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Review

Review of the Anatomy of the Distal Anterior Cerebral Artery and Its Anomalies

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ABSTRACT

The anterior cerebral artery (ACA) varies considerably and this complicates the description of the normal anatomy. The segmentation of the ACA is mostly agreed on by different authors, although the relationship of the pericallosal and callosomarginal arteries (CmA) is not agreed upon. The two basic configurations of the ACA are determined by the presence or absence of the CmA.

The diameter, length and origin of the cortical branches have been measured and described by various authors and display great variability. Common anomalies of the ACA include the azygos, bihemispheric, and median anterior cerebral arteries.

A pilot study was done on 19 hemispheres to assess the variation of the branches of the ACA. The most common variations included absence and duplication. The inferior internal parietal artery and the CmA were most commonly absent and the paracentral lobule artery was the most frequently duplicated (36.8%). The inferior internal parietal artery originated from the posterior cerebral artery in 40.0% and this was the most unusual origin observed.

It is important to be aware of the possibility of variations since these variations can have serious clinical implications. The knowledge of these variations can be helpful to clinicians and neurosurgeons. The aim of this article is to review the anatomy and variations of the anterior cerebral artery, as described in the literature. This was also compared to the results from a pilot study.

KEYWORDS: Anterior cerebral artery, Variation, Anomaly, Anatomy, Description, Origin

ABBREVIATIONS: ACA: *Anterior cerebral artery,* ***AcoA:*** *Anterior communicating artery,* ***AIFA:*** *Anterior internal frontal artery,* ***CmA:*** *Callosomarginal artery,* ***FpA:*** *Frontopolar artery,* ***IFA:*** *Internal frontal artery,* ***IfO:*** *Infraorbital artery,* ***IIPA:*** *Inferior internal parietal artery,* ***MIFA:*** *Middle internal frontal artery,* ***PIFA:*** *Posterior internal frontal artery,* ***PLA:*** *Paracentral lobule artery,* ***PrcA:*** *Pericallosal artery,* ***SIPA:*** *Superior internal parietal artery.*

INTRODUCTION

The cerebral cortex is primarily supplied by the anterior, middle and posterior cerebral arteries. The anatomy of the anterior cerebral artery (ACA) varies considerably and this complicates the description of the ACA and its branches. The segmentation of the ACA is mostly described similarly by different authors, although the relationship of the pericallosal (PrcA) and callosomarginal arteries (CmA) is not agreed upon (78).

Segmentation

Various authors have used different terms to describe the segments of the ACA (36, 64, 68). It can be divided into proximal and distal segments, or pre- and postcommunicating segments. The pericallosal artery is distal to the A1 segment and consists of several segments that can be divided according to its relationship with the corpus callosum. The A2 segment (also referred to as the infracallosal section) runs vertically

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from the anterior communicating artery (AcoA) to the genu of the corpus callosum. The A3 segment (also referred to as the precallosal part) curves around the genu, and the A4 segment (also referred to as the supracallosal section) usually runs in the callosal sulcus and almost reaches the splenium (3, 58, 62). The A5 segment (cortical branches) varies considerably; it is therefore difficult to describe a standard arterial pattern (78). The two basic configurations of the ACA are determined by the presence or absence of the CmA (6, 58, 64). The different segments of the ACA are illustrated in Figure 1A, B.

A number of authors only describe three separate segments, namely the A1 segment (also referred to as the horizontal proximal segment or precommunicating part), the A2 segment (vertical proximal segment or postcommunicating part) and the A3 segment (the distal segments and cortical branches) (3). The A2 and A3 segments have collectively been referred to as the ascending (or vertical) segment and the A4 and the A5 segments as the horizontal segment (62, 64). The ACA have also been divided into a basal (from the origin to the rostrum of the corpus callosum) and a distal part (runs around genu and above corpus callosum) (62).

