substance (APS) are important due to their role in supplying blood to important internal structures such as the internal capsule, putamen and caudate nucleus. The purpose of this study was to investigate in detail the arteries of the APS.

Methods: The arteries of the APS were investigated in 60 cerebral hemispheres from 30 adult cadaveric brains. The internal carotid arteries were cannulated and perfused with coloured latex. The branches of the middle cerebral artery (MCA) penetrating the APS were investigated. These arteries, known as the lateral lenticulostriate arteries and originating from the M1 segment, early temporal and early frontal branches of the MCA, were recorded.

Results: The branches of the anterior choroidal artery, which reached the APS, were seen in all specimens. We found one to three branches that arose from the A2 segment of the anterior cerebral artery (ACA) to the APS in all hemispheres, and one to three branches that originated from the A1 segment of the ACA in 48 hemispheres. In addition, two accessory MCAs that originated from the A2 segment of the ACA were recorded as variations, and perforating branches to the APS were observed.

Conclusion: Serious complications like motor deficits can occur as a result of injury to the arteries of the APS. Hence, neurosurgeons performing operations such as aneurysm or insular tumour surgeries must be aware of the importance of preserving these arteries.

Keywords: anatomy, anterior cerebral artery, anterior perforated substance, middle cerebral artery

Singapore Med J 2011;52(6):410-414

Department of Anatomy, Ankara University School of Medicine, Morfoloji Binasi, Sihhiye, Ankara 06100, Turkey

Sen T, MD
Senior Consultant

Esmer AF, MD
Senior Consultant

Acar HI, MD
Associate Professor

Karahan ST, MD
Professor

Tuccar E, MD, PhD
Professor

Correspondence to:
Dr Ali Firat Esmer
Tel: (90) 312 3105001
Fax: (90) 312 3105001
Email: alife76@yahoo.com

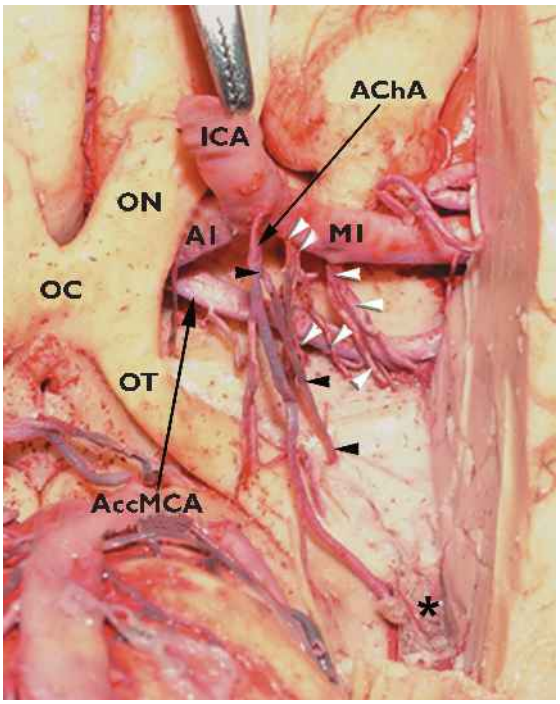

Fig. 1 Photograph shows the inferior aspect of a cadaveric brain. The ICA has been retracted anteriorly. The lateral lenticulostriate arteries (white arrowheads) that originate from the M1 and the branch of the AChA (black arrowheads) that penetrates the anterior perforated substance are seen.
* indicates choroidal plexus of the lateral ventricle.
ICA: internal carotid artery; A1: A1 segment of the anterior cerebral artery; M1: M1 segment of the middle cerebral artery; AccMCA: accessory middle cerebral artery; AChA: anterior choroidal artery; ON: optic nerve; OC: optic chiasm; OT: optic tract

INTRODUCTION

Anterior perforated substance (APS) is a landmark in the basal forebrain located between the olfactory trigonum and optic tractus above the cerebral arteries. The arteries of the APS play an important role in the supply of blood to the internal capsule, putamen, caudate nucleus and globus pallidus.[1] These arteries, known as the anterior perforating arteries, usually arise from the middle and anterior cerebral arteries and the anterior choroidal arteries. The branches of the middle cerebral artery (MCA) to the APS are known as the lenticulostriate arteries.[2] The purpose of this study was to investigate in detail the arteries of the APS.

