Variations in branching pattern of middle cerebral artery using CT angiography in South Indian population

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SUMMARY

Middle cerebral artery (MCA) variants are rare compared to that of the other two cerebral arteries. Incidence of variations like duplication, fenestration, accessory vessel and early branching ranges from 0.17 to 4%. However, the literature describing MCA variations using CT Angiography (CTA) is limited, so this study was planned to determine the incidence of MCA branching pattern in Indian population using CTA. Datasets of CTA of 578 MCA from 289 patients (180 males and 109 females), with average age of 49.29±16.16 years (range of 11 to 85 years), from a tertiary care hospital were systematically reviewed for variations in branching pattern. Cases involving aneurysms and infarcts were excluded from the study.

Four branching patterns of MCA were seen. Pattern I: single trunk in 0.17% (1/578) cases, on left side. Pattern II: early bifurcation in 0.52% (2/578) cases, two cases on right and one on left side. Pattern III: bifurcation, in 97.75%, (565/578) cases, 46.15% (6/13) cases on right and 53.84% (7/13) on left side. Pattern IV: trifurcation, in 1% (6/578), two cases on right and four on left side. Duplicated MCA seen in 0.34% (2/578) cases, both on the right side. The fenestration of MCA seen in 0.17% (1/578), on the left side. No case of accessory MCA was seen. Awareness of these anatomical variations in the branching pattern of MCA is valuable for clinicians and surgeons handling cases of intracranial aneurysms and infarcts. Thus, data from this study would help surgeons minimize errors and provide the best possible outcome to the patients.

Key words: Middle cerebral artery – CT angiography – Anatomical variations

INTRODUCTION

The middle cerebral artery (MCA) emerges from the internal carotid artery (ICA) in the interpeduncular fossa, at the lateral angle of the Willis circle (Almeida et al., 2017). From the carotid bifurcation, MCA runs in the lateral direction to reach the sylvian fissure (Shalom et al., 2021). It runs posterior to the lesser wing of the sphenoid, turns in the sylvian fissure between the temporal and frontal lobes to reach the insular surface

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(Almeida et al., 2017; Gibo et al., 1981), and divides into two secondary trunks (superior and inferior). MCA tributaries pass through the medial surface of the opercula of the frontal, parietal, and temporal lobes, then run over the brain surface as cortical branches, supplying the lateral and inferior surfaces of the cerebral hemispheres (Ture et al., 2000). As MCA supplies a large part of the cerebral hemispheres, it is the most exposed vessel during surgical intervention and its acute obstruction can lead to the development of brain infarct in most of the cases (Shalom et al., 2021). Awareness of its variations is essential in avoiding unnecessary endovascular procedures and planning the safest interventional practices (Lutz et al., 2018). Though anomalous MCA present as incidental findings, in case of obstruction of main MCA trunk, these vessels may provide a secondary blood supply (Teal et al., 1973).

The bifurcation is the most common branching pattern of MCA with minimum and maximum incidence in cadaveric studies reported to be 48% and 96.5% (Kadam et al., 2018; Reci, 2019), respectively. In cadavers from India, incidence varies from 64.7%-96.5% (Kadam et al., 2018; Gunnal et al., 2019). The bifurcation is seen in 73% to 92.7% in imaging studies (Sadatamo et al., 2013; Vuillier et al., 2008). Occasionally, the main MCA trunk remains as a single vessel. The incidence of such single trunk is highly variable from 1.7 to 20% (Umansky et al., 1988). The single trunk is seen in 3.8% to 20.6% in cadavers and 17% in imaging studies (Umansky et al., 1988; Gunnal et al., 2019; Vuillier et al., 2008). MCA branching 0.5 cm or less from origin is known as early bifurcation (Teal et al., 1973). It is a less common variation and thus reported in few studies. Its incidence varies from 3% to 24% in cadavers (Eve et al., 2021; Reci, 2019). Presence of three or four final MCA trunks is referred as trifurcation or quadrifurcation (Reci, 2019) Incidence of trifurcation is 1.7% to 26.6% in cadaveric studies and 7.3% to 13.8% in angiographic studies (Kadam et al., 2018; Jeyakumar and Veerapandan, 2018; Sadatamo et al., 2013; Brzegowy et al., 2018). Incidence of quadrifurcation is 0.7% to 3.8% (Ogeng'O et al., 2011; Umansky et al., 1988; Gunnal et al., 2019). Rarely, a branch is given off immediately after origin of the two MCA trunks that gives an appearance of pseudotrifurcation (Ogeng'O et al., 2011). Apart from the main trunk, an accessory or duplicated vessel can be present and supply MCA territory. An accessory MCA arises as a branch from anterior cerebral artery (ACA), whereas duplicated MCA comes from the distal ICA (Crompton, 1962). The division of a single vessel into two channels which later fuse together results in fenestration (Uchino et al., 2012).