Several authors refer to the A1 segment as the anterior cerebral artery and the artery distal to the AcoA as the pericallosal artery (6, 36, 62, 64, 68). A few authors have also referred to the A1 and A2 segments as the anterior cerebral artery, and the artery distal to the origin of the callosomarginal artery, the pericallosal artery (62). Since the origin of the callosomarginal artery can vary, this terminology can be problematic (36). The CmA is also not always present and therefore it is preferable to classify the pericallosal artery as the segment distal to the AcoA (28, 62). The callosomarginal artery has been observed in 40.0% to 93.4% of specimens (6, 17, 28, 34, 44, 54, 62, 64, 65, 68, 69, 78). The variability of the absence or presence of the CmA can be due to the different definitions used for this artery (65).

Cortical Branches

Callosomarginal Artery

The CmA can be seen as the largest branch of the pericallosal artery (6). The CmA has been defined as the artery that runs near the cingulate sulcus and gives off two or more cortical branches. This definition is problematic since there can occasionally be more than one artery that arises from the pericallosal artery, run in the cingulate sulcus and give rise to a number of cortical branches (78).

Ugur et al. (78) proposed a new classification system. The CmA was either defined as typical, atypical or absent. An atypical CmA was observed when there was only a very short artery coursing in the cingulate sulcus. Two symmetrical callosomarginal arteries can also be present in the same hemisphere (78). A typical CmA has a longer course compared to the two symmetrical atypical callosomarginal arteries and usually originates from the A3 segment (28, 62, 78). Ugur et al. (78) observed typical, atypical or absent CmA's in 49%, 34% and 17% respectively.

Infraorbital Artery

The infraorbital artery (IfO) normally originates from the A2 segment, the callosomarginal artery or as a common trunk with the frontopolar artery (36, 63, 68). In rare cases the IfO can originate from the A1 segment or from the internal frontal arteries. The infraorbital artery was present in 3.6% to 100% of cases (6, 17, 34, 62, 64, 68, 78). Duplication of the IfO have been observed in 6.0% (64), 39% (68) and 42% (78). Ugur et al. (78) observed three and four infraorbital arteries in 16% and 4%, respectively.