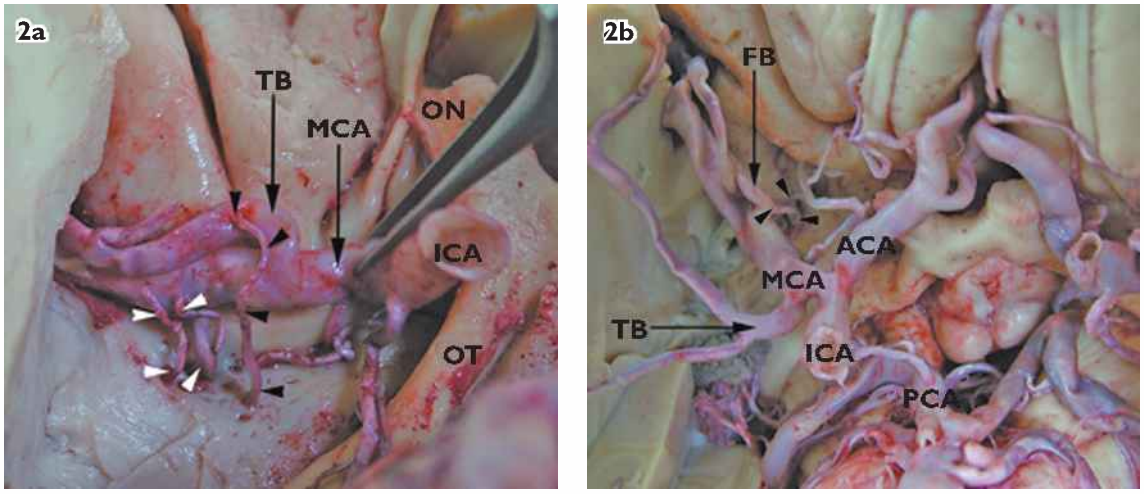

Fig. 2 Photographs show the inferior aspect of a right cerebral hemisphere. (a) The LLAs originate from the early temporal branch of the MCA (black arrowheads) and from the M1 segment of the MCA (white arrowheads). (b) The LLAs originate from the early frontal branch of the MCA (black arrowheads).
LLAs: lateral lenticulostriate arteries; MCA: middle cerebral artery; ICA: internal carotid artery; ON: optic nerve; OT: optic tract; TB: early temporal branch of the MCA; FB: early frontal branch of the MCA; ACA: anterior cerebral artery; PCA: posterior cerebral artery

METHODS

The arteries of the APS were investigated in 60 cerebral hemispheres from 30 adult cadaveric brains. Brains having signs of central nervous system trauma or disease were excluded. First, the internal carotid arteries were cannulated and perfused with coloured latex in fresh brains, after which the brains were embalmed in 10% formaline solution for fixation. Dissections were performed using microsurgical instruments and an OPMI 99 surgical microscope (Carl Zeiss, Göttingen, Germany). The number of arteries of the APS was recorded, and their origins were investigated. The Statistical Package for the Social Sciences version 15.0 (SPSS Inc, Chicago, IL, USA) was used for statistical analyses. A p-value < 0.05 was considered to be statistically significant. Overall measurements were evaluated with the Wilcoxon signed-rank test.