The prevalence of intracranial MCA aneurysms is approximately 20-43% (Wang et al., 2016). The recognition of MCA branching pattern is essential for handling the cases of aneurysm or stenosis of MCA (Umansky et al., 1988). The ischemic strokes and focal neurological deficits also follow disturbance in arterial circulation due to variations (Yasargil, 1984). MCA is the commonly occurring site for thrombus formation, which can be treated by mechanical thrombectomy. Thus, with the introduction of interventional stroke management, awareness of MCA anatomy has become more critical (Wang et al., 2016). A comprehensive data on variations in the branching pattern of MCA is thus needed for radiologists to interpret diagnostic images and for surgeons to execute complex brain surgeries (Teal et al., 1973).

There are multiple case reports and cadaveric investigations on the variations of MCA but with a narrow sample size. In addition, there is a difference in the prevalence of branching patterns of MCA among diverse populations due to the unpredictability of cerebral vasculature (Jeyakumar and Veerapandan, 2018). Three methods, i.e., computed tomography angiography (CTA), digital subtraction angiography and magnetic resonance angiography are suitable for diagnosis of cerebral vascular malformations (Seidlecki et al., 2021). However, CTA is the standard investigation method during the workup process. As the literature on MCA variations in CTA from Indian population is limited, this study was planned in subjects of a tertiary care hospital in south India.

MATERIALS AND METHODS

This descriptive Hospital-Record-based study was done in the departments of Radiology and

Anatomy in our institute from July 2017 to July 2020. The study was approved by Institute Human Ethics Committee (Ref. No. JIP/IEC/2019/421 dated 12/12/2019.

The CT cerebral angiography and multiphasic contrast enhanced records, from Picture Archiving Communication System (PACS) of the Department of Radiology, were retrieved. The scans in which branching pattern of MCA was not completely visible were excluded from the study. Also excluded were conditions like occlusion, dissection, aneurysm, and vasculitis that effect the normal vascular architecture. The sample size was calculated using formula for estimation of single population. The anatomic variation in the branching pattern of MCA was anticipated to be around 25% in CT Angiography (Jeyakumar and Veerapandan, 2018). The software for Power and Sample was applied at 5% level of significance and absolute precision of 5% for calculation, and the estimated total sample size was 289.

Plain CT brain was followed by CT angiogram. CT Angiogram was done using 128-slice multidetector CT system, Siemens Somatom 64 (3 mm slices were acquired with a 128 X 0.6 matrix and reconstructed to 1 mm slice thickness. A rotation time of 0.5 seconds and a pitch 1.2, delivered an effective mAs of 300 at a voltage of 120 kV. The average acquisition time was around 10 to 15 sec). Non-ionic contrast (400 mg Iodine /ml) at injection rate of 4-6 ml/sec with saline flush of 40 ml was given. The angiographic CT data sets were loaded in Siemens Syngo via server workstation and 3D angiographic images were obtained using Maximum Intensity projection (selected and displayed voxels with high attenuation value) and volume rendered technique (VRT) reconstruction.

Bone removal was done by slab editing to evaluate cerebral vasculature. VRT allowed good visualisation of cerebral vasculature and their 3D relationship. All the CTA images were analyzed under the arterial phase and branching pattern of MCA on both the sides were seen and documented. The variables like age were expressed as mean with standard variation, and gender as frequency and percentage. The variations in branching pattern were summarized as frequency and percentage.