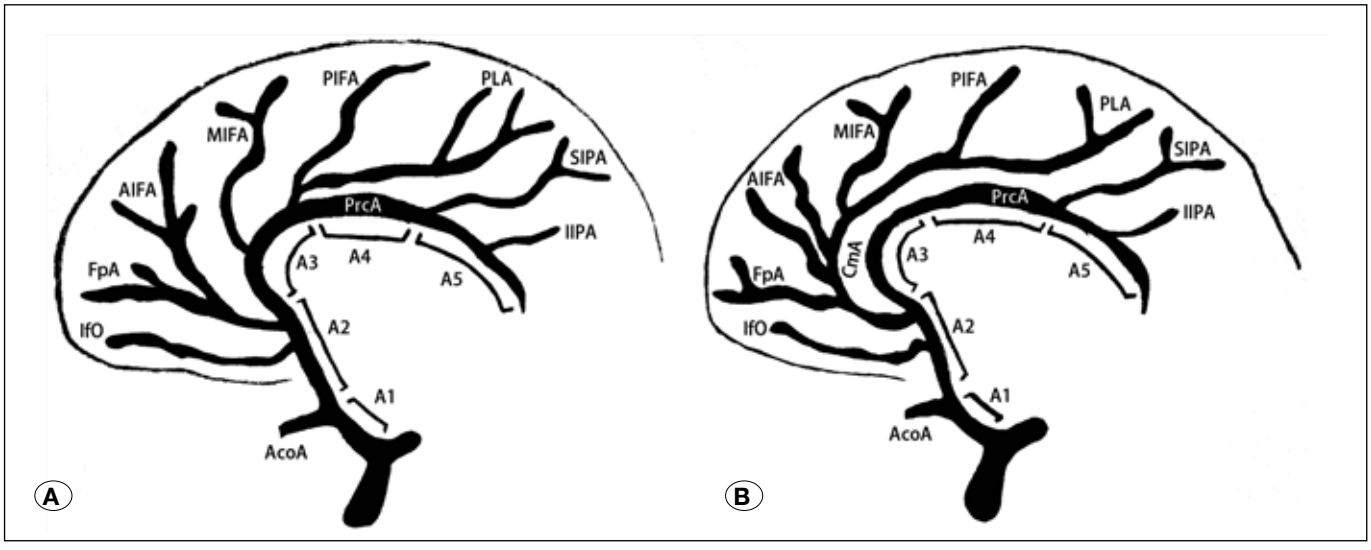

Figure 1: The different configurations of the anterior cerebral artery**: A)** CmA is absent**, B)** CmA is present**.** (AcoA) Anterior communicating artery; (AIFA) Anterior internal frontal artery; (CmA) Callosomarginal artery; (FpA) Frontopolar artery; (IfO) Infraorbital artery; (IIPA) Inferior internal parietal artery; (MIFA) Middle internal frontal artery; (PLA) Paracentral lobule artery; (PIFA) Posterior internal frontal artery; (PrcA) Pericallosal artery; and (SIPA) Superior internal parietal artery.

Frontopolar Artery

The frontopolar artery (FpA) usually arises from the A2 segment or callosomarginal artery (36, 68, 78). The FpA was present in 12.5% to 100% of cases (6, 17, 34, 62, 68, 78).

Internal Frontal Arteries

The anterior, middle and posterior internal frontal arteries usually arise separately or in groups of two from the CmA, although the internal frontal branches can occasionally originate from a common trunk, referred to as the internal frontal artery (IFA) (78). Ugur et al. (78) found that the internal frontal artery was present in 58% of cases. A number of studies (6, 17, 28, 34, 62, 68, 78) observed the anterior internal frontal artery (AIFA) in 33.9% to 100% of cases, the middle interal frontal artery (MIFA) in 64.3% to 100% of cases and the posterior internal frontal artery (PIFA) in 67.9% to 100% of cases.

Paracentral Lobule Artery

The paracentral lobule artery (PLA) can be viewed as the vessel with the most regular origin, course and area supplied, and was present in 53.6% to 100% of cases studied (6, 17, 34, 62, 68, 78).

Internal Parietal Arteries

The superior internal parietal artery normally originates from the A4 segment and runs to the precuneus (36). Ugur et al. (78) found that the superior internal parietal artery (SIPA) can also arise from the callosomarginal artery or the paracentral lobule artery. The inferior internal parietal artery (IIPA) originates from the A5 segment and runs to the lower third of the precuneus (36). A number of studies (17, 28, 34, 62, 68, 78) observed the SIPA in 78% to 100% of cases and the IIPA was present in 60% to 85% of cases observed.

Anomalies and Variations

The abnormalities of the distal ACA have been divided into three major groups (Figure 2A-D) namely; azygos ACA, bihemispheric ACA and a median anterior cerebral artery. Other variations include complete absence of a pericallosal artery and four pericallosal vessels (25, 59). Ozaki et al. (59) described one case (0.7%) of duplication of the ACA bilaterally (four pericallosal vessels). Ladziński et al. (39) observed an extra ACA branch that originated from the internal carotid artery. Burbank and Morris (4) observed a left ACA arising from the right internal carotid artery and noted that only one other case has been observed in the literature.

Azygos Anterior Cerebral Artery

The azygos ACA (Figure 2A-D) is formed by the fusion of the two A2 segments and runs into the medial surface of the hemispheres and usually divides below the genu to supply both hemispheres (4, 6, 9-11, 17, 21, 25, 28, 32, 34, 36, 39, 42, 44, 49, 54, 57, 59, 60, 62, 63, 65, 69, 78). The azygos ACA can also be formed when the embryonic median artery persists (60).

