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ORIGINAL ARTICLES

Variations of anterior cerebral artery in human cadavers

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Abstract

Background: Anterior cerebral artery is an important terminal branch of internal carotid artery. It forms the anterior component of circle of Willis along with the anterior communicating artery. Circle of Willis is known for the frequent variations. The knowledge of anatomical variations in anterior cerebral artery is of considerable help to clinicians. *Method:* Morphology and variations of the anterior cerebral arteries and the anterior communicating artery were studied in 112 formalin preserved brain. *Results:* Variations were found in 31.3% (n=35). Variations of the segments in relation with size, course, communications and terminations of the anterior cerebral artery (ACA) were noted. These were divided into different groups like hypoplasia, aplasia, duplication and fenestrations. The mean diameter and length of the proximal segment of the anterior cerebral artery (A1) was 3.2 mm and 15.7 mm, anterior communicating artery (ACoA) was 2.4 mm and 3.3 mm and distal segment of the anterior cerebral artery (A2) was 2.5 mm and 42.1 mm respectively.
Conclusion: Variation of anterior cerebral artery is common in this study of Indian human cadavers.

INTRODUCTION

Anterior cerebral artery (ACA) is an important terminal branch of internal carotid artery (ICA). It forms the anterior component of circle of Willis along with the anterior communicating artery (ACoA). It supplies orbitofrontal and medial hemispheric portions of the brain. It curves around and over the corpus callosum up to the splenium, with central and cortical branches.

Circle of Willis shows a large number of morphologic and angiographic anomalies.[1] These anomalies are not rare. It is important to keep the anomalies in mind since they could have serious clinical implications.[2,3] Diagnosis of cerebral aneurysms, strokes, ischemia and revascularization procedures will be facilitated to a great extent if the data regarding the mean diameter and length of the postcommunicating segment of ACA (A2) in a given population is available. The knowledge of anatomical variations in ACA can be of considerable help to the clinicians including Neurosurgeons.[4-7] Hence the present study was undertaken, to study the morphological and morphometrical aspects of ACA and ACoA regarding the origin, course, branching pattern and termination.

METHODS

This study was approved by the Rural Medical College Research Ethics committee (PMT/PIMS/RC/2010/18) / (Registration FN. 18/2010), and performed in accordance with institutional ethics committee guidelines. Morphology and variations of the ACA and the ACoA were studied on 112 formalin preserved brains. The cadaveric bodies from which brains removed were of unknown age and unknown cause of death. The brains with the gross morphological variations were excluded from the study. Anterior part of the circle of Willis was exposed. Branching pattern and course of the ACA and ACoA were observed and the variations were photographed. Variations of the size, course, segments, communications and terminations of the anterior cerebral artery were noted. These variations were divided into different groups like hypoplasia, aplasia, and duplication of precommunicating segment of ACA (A1), double ACoA, fenestrations, azygos ACA and variation in the A2 segment of ACA in its terminal branches. The diameter and length of the proximal segments of the ACA (A1), distal segment of the ACA (A2) and ACoA were measured.

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RESULTS

Morphologic variations were present in 31.3% (35) of cases.

Morphologic variations of A1

Variations related with the A1 segment of ACA are agenesis, hypoplasia and duplication. Two cases of the agenesis of A1 were found. It was present unilaterally (1.8%). In one case it was seen on right side and on left side in the other. (Figure 1A) Hypo- plastic/ under-developed A1 segment was present in 9 cases (8.0%). It was seen in 5 on the right and 4 on the left A1 segment. (Figure 1B) Duplication of A1 was seen in one case. It was present on right side (1.1%). (Figure 1C)

Morphologic variations of ACoA

Thin ACoA was seen in 6 cases (5.4%) (Figure 2A) and short ACoA was present in 13 cases (11.6%). (Figure 2B) They were less than 1.5 mm. Double ACoA was seen in 11 cases (9.8%) (Figure 2C) and fenestrations were seen in 5 (4.5%) (Figure 2D)

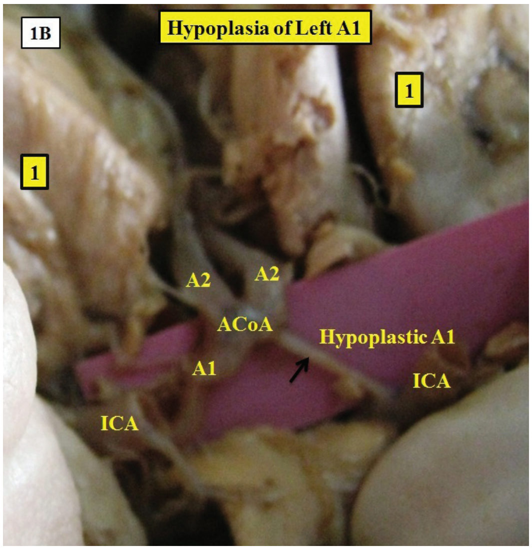

Figure 1B. Photograph of inferior view of brain showing hypoplasia of left A1.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; Arrow – Hypoplasia of left A1; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery; 1 – Inferior surface of frontal lobe of cerebrum.