RESULTS

A total of 289 CT cerebral angiograms (right- 289, left- 289), from 180 (62%) males and 109 (38%) females, were studied for variations of MCA. The average age of subjects was 49.3±16.2 years (range- 11 to 85 years). The distribution of records in various age groups is given in Table 1.

The branching pattern of the MCA was determined by the division of the main trunk into smaller or secondary trunks. The four patterns namely single trunk (pattern 1), early bifurcation (pattern 2), bifurcation (pattern 3) and trifurcation (pattern 4) were observed. The bifurcation (fig 1.3) was the most observed pattern (Table 2), in which MCA main trunk divided into two secondary trunks, superior and inferior. MCA bifurcated distal to the genu in 97.5% (551/565), proximal to it in 1.4% (8/565) and at genu in 1.1% (6/565). If the main trunk of MCA did not divide from its origin to the posterior end of lateral cerebral fissure, it was referred to as single trunk or pattern 1 (Fig. 1.1). The diameter and length of single trunk was 2.89 mm and 26.56 mm, respectively. MCA divided at 5 mm or less from its origin in pattern 2 or early bifurcation (Fig. 1.2). The mean length of MCA was 4.4±0.65 mm in this pattern. The length

Table 1. Age group distribution of CT Scan records.

Group	Age (Years)	Male N=180 (%)	Female N=109 (%)	Total No. of scan records N=289 (%)
I	0-20	7 (3.9)	10 (9.2)	17 (5.9)
II	21-40	44 (24.4)	23 (21.1)	67 (23.2)
III	41-60	79 (43.9)	55 (50.4)	134 (46.4)
IV	61-100	50 (27.8)	21 (19.3)	71 (24.5)

Table 2. Termination of middle cerebral artery.

Branching pattern/ variation	Total (%) N=578	Right (%) N=289	Left (%) N=289
Pattern 1/ Single trunk	1 (0.17)	0	1 (0.34)
Pattern 2/ Early bifurcation	3 (0.51)	2 (0.69)	1 (0.34)
Pattern 3/ Bifurcation	565 (97.77)	283 (97.92)	282 (97.57)
Pattern 4/ Trifurcation	6 (1.04)	2 (0.69)	4 (1.38)
Duplicated	2 (0.34%)	2 (0.69%)	-
Fenestration	1 (0.17%)	-	1 (0.34%)

Table 3. Variations in different age groups.

Branching pattern/ variation	Group I N=34 (%)	Group II N=134 (%)	Group III N=268 (%)	Group IV N=142 (%)
Pattern I	-	-	-	1 (0.7)
Pattern 2	1 (2.9)	1 (0.8)	1 (0.4)	-
Pattern 3	32 (94.1)	132 (98.5)	263 (98.1)	138 (97.2)
Pattern 4	-	1 (0.8)	3 (1.1)	2 (1.4)
Duplicated	1 (2.9)	-	1 (0.4)	-
Fenestration	-	-	-	1 (0.7)

on the right and left sides was 4.9±0.1 mm and 3.5 mm, respectively. In pattern 4 (Fig 1.4), the MCA main trunk divided into three secondary trunks (superior, middle, and inferior). The pattern 3 was bilateral in 95.5% (276/289) cases. It was bilateral in 97.8% (176/180) males and unilateral in 2.2% (4/180). In females, it was bilateral in 91.7% (100/109) and unilateral in 8.3% (9/109). All cases of patterns 1, 2 and 4 were unilateral.

A duplicated MCA (Fig 2.1) appeared at the bifurcation of ICA parallel to the main trunk. The mean length of duplicated MCA was 13.7±1.3 mm while the length of main MCA trunk was 14.42 mm. An oval-shaped fenestration (Fig 2.2) was on the distal segment of left MCA at 12.9 mm from its origin. No case of quadrifurcation or multiple trunks (>4) or accessory MCA was observed. The trifurcation was present in patients over 40 years of age, whereas single trunk and fenestration were seen in patients over 60 years (Table 3). MCA variations in males and females are depicted in Table 4.