The azygos ACA usually has little clinical significance (57) although this variation may be associated with other anomalies including agenesis of the corpus callosum, formation of arteriovenous malformations and ischemia (18, 24). Some authors state that aneurysms are frequently associated with an azygos ACA (9, 85), whereas others state that this association is extremely rare (35, 82). Since this artery supplies parts of both hemispheres, occlusion may result in a large ischemic area (9, 31, 57). The azygos ACA have been observed in 0.1% to 11.6% (1, 2, 12, 14, 17, 18, 20, 30, 43, 45, 51, 54, 67, 68, 74, 76, 78, 82, 83, 85) of cases studied.

The degree of fusion between the left and right ACA can vary from minor contact to a long single trunk (52, 70). Kapoor et al. (30) found that the trunk could be joined for 0.5cm to 4cm. When the arteries are connected for a shorter length, the variation can also be termed long fusion. Vasović (80) observed an azygos ACA that was fused for 3.3 mm and then divided into three arteries, the right and left A2 segments and a median anterior cerebral artery.

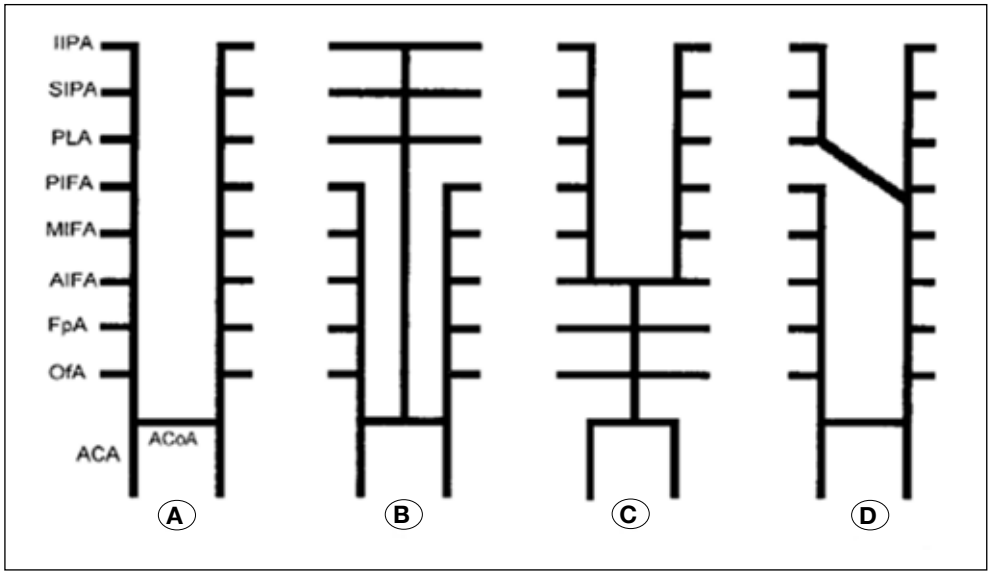

Figure 2: The different patterns of the anterior cerebral artery (68). **A)** Normal pattern, **B)** Median anterior cerebral artery, **C)** Azygos ACA, and **D)** Bihemispheric ACA.

Gunnal et al. (18) divided the azygos ACA into five subgroups (Figure 3). Type I is the classic or true azygos ACA while Type II consists of a shorter stem. In Type III there are two A2 segments, although one terminates early. In Type IV there are two A2 segments, although one terminates as the callosomarginal artery. Type V is the median anterior cerebral artery (18). Gunnal et al. (18) observed these five types in 2.7%, 1.8%, 3.6%, 2.7% and 0.9% respectively. The azygos ACA should not be confused with the bihemispheric ACA (classified as Type III and Type IV) (31, 73, 76).

The classic or true azygos anterior cerebral artery (Type I) can be described as an artery that does not divide into two distal ACA and gives rise to all cortical branches of both hemispheres. The azygos ACA usually divides close to the genu (Type II) into two pericallosal arteries to supply both hemispheres (18). This variation is more commonly observed compared to the true azygos ACA (21).