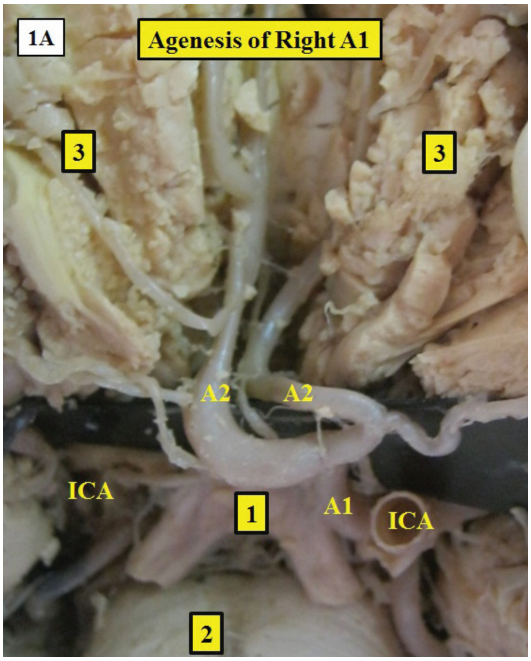

Figure 1A. Photograph of inferior view of brain showing agenesis of right A1.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery; 1 – Optic chiasm; 2 – Pons; 3 – Inferior surface of frontal lobe of cerebrum.

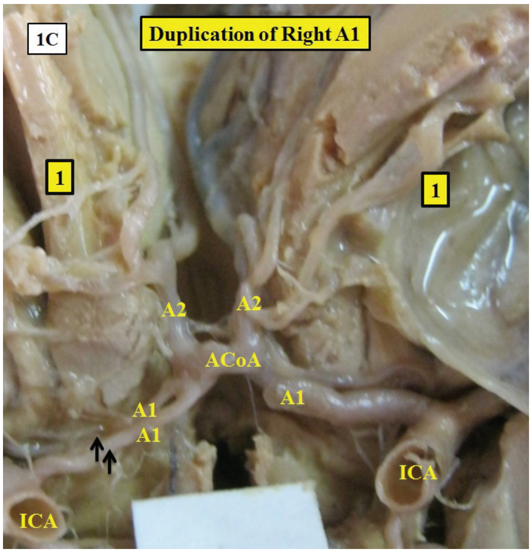

Figure 1C. Photograph of inferior view of brain showing duplication of right A1.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery; Arrows – Duplication of right A1; 1 – Inferior surface of frontal lobe of cerebrum.

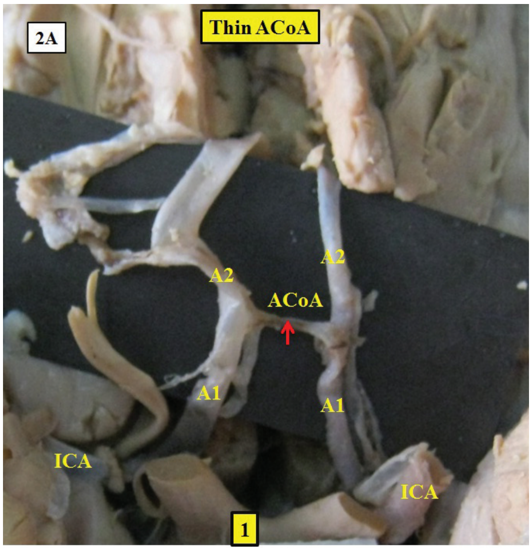

Figure 2A. Photograph of inferior view of brain showing thin ACoA.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery; 1 – Optic chiasm.