DISCUSSION

The present study identified four branching patterns of MCA in 289 CT angiography records from tertiary care hospital of south India. Pattern 3 or bifurcation (97.8%) was the most common, followed by trifurcation (1.04%), early bifurcation (0.51%) and single trunk (0.17%). The duplicated MCA and fenestration were seen in 0.34% and 0.17%, respectively.

The incidence of bifurcation in the present study is comparable to that in the study by Kadam et al. (2018). The incidence of bifurcation was higher in males (97.8%) as compared to females (91.7%) in our study. In a study conducted by Ogeng'O et al. (2011), bifurcation was seen in 82.3% cases and it was similar to the study conducted in Nigeria, America and India (Tanriover et al., 2003; Idowu et al., 2002; Pai et al., 2005). The differences in incidence in different populations is due to geographical variation and methodological differences (Ogeng'O et al., 2011). The obstruction of the superior trunk in bifurcation increases risk of contralateral hemiparesis as compared to that in trifurcation and quadrifurcation (Kahilogullari et al., 2012). Emboli are frequently trapped at a bifurcation point, preventing them from migrating further (Shapiro et al., 2020).

When present as single trunk, the main trunk of MCA extends without any division from its beginning to the posterior end of lateral cerebral fissure

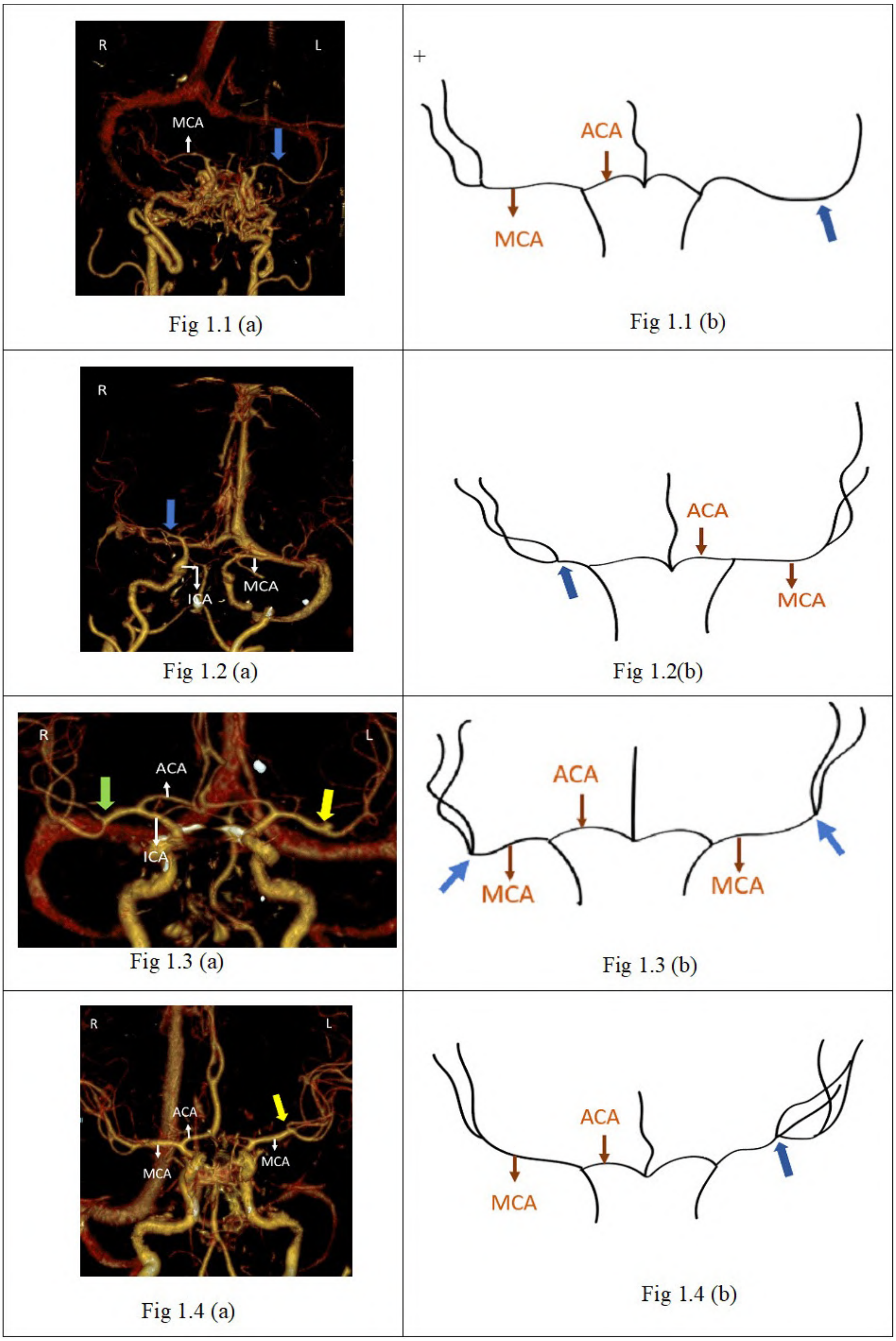

Fig. 1.- VRT images (3D) and schematic diagrams showing variations in branching pattern of middle cerebral artery. **1.1 (a):** VRT image (3D) showing unilateral single trunk of middle cerebral artery on the left side. Blue arrow- single trunk middle cerebral artery. **1.1 (b):** Schematic diagram showing unilateral single trunk of middle cerebral artery on the left side. Blue arrow- single trunk middle cerebral artery. **1.2 (a):** VRT image (3D) showing unilateral early bifurcation of middle cerebral artery on the right side. Blue arrow- early bifurcation of middle cerebral artery. **1.2 (b):** Schematic diagram showing unilateral early bifurcation of middle cerebral artery on the right side. Blue arrow- early bifurcation of middle cerebral artery. **1.3 (a):** VRT image (3D) showing