Bihemispheric Anterior Cerebral Artery

A bihemispheric ACA is defined when one A2 segment is hypoplastic (or terminates early) and the contralateral artery divides to supply both hemispheres (3, 11, 42, 57, 60, 62, 64). A bihemispheric ACA was present in 0.2% to 8.0% (20, 34, 62, 64, 65, 69,) of specimens cited in the literature.

Median Anterior Cerebral Artery

When the median ACA is observed, a third distal ACA is present and can branch to the distal medial surface of one or both hemispheres (11, 30, 36, 52, 60, 61, 68). The median ACA usually curves around the genu and ends at the level of the body of the corpus callosum (26). The cause of this variation is unknown although this artery can be the result of the persistent or patent development of the median artery of corpus callosum, possibly due to a hypoplastic ACA (11, 57, 61).

The median anterior cerebral artery usually originates from the AcoA (10, 13, 21, 46, 57, 61, 74). In the literature the median ACA originated from the AcoA in 87% (30), 90% (26) and 100% (28, 34, 37, 59, 65, 75, 83) of cases. The artery can additionally originate from the junction of the A1 and A2 segments in 10% (26) and 13% (30) of cases. A median ACA was present in 1.0% to 35.0% (1, 8, 12, 13, 17, 26, 28, 30, 33, 34, 37, 38, 45, 47, 51, 53, 56, 59, 65, 67-69, 71, 74-76, 83, 85) of cases by previous authors. The average diameter of the median ACA has been measured to be 0.9 mm (75) and 1.28 mm (26).

Supreme Anterior Communicating Artery

This junction can also be termed the superior anterior communicating artery (23). There is an additional connection between the right and left A2 segments above the AcoA (18, 41). Laitinen and Snellman (41) observed this variation between the two pericallosal bifurcations. This variation has been observed in 20% (23) and 21.4% (41) of cases in the literature.

Fenestration

Fenestration occurs when the lumen of an artery is divided into two segments. It can also be referred to as partial duplication (2, 5, 16, 60, 72). Both segments have an endothelium and muscular layer although the adventitia can be shared (60). There are two types of fenestrations; small slit-like and large convex-like fenestrations. The small slit-like fenestration is the most common type (77).

These incomplete duplications are usually present in the vertebrobasilar region although it has been observed in the cerebral arteries (2, 19, 55, 60, 77). The weakness of the wall of the fenestration and hemodynamic stress at these locations can play a role in aneurysm formation (76).

Fenestrations of the ACA usually occur at the distal part of A1 segment (76) specifically, the distal half or two-thirds of the A1 segment (7, 48, 50). Most authors do not specify which part of the A1 segment the fenestration was observed. Ito et al. (22) stated that in all three cases the fenestration was located at the medial half of the A1 segment while Yamada et al. (84) also observed a fenestration at the middle part of the A1 segment. The cause is unknown although these fenestrations may be remnants of a plexiform anastomosis (57). Fenestrations of the ACA have been observed in the literature in 0.1% to 4.9% (30, 59, 66, 76, 79) of cases previously studied.