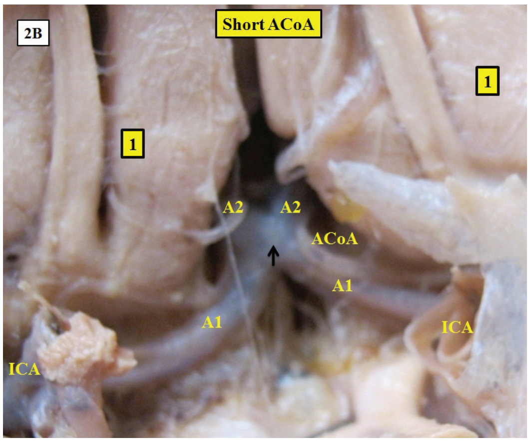

Figure 2B. Photograph of inferior view of brain showing short ACoA.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery; Arrow – Short ACoA; 1 – Inferior surface of frontal lobe of cerebrum.

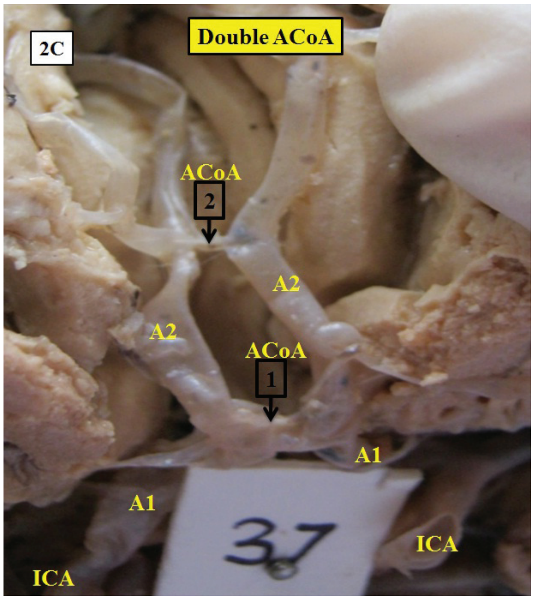

Figure 2C. Photograph of anteroinferior view of brain showing double ACoA.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA 1 – First communicating segment of ACA; ACoA 2 – Second communicating segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery.

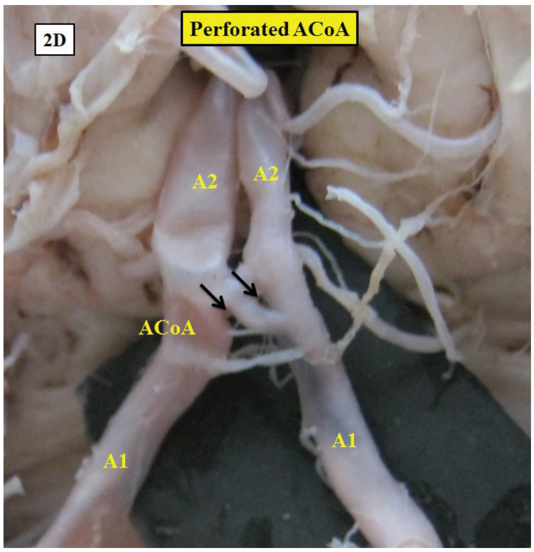

Figure 2D. Photograph of inferior view of brain showing perforated ACoA.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; Arrows – perforations in the anterior communicating artery.

Morphologic variations of A2

Azygos anterior cerebral artery was found in 13 (11.6%). Five subtypes of the azygos ACA were found, as shown in the schematic diagrams in Figure 3. These are as follows:

Type I was the classical azygos anterior cerebral artery. This was seen in the anterior median cerebral fissure of brain and providing nutrition to both the hemispheres through its branches on either side. This type was seen in 3 cases (2.7%). (Figure 3A and Figure 3A schematic diagram of Type I)

Type II was a short median stem of azygos anterior cerebral artery. This divides into further branches to supply both the hemispheres separately. This was found in 2 cases (1.8%). (Figure 3B and Figure 3B schematic diagram of Type II)

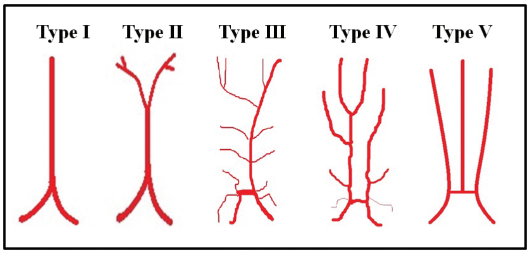

Figure 3. Schematic diagram of azygos ACA showing different types.