bifurcation on both the sides. Green arrow- right middle cerebral artery, Yellow arrow- left middle cerebral artery. **1.3 (b):** Schematic diagram showing bifurcation on both the sides. Blue arrow-Bifurcation of middle cerebral artery. **1.4 (a):** VRT image (3D) showing unilateral trifurcation on the left side, arising from the main trunk of MCA. Yellow arrow- trifurcation. **1.4 (b):** Schematic diagram showing unilateral trifurcation on the left side, arising from the main trunk of MCA. Blue arrow-trifurcation. MCA- middle cerebral artery; ICA- internal carotid artery; ACA- anterior cerebral artery.

(Gunnal et al., 2019). The obstruction of the MCA in this pattern will have a larger area of ischemia as compared to that in the other patterns (Serrador et al., 2000). The incidence of single trunk in a study by Gunnal et al. (2019) was higher than the average in other studies (Gunnal et al., 2019). Even though literature is reserved on the consequences of this variation, it is likely that its significance is closer to trifurcation as few cases resemble trifurcation very closely (Ogeng'O et al., 2011).

Incidence of early bifurcation in present study is slightly less as compared to cadaveric studies (Ogeng'O et al., 2011; Eve et al., 2021). Early bifurcation was found to be significantly higher in a study conducted by Reci (2019) (Table 5). Teal et al. (1973) identified two cases of early bifurcation. In unilateral case on the left side, the division occurred at a distance of 4 mm. The branching was seen at a distance of 3 mm on right side and 4 mm on the left in bilateral presentation (Teal et al., 1973). Dimmick and Faulder (2009) described early bifurcation as when branching occurs at a distance of 1 cm). Incidence in cadaveric study is found to be high compared with angiographic study, as vessels are not clearly identified because of overlapping in case of angiography (Teal et al., 1973). Early bifurcation is mostly related with perforating branches, which arise from post-bifurcation segment of MCA. As a result, extreme caution needs to be exercised during surgical treatment of MCA aneurysms in patients with early bifurcation in order to avoid harm to perforating branches