RESULTS

In all the 60 specimens, the internal carotid artery (ICA) bifurcated into the MCA and anterior cerebral artery (ACA) below the central portion of the APS. The branches of the MCA that penetrated the APS (lateral lenticulostriate arteries [LLAs]) were investigated. In all hemispheres, the average number of LLAs that arose from the M1 segment of the MCA was seven (range 4–11) (Figs. 1 & 2a). The number of LLAs on the left and right cerebral hemispheres was 6–11 and 4–10, respectively. No statistically significant difference was observed between the two sides with the Wilcoxon signed-rank test ($p = 0.764$ left, $p > 0.05$ right). We observed early temporal branches, which arose from the M1 segment in 41 (68.3%) specimens (22 on the left hemisphere and 19 on the right). In five (8.3%) of these specimens, the early frontal branches were also determined (three on the left hemispheres and two on the right) as a branch of the M1 segment.

The LLAs arose from the early temporal branch in eight (13.3%) hemispheres (three on the left side and five on the right), and the average number was one (range 1–3) (Fig. 2a). In four (6.6%) hemispheres (two on the left side and two on the right), the LLAs arose from the early frontal branch with an average number of two (range 1–4) (Fig. 2b). We also determined an LLA (one right and one left hemisphere) that originated from the superior trunk of the MCA, immediately after the bifurcation in the two hemispheres (Fig. 3).

The branches of the anterior choroidal artery that penetrated the APS were investigated. We observed 1–2 branches of the anterior choroidal artery in all hemispheres (Fig. 1). The branches of the ACA that penetrated the APS usually arose from the A2 segment of the ACA. The average number of anterior perforated arteries originating from the A2 segment was one (range 1–3) in all hemispheres (Fig. 3). In 48 (79.8%) of the hemispheres (27 left and 21 right), we also observed that 1–3 branches originating from the A1 segment of the ACA penetrated the APS (Fig. 4).

Two accessory MCAs (accMCAs) were also found to be variations, with both of them originating from the A2 segment of the ACA near the anterior communicating artery (AComA) and coursing parallel to the MCA. Both

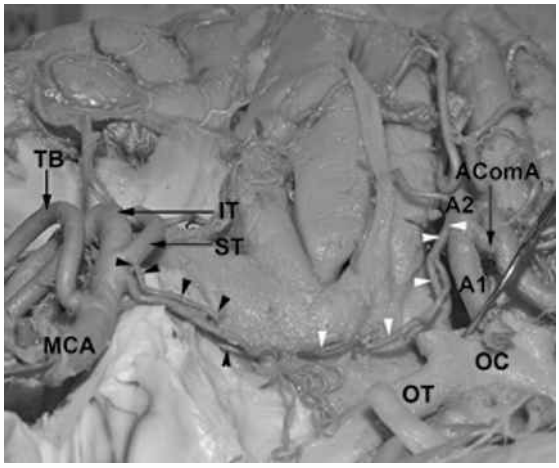

Fig. 3 Photograph shows bifurcation of the ICA. The ICA is dissected to separate the MCA and ACA, after which they are respectively retracted laterally and medially to expose the arteries of the anterior perforated substance. The lateral lenticulostriate artery originates from the ST trunk of the MCA (black arrowheads), while the anterior perforating artery arises from the A2 segment of the ACA (while arrowheads).
ICA: internal carotid artery; ACA: anterior cerebral artery; MCA: middle cerebral artery; TB: early temporal branch of the MCA; IT: inferior trunk of the MCA; ST: superior trunk of the MCA; OC: optic chiasm; OT: optic tract; A1: A1 segment of the ACA; A2: A2 segment of the ACA; AComA: anterior communicating artery