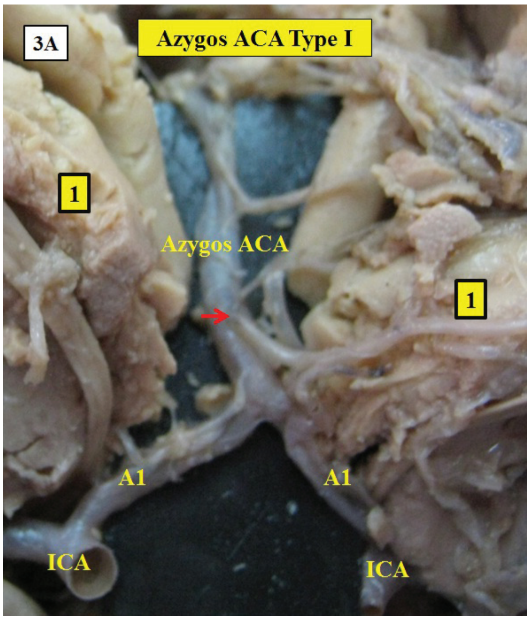

Figure 3A. Photograph of anteroinferior view of brain showing azygos ACA of Type I.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ICA – Internal carotid artery; Arrow – Azygos ACA in anterior median cerebral fissure; 1 – Inferomedial part of frontal lobe of cerebrum.

Type III shows 2 separate A2 segments, out of which one remained very short and end earlier, hardly giving any branches. On the other hand, A2 in the opposite side was large and dominant. It showed an azygos course with branches to both the hemispheres. This was present in 4 cases (3.6%). (Figure 3C and Figure 3C schematic diagram of Type III)

Type IV shows an azygos pericallosal artery. There was normal appearance of anterior circulation except for the pericallosal arteries. The pericallosal arteries both sides were the terminal branches of one A2. Opposite A2 was terminating as the callosomarginal artery. This was present in 3 cases (2.7%). (Figure 3D and Figure 3D schematic diagram of Type IV)

Type V shows a third azygos median A2 artery. This was seen in one case. (0.9%) (Figure 3E and Figure 3E schematic diagram of Type V)

Variations related with terminal branches were seen in 6 cases (5.4%). There were a number of variations as branches were taking origin from opposite A2. The branches were arising from an extra communicating artery between two A2 (Figure 4A). Out of two terminal branches one was with very much larger diameter than the other (Figure 4B). A2 was terminating into three terminal branches instead of two (Figure 4C). Variation in diameter of A2 was seen in 4 cases (3.6%) (Figure 4D).

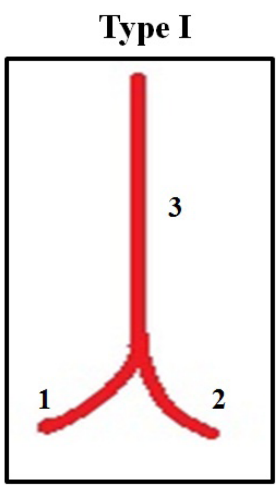

Figure 3A. Schematic diagram of azygos ACA Type I. 1 – Right A1; 2 – Left A1; 3 – Classical azygos median ACA.

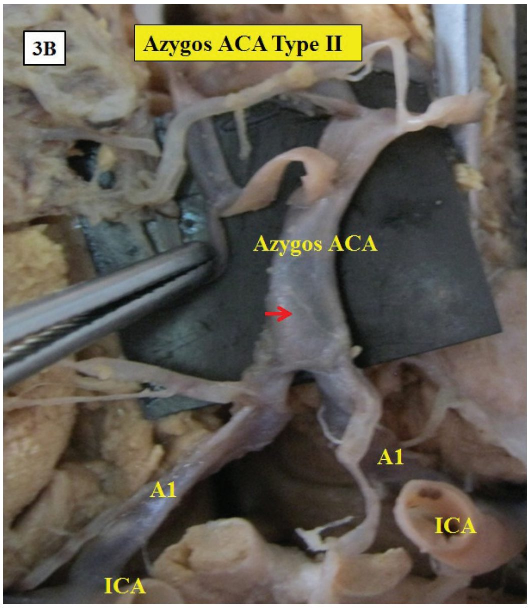

Figure 3B. Photograph of anteroinferior view of brain showing azygos ACA of Type II.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ICA – Internal carotid artery; Arrow – Short segment of azygos ACA in anterior median cerebral fissure.

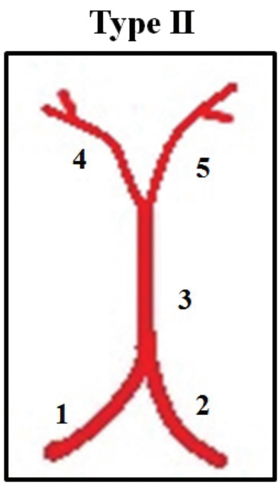

Figure 3B. Schematic diagram of azygos ACA Type II. 1 – Right A1; 2 – Left A1; 3 – Short segment of azygos median ACA; 4 – Right A2; 5 – Left A2.