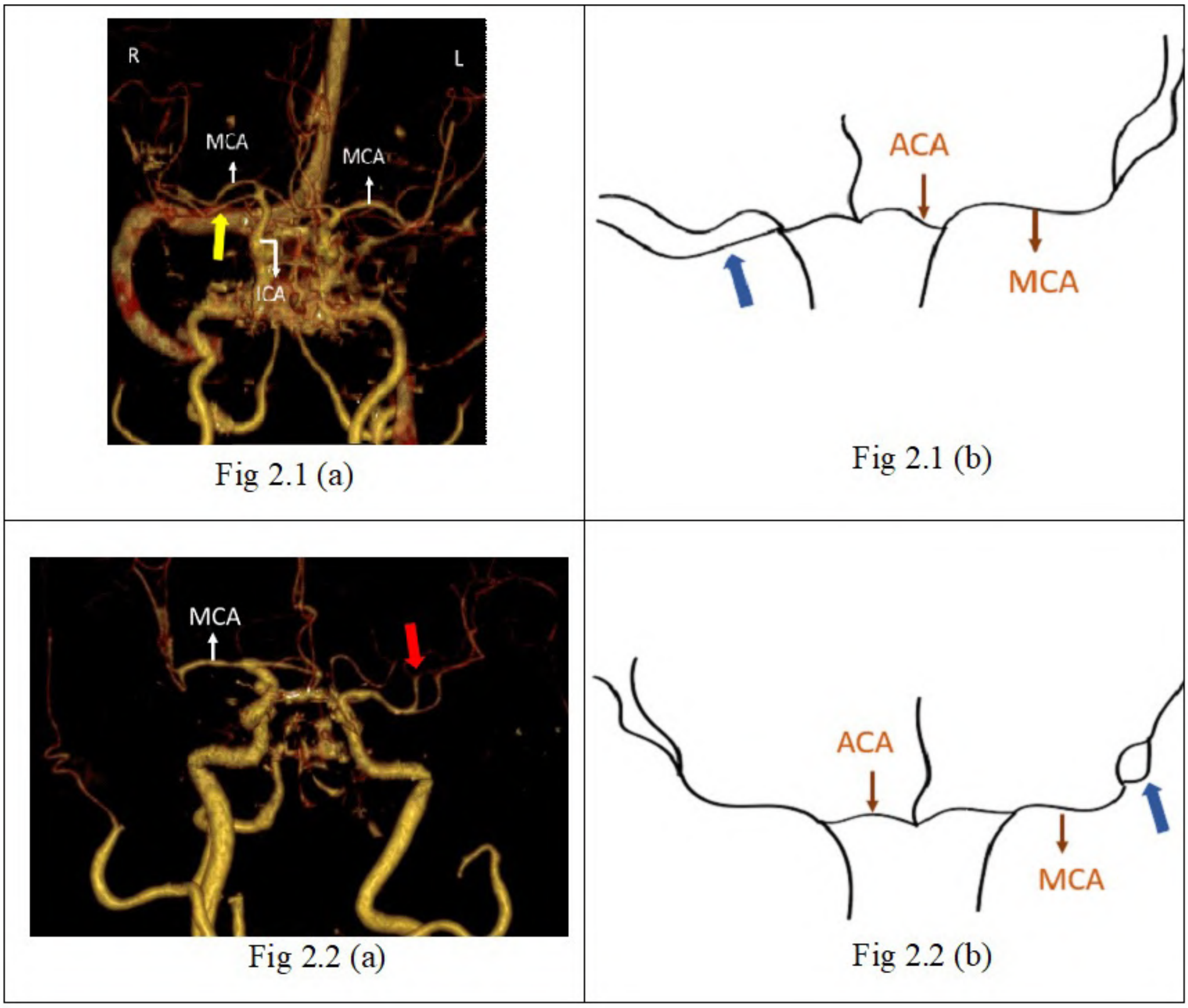

Fig. 2.- VRT images (3D) and schematic diagrams showing anomalies in branching pattern of middle cerebral artery, **2.1 (a):** VRT image (3D) showing unilateral duplicated middle cerebral artery on the right side. Yellow arrow- duplicated middle cerebral artery. **2.1 (b):** Schematic diagram showing unilateral duplicated middle cerebral artery on the right side. Blue arrow-duplicated middle cerebral artery. **2.2 (a):** VRT image (3D) showing unilateral left side fenestration on the distal part of middle cerebral artery. Red arrow-Fenestration. **2.2 (b):** Schematic diagram showing unilateral left side fenestration on the distal part of middle cerebral artery. Blue arrow-Fenestration. MCA- middle cerebral artery; ICA- internal carotid artery; ACA- anterior cerebral artery.

arising from the post-bifurcation section (Eve et al., 2021). As early bifurcation is not related with an increased risk in the formation of aneurysm; it is of relatively less clinical significance (Dimmick and Faulder, 2009).