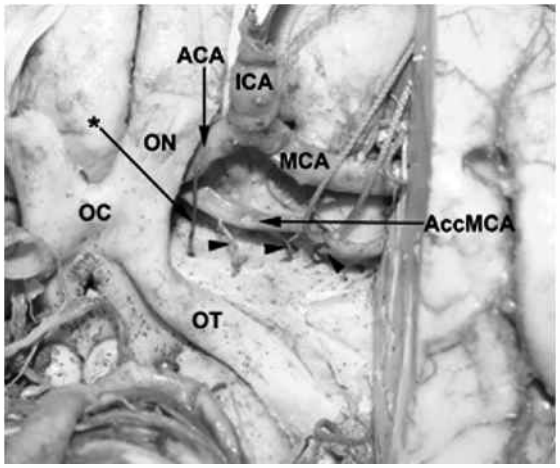

Fig. 4 Photograph shows the anterior choroidal artery and LLAs arising from the MCA, which are removed for a better aspect of the AccMCA. The AccMCA is retracted anteriorly with a suture to show the LLAs that originated from it. The LLAs arise from the AccMCA (black arrowheads) and the anterior perforating artery arises from the A1 segment of the ACA (*).
LLAs: lateral lenticulostriate arteries; ON: optic nerve; OC: optic chiasm; OT: optic tract; ICA: internal carotid artery; ACA: anterior cerebral artery; MCA: middle cerebral artery; AccMCA: accessory middle cerebral artery

accMCAs were found in the left cerebral hemispheres, and gave rise to three and four perforating branches of the APS (Fig. 4).

DISCUSSION

The MCA is divided into four major segments: (a) The M1 (sphenoidal) segment extends from the terminal bifurcation of the ICA to the main MCA bifurcation, which is usually located at the level of the limen insulae; (b) The M2 (insular) segment, which includes the superior and inferior trunks of the MCA, extends from the main bifurcation to the peri-insular sulci; (c) The M3 (opercular) segment extends from the peri-insular sulci to the cortical surface of the sylvian fissure; and (d) The M4 (cortical) segment is located on the parasylvian surface of the brain and spreads over the cortical surface.[3]

According to Fischer,[4] the ACA is divided into five major segments. The A1 segment (proximal ACA) extends from the terminal bifurcation of the ICA to the AComA. The A1 segment ends and the A2 segment begins at the level of the AComA. The A2 segment extends to the region between the rostrum and the genu of the corpus callosum (CC). The A3 segment curves around the genu of CC and ends at the rostral part of the body of the CC. The A4 and A5 segments follow the superior surface of the CC. The A4 segment 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. The A5 segment extends from the point at which the CC intersects with the coronal suture to the splenium of the CC.[4] In this study, we focused on the perforating branches of the A1 and proximal A2 segments of the ACA.

The microsurgical anatomy of the LLAs has been examined in detail in many studies.[1,3,5-7] Türe et al found 1–15 (average 7.75) LLAs, while Marinkovíc et al observed 3–18 (average nine) LLAs that originated from the M1 segment of the MCA.[1,5] Similar findings were noted in our study as well. The cortical arteries arising from the main trunk of the MCA before bifurcation are called 'early branches'.[8] Türe et al reported LLAs originating from the early frontal branch of the M1 in nine (22.5%) hemispheres,[1] while we observed this in four (6.6%) hemispheres and LLAs from the early temporal branch in eight (13.3%) hemispheres. Umansky et al reported 5.7% of perforating arteries arising from the early branches of the MCA,[9] while Marinkovíc et al found one or more LLAs originating from the early branches in a quarter of the hemispheres.[5] Also, nearly one in five LLAs arose from an early branch in the study of Tanriover et al.[10] When early cortical branches exist as a branch of the MCA, the LLAs have a high possibility of originating from these arteries. Yasargil's studies found that the frequency and site of origin of the early branches as well

as the course and number of LLAs arising from them have practical application in transsylvian approaches, which require exposure of part or all of the insula.[11,12]

Chyatte and Porterfield reported that LLAs arising from the M1 trunk never supply the frontal lobe, and therefore, it is easier to retract the frontal lobe away from the MCA during surgery.[13] Moreover, Tanrıover et al also reported in their study that an early frontal branch arising from the M1 segment may exist in more than 30% of cases, and on average, this gives rise to more LLAs per vessel than the early temporal branch. They also added that if a large, proximal early frontal branch is seen to give rise to several LLAs on an angiogram, consideration should be given to the initial retraction of the temporal lobe rather than the frontal lobe, away from the MCA.[10] Hence, surgeons must be aware of the possibility of such a situation arising during surgery. Türe et al recorded LLAs originating from the superior or inferior trunk of the M2 segment, which are located near the main bifurcation of the MCA, in three (7.5%) hemispheres.[1] However, we observed that the LLAs originated from the superior trunk of the MCA in only two (3.3%) hemispheres, but none from the inferior trunk. In addition, it has been noted that the LLAs usually arise from the pre-bifurcation trunk of the MCA in previous studies, and our results were concordant with this finding.[1,11,12]