Morphometric observations

The cases with gross morphological variations were excluded from statistical analysis in the morphometric observations. These observations are described in Table 1 in millimeters. The mean diameter and length of the proximal segment of the anterior cerebral artery (A1) was 3.2 mm and 15.7 mm, anterior communicating artery (ACoA) was 2.4 mm and 3.3 mm and distal segment of the anterior cerebral artery (A2) was 2.5 mm and 42.1 mm respectively.

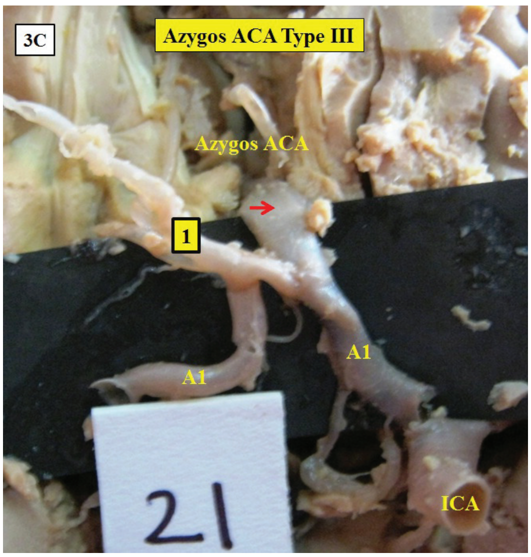

Figure 3C. Photograph of Inferior view of brain showing azygos ACA of Type III.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ICA – Internal carotid artery; Arrow – Dominant left A2 forming an azygos ACA in anterior median cerebral fissure; 1 – Right A2 termination.

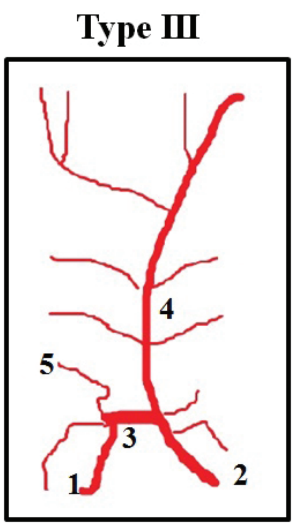

Figure 3C. Schematic diagram of azygos ACA Type III. 1 – Right A1; 2 – Left A1; 3 – ACoA; 4 – Left A2 forming azygos ACA; 5 – Right A2 termination.

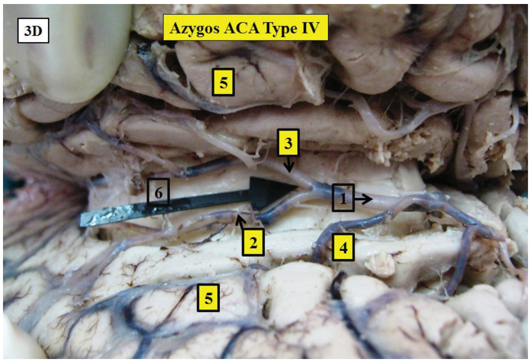

Figure 3D. Photograph of superior view of median cerebral fissure in supracallosal part showing Azygos ACA of Type IV.
1 – Left A2 acting as azygos pericallosal artery forming azygos ACA; 2 – Right pericallosal artery; 3 – Left peicallosal artery; 4 – Right A2 ending as right callosomarginal artery; 5 – Medial surface of cerebrum; 6 – Corpus callosum.

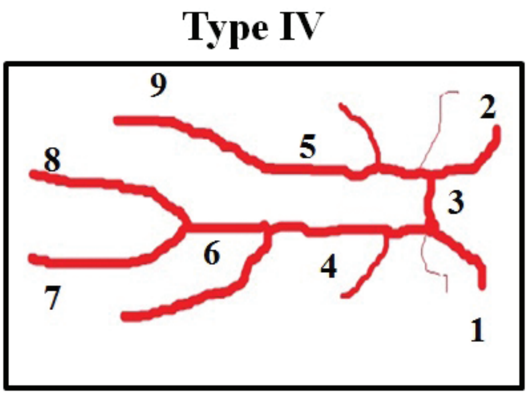

Figure 3D. Schematic diagram of azygos ACA Type IV. 1 – Right A1; 2 – Left A1; 3 – ACoA; 4 – Right A2; 5 – Left A2; 6 – Azygos ACA forming azygos pericallosal artery; 7 – Right pericallosal artery; 8 – Left pericallosal artery; 9 – Left callosomarginal artery.