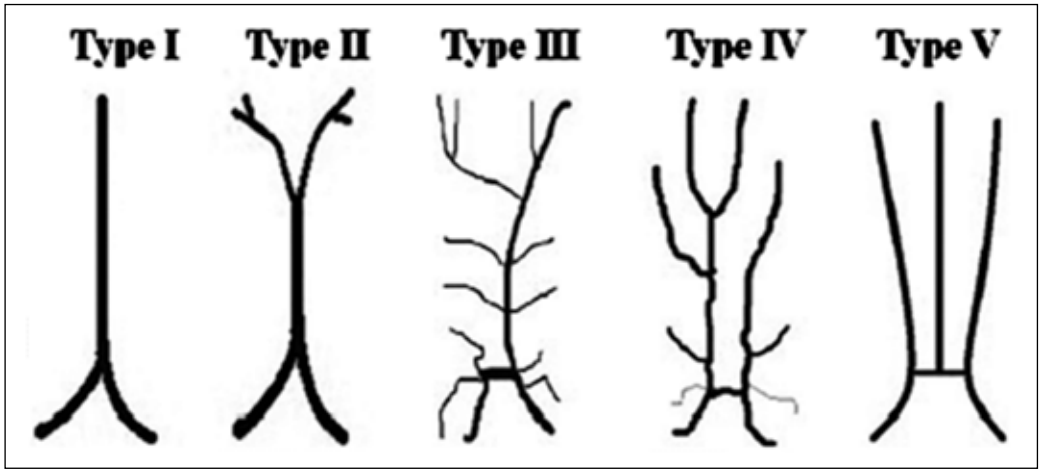

Figure 3: Four different types of an azygos anterior cerebral artery and the median anterior cerebral artery (18).

Very few authors specified if the fenestrations were small slit-like or large convex-like. Large convex-like fenestrations were observed in 1.0% and smaller slit-like fenestrations were observed in 0.2% of cases by Uchino et al. (76). Fenestrations of the ACA on both sides are extremely rare (22), although Friedlander and Oglivy (15) and Vucetić (81) reported bilateral fenestration of the A1 segment.

Pilot Study

A pilot study was done on 19 hemispheres to assess the anatomy of the ACA and its branches. The anterior cerebral arteries were injected with an isotonic saline solution to remove any blood or blood clots and were then injected with a coloured silicone. After perfusion the specimens were fixed in 10% buffered formaldehyde for at least two weeks. The external diameter was measured using a digital micrometre and the length was measured using string and a ruler.

The most common variations were complete absence of an artery and duplication. The infraorbital artery and the FpA were absent in 42.1% and 47.4% of cases respectively. The anterior, middle and posterior internal frontal arteries were always present, although the AIFA and PIFA were duplicated in one case each. The MIFA was the most consistent artery, since it was always present and was never duplicated. The paracentral lobule artery was the most frequently duplicated and this was observed in 36.8% of cases. The superior and inferior internal parietal arteries were absent in 10.5% and 26.3% respectively and the IIPA was duplicated in one case. The callosomarginal artery and the IFA were observed in only 31.6% of cases in the pilot study. The callosomarginal artery and IFA were only present in the same hemisphere in one case.

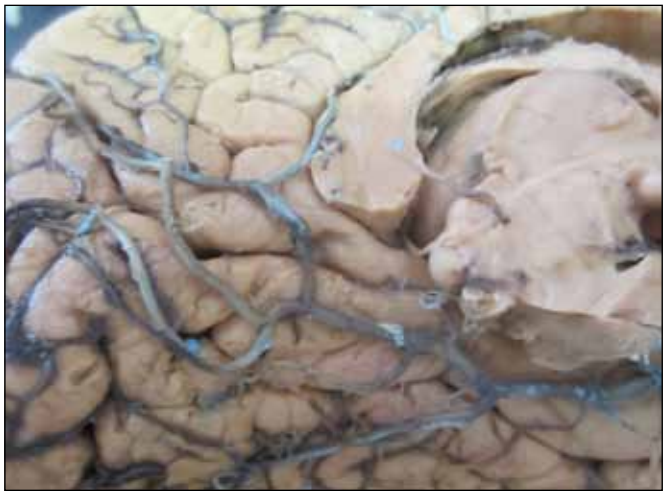

Figure 4: The inferior internal parietal artery originating from the posterior cerebral artery.

The diameter, length and origin of the cortical branches of the ACA have been measured previously in the literature and this is depicted in Table I to Table IV. The data from the pilot study are tabulated in Table V. The diameters are measured at the origin of the cortical branch and the length is measured from the origin of the artery to the AcoA.

Knowledge of the course, length and curvature of the arteries is vital for treatment of pathologies. Variation of the length is important in neurosurgical procedures since a shorter trunk may play a role in aneurysm formation. Changes in vessel diameter could also indicate early signs of several pathological conditions (85).