The LLAs that penetrate the APS play an important role in the supply of blood to the internal capsule, putamen, caudate nucleus and globus pallidus.[1,14] The APS lies just medial to the limen insulae and serves as an important surgical landmark. In their study, Tanrıover et al considered the point of entrance of the most lateral LLA to be the lateral limit of the APS, and referred to it as the "limen recess", which is between the medial border of the limen insulae and the point of entrance of the most lateral LLA.[15] The limen recess is devoid of important perforating arteries and may be used as the medial limit of dissection during insular tumour surgery. Thus, an awareness of the location of the most lateral LLA may be helpful during insular tumour surgery, as motor deficits, such as hemiparesis due to obliteration of these perforating arteries, constitute a significant number of complications that occur following such surgeries.[15-17] It is well known that aneurysms on the MCA are not unusual. The orifices of LLAs can be affected by these aneurysms, and thus, the surgical procedures used for the treatment of aneurysms may damage the LLAs.[12,18]

In our study, the anterior perforating arteries arose from the anterior choroidal artery in all 60 hemispheres. However, Rosner et al noted that these arteries arose from the main trunk or superior branch of the anterior choroidal artery and enter the brain through the APS. In addition, they also reported that the anterior perforating arteries arose from the ICA,[2] which differs from our findings. Previous studies have found that the arteries of APS originate from the A1 or A2 segments of the ACA;[2,19,20] these findings were also observed in our study. As mentioned earlier, like the LLAs that originate from the MCA, these arteries have an important role to play in the supply of blood to some important internal structures such as the internal capsule or nuclei basales.[2,12,21]

The accMCA usually originates from the ACA, particularly from its A1 or the proximal part of the A2 segments, and courses parallel to the MCA. This artery supplies the orbitofrontal and prefrontal regions of the territory of the MCA.[10,22,23] Knowledge of the accMCA is important for the surgical treatment of cerebral aneurysms and for understanding the collateral blood supply in cerebral ischaemia.[24,25] The incidence of accMCA has been reported to be 0.4%–4% (approximately 3%).[10-12,22,23] In our study, this variation was seen in two (3.3%) hemispheres. The perforating branches of the accMCA to the APS have been mentioned in previous studies,[3,10,11,22,23,26] and this finding was observed in both cases of accMCA in our study. Therefore, when the accMCA appears as a variation, the high possibility of its branches perforating to the APS must be considered during surgery.

In conclusion, this study highlights the complex arterial vascularisation of the APS. The arteries of APS are important due to their role in supplying blood to important structures such as the internal capsule, putamen, caudate nucleus and globus pallidus. Neurosurgeons must be aware of the importance of preserving these arteries and should also keep in mind that damage to these arteries during aneurysm or insular tumour surgery can cause serious motor complications such as dyskinesias, hemiparesis or hemiplagias.

REFERENCES

1. Türe U, Yaşargil MG, Al-Mefty O, Yaşargil DC. Arteries of the insula. J Neurosurg 2000; 92:676-87.
2. Rosner SS, Rhoton AL Jr, Ono M, Barry M. Microsurgical anatomy of the anterior perforating arteries. J Neurosurg 1984; 61:468-85.
3. Gibo H, Carver CC, Rhoton AL Jr, Lenkey C, Mitchell RJ. Microsurgical anatomy of the middle cerebral artery. J Neurosurg 1981; 54:151-69.
4. Fischer E. [Positional variations of the anterior cerebral artery in the vascular picture]. 1938; 3:300-12. German.
5. Marinković SV, Kovacević MS, Marinković JM. Perforating branches of the middle cerebral artery. Microsurgical anatomy of their extracerebral segments. J Neurosurg 1985; 63:266-71.
6. Marinkovic SV, Milisavljevic MM, Kovacevic MS, Stevic ZD. Perforating branches of the middle cerebral artery. Microanatomy