DISCUSSION

Agenesis and hypoplasia resulting in defective circulation has been reported in the medical literature.[8] If the artery on one side is narrowed, the vascular insufficiency is compensated by crossing over by opposite side artery, or by giving branches that cross over to the other side. It indicates that the *circulus arteriosus* offers a potential shunt in abnormal conditions such as occlusions and spasms. In normal circumstances it is not an equalizer and distributer of blood from different sources.[9] Table 2 shows the variations of A1 in the present study with the previous studies.[10-13] In general, our study shows a higher percentage of variations.

Cerebral infarct due to occlusion of ACA is common in stroke and has grave morbidity. Therefore variation in anterior circulation of the brain is of great importance particularly in the surgery of the region. The vascular anatomy of the region of ACoA is generally complex due to its development. In the 24 mm embryo the ACoA is still a plexiform structure connecting both ACA. Incomplete fusion of this anastomosis may lead to fenestration, doubling or tripling of the ACoA.[14,15] Fenestration can be a protective mechanism for stenosis, injury to, or occlusion of

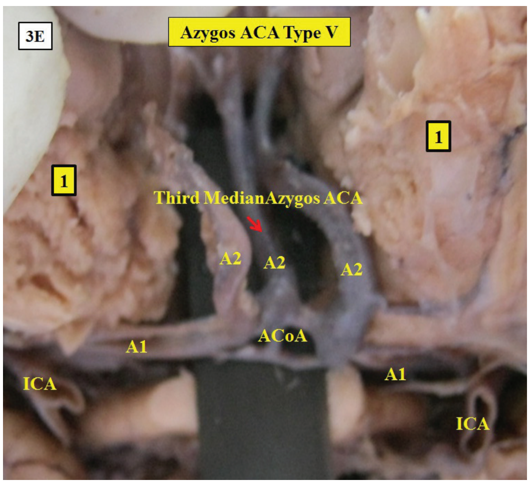

Figure 3E. Photograph of anteroinferior view of brain showing azygos ACA of Type V.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; Arrow – Third median azygos distal segment of ACA; ICA – Internal carotid artery; 1 – Inferior surface of frontal lobe of cerebrum.

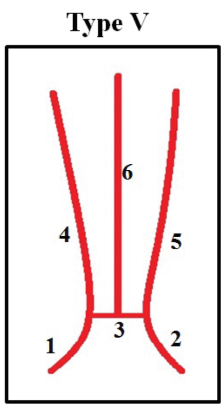

Figure 3E. Schematic diagram of azygos ACA Type V. 1 – Right A1; 2 – Left A1; 3 – ACoA; 4 – Right A2; 5 – Left A2; 6 – Third median azygos ACA.

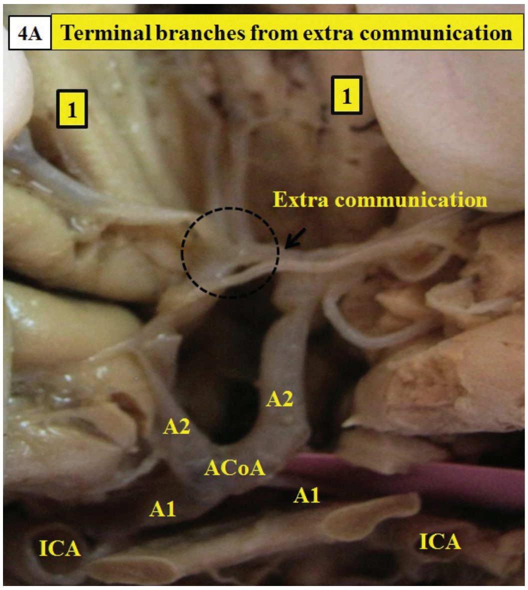

Figure 4A. Photograph of anteroinferior view of brain showing terminal branches from extra communicating artery.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; Arrow – extra communicating artery; Dotted circle – Terminal branches from extra communicating artery; ICA – Internal carotid artery; 1 – Inferomedial surface of frontal lobe of cerebrum.