The most notable origin was the IIPA originating from the posterior cerebral artery in 40.0% (Figure 4). This is a rare variation although Ladziński and Maliszewski (40) observed the inferior and superior internal parietal arteries arising from the posterior cerebral artery in one case (1.1%), and the IIPA arising from the posterior cerebral artery in five cases (5.3%).

The average diameters of the branches are similar to the results of Ugur et al. (78), Stefani et al. (68) and Perlmutter and Rhoton (62). The IIPA originated from the posterior cerebral artery in six cases, resulting in a much shorter length compared to when the IIPA originated from the anterior cerebral artery.

The differences of measured length between studies show that there might be marked difference between populations

Table I: The Average Diameter (mm) at the Origin of the Arteries and the Average Length (mm)

Diameter	**IfO**	**FpA**	**CmA**	**IFA**	**AIFA**	**MIFA**	**PIFA**	**PLA**	**SIPA**	**IIPA**
Gomes et al. (1986)	0.9	1.2	1.8	-	1.0	1.0	1.0	1.1	0.8	0.7
Perlmutter and Rhoton (1978)	0.9	1.3	1.8	-	1.3	1.3	1.4	1.3	1.2	1.1
Stefani et al. (2000)	0.9	1.1	1.8	-	1.3	1.4	1.3	1.2	1.0	0.8
Ugur et al. (2006)	1.1	1.4	1.9	1.7	1.3	1.2	1.3	1.4	1.3	1.2
Cavalcanti et al. (2010)	0.6	0.9	1.5	-	1.1	1.1	1.0	1.0	1.1	-
Kedia et al. (2013)	0.2	0.5	1.1	-	0.4	0.4	0.3	0.3	0.3	0.2
Length	**IfO**	**FpA**	**CmA**	**IFA**	**AIFA**	**MIFA**	**PIFA**	**PLA**	**SIPA**	**IIPA**
Perlmutter and Rhoton (1978)	5.0	14.0	43.0	-	47.0	65.0	73.0	79.0	92.0	131.0
Stefani et al. (2000)	7.7	21.6	29.4	-	41.3	56.8	70.3	84.8	101.6	112.6
Avci et al. (2001)	6.0	14.6	-	-	-	-	-	-	-	-

Table II: The Origins of the Infraorbital, Frontopolar and Callosomarginal Arteries

	Authors	Present	A1	A2	A3	CmA	A4	Special
OfA	Ugur et al. (2006)	100%	1.0%	64.0%	-	-	-	-
	Perlmutter and Rhoton (1978)	100%	-	82.0%	-	-	-	Common trunk FpA: 18.0%
	Kedia et al. (2013)	100%	16.3%	83.3%	-	-	-	-
	Gomes et al. (1986)	100%	-	100%	-	-	-	-
	Kakou et al. (2000)	100%	17.0%	83.0%	-	-	-	-
	Avci et al. (2001)	100%	-	100%	-	-	-	-
FpA	Ugur et al. (2006)	98.0%	-	72.0%	-	9.0%	-	IFA: 14.0% AIFA: 3.0%
	Perlmutter and Rhoton (1978)	100%	-	90.0%	-	10.0%	-	-
	Kedia et al. (2013)	100%	-	40.0%	56.6%	3.3%	-	-
	Gomes et al. (1986)	100%	-	100%	-	-	-	-
	Kakou et al. (2000)	100%	17.0%	65.0%	9.0%	9.0%	-	-
	Avci et al. (2001)	100%	-	95.0%	5.0%	-	-	-
CmA	Ugur et al. (2006)	83.0%	-	18.0%	64.0%	-	12.0%	AcoA: 6.0%
	Perlmutter and Rhoton (1978)	82.0%	-	12.2%	73.2%	-	14.6%	-
	Kedia et al. (2013)	93.4%	-	10.0%	50.0%	-	40.0%	-
	Gomes et al. (1986)	91.6%	-	3.6%	90.9%	-	5.4%	-
	Kawashima et al. (2003)	91.0%	-	4.5%	91.0%	-	-	AcoA: 4.5%
	Cavalcanti et al. (2010)	93.3%	-	10.3%	55.2%	-	24.1%	AcoA: 10.3%