and clinical significance of their intracerebral segments. Stroke 1985; 16:1022-9.
7. Umansky F, Juarez SM, Dujovny M, et al. Microsurgical anatomy of the proximal segments of the middle cerebral artery. J Neurosurg 1984; 61:458-67.
8. Crompton MR. The pathology of ruptured middle-cerebral aneurysms, with special reference to the differences between the sexes. Lancet 1962; 2:421-5.
9. Umansky F, Gomes FB, Dujovny M, et al. The perforating branches of the middle cerebral artery. A microanatomical study. J Neurosurg 1985; 62:261-8.
10. Tanriover N, Kawashima M, Rhoton AL Jr, Ulm AJ, Mericle RA. Microsurgical anatomy of the early branches of the middle cerebral artery: morphometric analysis and classification with angiographic correlation. J Neurosurg 2003; 98:1277-90.
11. Yasargil MG. Microneurosurgery, Vol I. Stuttgart: George Thieme Verlag, 1984.
12. Yasargil MG. Microneurosurgery, Vol II. Stuttgart: George Thieme Verlag, 1984.
13. Chyatte D, Porterfield R. Nuances of middle cerebral artery aneurysm microsurgery. Neurosurgery 2001; 48:339-46.
14. Marinkovic S, Gibo H, Milisavljevic M, Cetkovic M. Anatomic and clinical correlations of the lenticulostriate arteries. Clin Anat 2001; 14:190-5.
15. Tanriover N, Rhoton AL Jr, Kawashima M, Ulm AJ, Yasuda A. Microsurgical anatomy of the insula and the sylvian fissure. J Neurosurg 2004; 100:891-922.
16. Lang FF, Olansen NE, DeMonte F, et al. Surgical resection of intrinsic insular tumors: complication avoidance. J Neurosurg 2001; 95:638-50.
17. Zentner J, Meyer B, Stangl A, Schramm J. Intrinsic tumors of the insula: a prospective study of 30 patients. J Neurosurg 1996; 85:263-71.
18. Rhoton AL Jr. Anatomy of saccular aneurysms. Surg Neurol 1980; 14:59-66.
19. Gomes FB, Dujovny M, Umansky F, et al. Microanatomy of the anterior cerebral artery. Surg Neurol 1986; 26:129-41.
20. Perlmutter D, Rhoton AL Jr. Microsurgical anatomy of the anterior cerebral-anterior communicating-recurrent artery complex. J Neurosurg 1976; 45:259-72.
21. Marinkovic S, Gibo H, Brigante L, Milisavljevic M, Donzelli R. Arteries of the Brain and Spinal Cord. Anatomic Features and Clinical Significance. Avellino: De Angelis, 1997: 201-25.
22. Takahashi S, Hoshino F, Uemura K, Takahashi A, Sakamoto K. Accessory middle cerebral artery: is it a variant form of the recurrent artery of Heubner? AJNR Am J Neuroradiol 1989; 10:563-8.
23. Umansky F, Dujovny M, Ausman JI, Diaz FG, Mirchandani HG. Anomalies and variations of the middle cerebral artery: a microanatomical study. Neurosurgery 1988; 22:1023-7.
24. Komiyama M, Nishikawa M, Yasui T. The accessory middle cerebral artery as a collateral blood supply. AJNR A J Neuroradiol 1997; 18:587-90.
25. Kwak R, Kuwahara K, Niizuma H, Suzuki J. [Anomalies of the middle cerebral artery with intracranial saccular aneurysms: duplication and fenestration]. No Shinkei Geka. 1979; 7:691-6. Japanese.
26. Komiyama M, Nakajima H, Nishikawa M, Yasui T. Middle cerebral artery variations: duplicated and accessory arteries. AJNR Am J Neuroradiol 1998; 19:45-9.