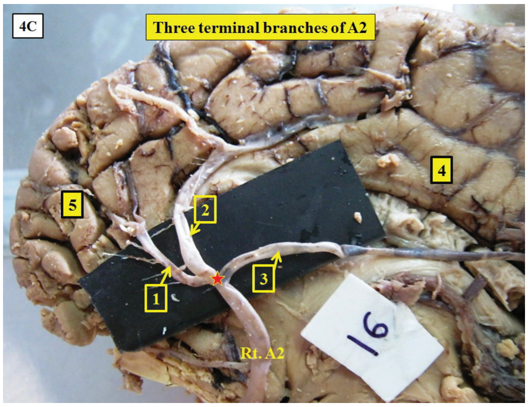

Figure 4C. Photograph of medial surface of right cerebral hemisphere showing three terminal branches of A2.
ACA – Anterior cerebral artery; Rt. A2 – Distal segment of ACA; 1 – Frontopolar artery; 2 – Callosomarginal artery; 3 – Pericallosal artery; 4 – Cingulate gyrus; 5 – Medial surface of frontal lobe of cerebrum; Star – Point of termination of Rt. A2 into three terminal branches.

one of the duplicated limbs. Such anomalies may become important in the planning of interventional procedures.[16,17]

Fenestration can pose unexpected difficulties in the surgical treatment, as unilateral or bilateral fenestration often accompanies aneurysms or other anomalies.[18] The possible explanations for the development of fenestrations could be hemodynamic.

Table 3 shows the variations of ACoA of this study in comparison with the previous studies.[11,15,19-26] Our percentage of variation was less than the previous studies.

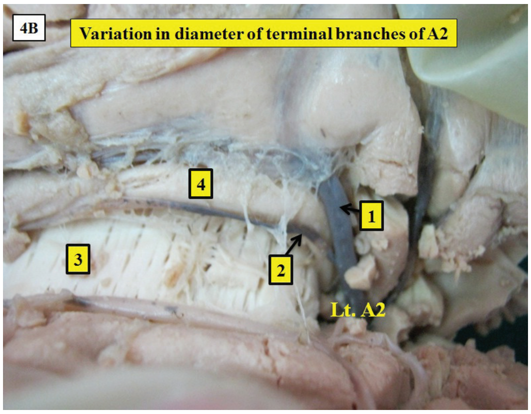

Figure 4B. Photograph of medial surface of left cerebral hemisphere showing variation in diameter of terminal branches of A2.
ACA – Anterior cerebral artery; Lt. A2 – Distal segment of ACA; 1 – Left callosomarginal artery; 2 – Left pericallosal artery; 3 – Corpus callosum; 4 – Cingulate gyrus.

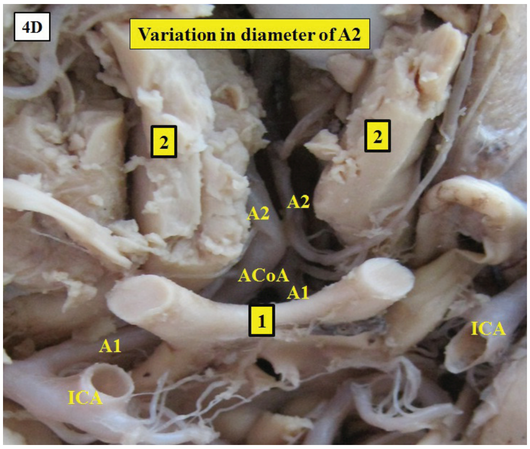

Figure 4D. Photograph of inferior view of brain showing variation in diameter of A2.
ACA – Anterior cerebral artery; A1 – Proximal segment of ACA; ACoA – Communicating segment of ACA; A2 – Distal segment of ACA; ICA – Internal carotid artery; 1 – Optic chiasm; 2 – Inferomedial part of frontal lobe of cerebrum.

Table 1. Morphometric observations in millimeters

Morphometric observations	Minimum	Maximum	Average	Std. Deviation	No of cases (n)
A1 length	11	25	15.7	2	77
A1 diameter	2	5	3.2	0.6	77
ACoA length	1	9	3.3	1.3	77
ACoA diameter	1	4	2.4	0.7	77
A2 length	25	75	42.1	10.8	77
A2 diameter	2	4	2.5	0.6	77

Table 2: Variations of A1 in percent

Morphologic variations of A1	Riggs & Rupp[10]	Pai *et al.*[11]	Piganiol *et al.*[12]	Macchi *et al.*[13]	Present Study
A1 agenesis	-	0	2.1	-	1.8
A1 hypoplasia	7	0	-	0.7	8.0
A1 duplication	-	-	-	-	1.1

Table 3: Variations of ACoA in percent

Morphologic variations of ACoA	Pai, *et al.*[11]	Gomes *et al.*[15]	Zhao *et al*[19]	Uchino *et al.*[20]	Saidi *et al.*[21]	Perlmutter & Rhoton[22]	Hillen *et al.*[23]	De Almeida[24]	Fisher[25]	Crowell & Morawetz[26]	Present Study
Thin	-	-	-	-	-	-	-	-	-	-	5.4
Short	20	-	-	-	-	-	-	-	-	-	11.6
Double	-	43.3	-	-	14	30	33	18	33	33.3	9.8
Fenestrated	-	-	0.8	1.2	26	-	-	-	-	-	4.5