Table III: The Origins of the Anterior, Middle and Posterior Internal Frontal Arteries

	Authors	Present	A2	A3	CmA	IFA	A4	Special
AIFA	Ugur et al. (2006)	100%	4.0%	10.0%	18.0%	53.0%	-	FpA: 15.0%
	Perlmutter and Rhoton (1978)	86.0%	16.3%	55.8%	27.9%	-	-	-
	Kedia et al. (2013)	100%	13.3%	60.0%	26.6%	-	-	-
	Gomes et al. (1986)	96.6%	-	6.8%	84.4%	-	8.6%	-
	Kakou et al. (2000)	100%	-	65.0%	35.0%	-	-	-
MIFA	Ugur et al. (2006)	100%	-	21.0%	25.0%	50.0%	-	FpA: 4.0%
	Perlmutter and Rhoton (1978)	90.0%	2.2%	46.7%	46.7%	-	4.4%	-
	Kedia et al. (2013)	100%	-	43.3%	43.3%	-	13.4%	-
	Gomes et al. (1986)	98.3%	-	3.3%	77.9%	-	16.9%	A5: 1.6%
PIFA	Ugur et al. (2006)	100%	-	12.0%	48.0%	32.0%	2.0%	PLA: 6.0%
	Perlmutter and Rhoton (1978)	76.0%	-	31.6%	36.8%	-	31.6%	-
	Kedia et al. (2013)	100%	-	10.0%	80.0%	-	10.0%	-
	Gomes et al. (1986)	91.6%	-	-	56.3%	-	36.3%	A5: 7.2%

Table IV: The Origins of the Paracentral Lobule Artery and Internal Parietal Arteries (Superior and Inferior)

	Authors	Present	A3	CmA	A4	A5	Special:
PLA	Ugur et al. (2006)	100%	12.0%	66.0%	18.0%	-	Opposite A4: 2.0% IFA: 2.0%
	Perlmutter and Rhoton (1978)	90.0%	20.0%	28.9%	35.6%	15.6%	-
	Kedia et al. (2013)	100%	-	93.4%	6.6%	-	-
	Gomes et al. (1986)	98.3%	-	16.9%	33.8%	49.1%	-
	Kakou et al. (2000)	-	50.0%	50.0%	-	-	-
SIPA	Ugur et al. (2006)	88.0%	3.0%	30.0%	33.0%	24.0%	PLA:10.0%
	Perlmutter and Rhoton (1978)	78.0%	-	23.1%	12.8%	64.1%	-
	Kedia et al. (2013)	93.0%	-	-	80.0%	20.0%	-
	Gomes et al. (1986)	85.0%	-	-	-	100%	-
	Kakou et al. (2000)	100%	-	15.0%	35.0%	50.0%	-
IIPA	Ugur et al. (2006)	85.0%	-	-	10.0%	75.0%	SIPA:15.0%
	Perlmutter and Rhoton (1978)	64.0%	-	3.1%	16.6%	81.3%	-
	Kedia et al. (2013)	60.0%	-	-	-	100%	-
	Gomes et al. (1986)	60.0%	-	-	-	100%	-
	Kakou et al. (2000)	67.0%	-	-	-	100%	-

and therefore more studies need to be conducted on the length of these arteries. No triplication or other anomalies were observed in these specimens, which emphasizes the necessity for a large sample size to ensure that rare variation are observed.

CONCLUSION

The knowledge of the variations of the cerebral arteries is important to ensure that there are no complications during neurosurgery, surgical and endovascular interventions and it is essential for the treatment of cerebrovascular disease (6, 28, 64, 78). Aneurysms frequently occur at the branching of cerebral vessels and thus a thorough knowledge of the anatomy is important (4, 27, 29, 62). Information on the pattern of the cerebral arteries is important in interpretation of strokes and the obliteration of an arterial segment may cause unwanted or unexpected clinical consequences (21, 28).

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