Table 4: Variations of A2 in percent

Morphologic variations of A2	Schick *etal.*[28]	Dietrich *et al.*[33]	Baptista *et al.*[35]	Belenkaya *et al.* [36]	Kakau *et al.*[37]	Hashizume *et al.* [38]	Osborn et al[39]	Present Study
Azygos ACA	1.1	0.1–5	0 - 5	0.2-3.7	0.1–5	1.1	10	11.6
Terminal branches		-	-	-		-	-	5.4
Hypoplasia		-	-	-		-	-	3.6

In 1885, Wilders described arteria termatica, the formation of one artery from fusion of the A2 in the anterior cerebral artery. He also called it the azygos artery of the pericallosal artery.[27,28] The unusual fusion of the paired A2 in the ACA originates either from the medial branch of the olfactory artery at the initial 16 mm stage of embryogenesis or the continuation of the median artery in the corpus callosum at the 20-24 mm stage. It can also be generated by a lack of development or regression of the ACA.[29-31]

The clinical significance of the azygos artery is great. It is intimately associated with the formation of aneurysms and possible neurological deficiencies. These deficiencies can be caused by ischemia in both hemispheres brought on by arterial damage or occlusion during an operation for an aneurysm.[32,33]

In patients with an azygos ACA, aneurysms of a distal segment of ACA occur relatively frequent. The aneurismal development may be due to burden of blood from the bilateral A1 segment prior to anomaly of A2 segment.[34]

Baptista divided abnormalities of the distal portion of the ACA into three groups: 1) Single unpaired ACAs, in which a single ACA feeds into the medial surface of both cerebral hemispheres; 2) Bihemispheric ACAs, in which there are two

Table 5: Comparison of morphometric observations of ACA in millimeters

Morphometric observations	Pai *et al.* [11]	Perlmutter&Rhoton.[22]	Stefani *et al.*[31]	Zurada *et al.*[40]	Avci *et al.*[41]	Kwolek-Klimkiewicz *et al.*[42]	Kawashima *et al.*[43]	Ugur *et al.* [44]	Lang[45]	Present Study
A1 Length	14.6	-	-	-	-	-	-	-	-	15.7
A1 Diameter	2.8	-	-	-	-	-	-	-	-	3.2
ACoA Length	2.5	-	-	-	-	-	-	-	-	3.3
ACoA Diameter	2.1	-	-	-	-	-	-	-	-	2.4
A2 Length	-	28	-	11.9	-	-	-	-	15.3	42.1
A2 Diameter	2.5	-	2.6	1.9	2.0	2.2	2.4	2.8	-	2.6

ACAs, but one is clearly dominant with branches extending into the contralateral hemispheres; 3) Accessory ACAs, in which a third, or median artery, is distributed to either one or both hemispheres.[35] In the present study, we found all these types of azygos ACA. In addition, there was a short stem azygos ACA and azygos pericallosal artery.

Table 4 shows the variations of A2 in our study as compared to the previous studies.[28,33,35-39] As shown, it they are higher than the previous studies.

Table 5 shows the morphometric observations of ACA in our study as compared with the previous studies.[11,22,31,40-45] As shown, the results in the present study are similar with the observations of Pai *et al.*[11]Perlmutter and Rhoton observed that there was a direct correlation between the difference in size between the A1 segments and the diameter of the ACoA – the greater the difference, the larger the diameter of the ACoA.2 This correlation however was not observed in our study.[22]

There are a number of case reports indicating variations of ACA and communicating artery observed during operation.[46-50] Angiographic evidence of defective circulation was noted in one-third of these reported cases.[9] Therefore, even for a routine surgical procedure, presence of efficient and effective circulation should never be assumed.

All these variations are associated with one another. If one vessel is thin or hypoplastic, opposite vessel becomes large and dominant to compensate for the diminution of blood supply. In such cases, there are often found double ACoA (extra communication), fenestrated ACoA or azygos arteries. When there is variation in the diameter of proximal part of A2, one may observe variation in the terminal branches, extra communication or azygos pericallosal arteries.

In conclusion, the incidence of anatomical variations according to present study is 31.3%. It confirms a high percentage of variations of ACA. Awareness of the anatomical variation is particularly important in the neurovascular procedures. In view of such high percentage of variations, all surgical interventions of the ACA should be preceded by angiography.

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