In our study, females (2.8%) have slightly higher incidence of trifurcation than males (1.7%), while in a study conducted by Idowu et al. (2002) incidence was slightly higher in males than females. In the present study, incidence on the left

Table 4. Variations of middle cerebral artery in males and females.

Branching pattern/ variation	M N=360	F N=218	Group I		Group II		Group III		Group IV	
			M (N=14) (%)	F (N=20) (%)	M (N=88) (%)	F (N=46) (%)	M (N=158) (%)	F (N=110) (%)	M (N=100) (%)	F (N=42) (%)
Pattern I	0	1	-	-	-	-	-	-	-	1(2.38)
Pattern 2	1	2	1(7.14)	-	-	1(2.17)	-	1(0.90)	-	-
Pattern 3	176	100	13(92.85)	19(95)	87(98.86)	45(97.82)	158(100)	105(95.45)	98(98)	40(95.23)
Pattern 4	3	3	-	-	1(1.13)	-	-	3(2.72)	2(2)	-
Duplicated	-	2	-	1(15)	-	-	-	1(0.90)	-	-
Fenestration	-	1	-	-	-	-	-	-	-	1(2.38)

Table 5. The branching pattern of middle cerebral artery in different studies.

Authors, Year, Population	Type of study	Number of cases	Branching pattern				
			Pattern 1	Pattern 2	Pattern 3	Pattern 4	Quadrifurcation
Umansky et al., 1988; USA	Cadaveric	104	3.8%	-	66.3%	26%	3.8%
Meneses et al., 1997; Brazil	Cadaveric	14	-	-	85.6%	7.2%	-
Tanriover et al. 2003; Florida	Cadaveric	50	-	-	88%	12%	-
Vuillier et al., 2008; France	MRA	100	17%	-	73%	9%	-
Ogeng’0 et al. 2011; Kenya	Cadaveric	288	6.2%	5.2%	82.3%%	10.8%	0.7%
Sadatamo et al., 2013; Japan	MRA	124	-	-	92.7%	7.3%	-
Brzegowy et al., 2017; Poland	CTA	500	-	-	86.2%	13.8%	-
Jeyakumar and Veerapandan, 2018; India	Cadaveric	30	-	-	73.3%	26.6%	-
Kadam et al., 2018; India	Cadaveric	58	-	-	96.5%	1.7%	Multiple trunks-1.7%
Reci, 2019; Macedonia	Cadaveric	50	-	24%	48%	26%	-
Gunnal et al., 2019; India	Cadaveric	340	20.6%	-	64.7%	12.4%	2.4%
Pai et al., 2021; India	Cadaveric	10	-	-	80%	20%	-
Eve et al., 2021; Myanmar	Cadaveric	100	12%	3%	72%	16%	-
Present study, 2021; India	CTA	578	0.2%	0.5%	98%	1%	-

was higher than on the right side. In contrast, in a study conducted by Gunnal et al. (2019) incidence was higher on the right side as compared to the left. According to Umansky et al. (1988) incidence of trifurcation or quadrifurcation is seen in 30-40% cases, and the ischemia caused by the obstruction of one trunk will be smaller if there is a higher number of secondary trunks. Thus, obstruction in trifurcation results in less severe neurological impairment compared to bifurcation, which results in contralateral hemiplegia.

The variation in MCA branching has its basis in the development of intracranial vessels. MCA development is associated with that of the lobes of the cerebrum (Brzegowy et al., 2018). In fetal life, ICA branches into two divisions, anterior and posterior (Dudek, 2014). Initially, anterior division gives rise to primitive arteries and these arteries supply the optic and olfactory region (Dudek, 2014). With further development, MCA originates as small buds at 35 days of intrauterine life (11-12 mm stage) from the anterior division. At this stage, the major part of the cerebral hemispheres is supplied by it, but it is still plexiform and is not a true artery. It becomes prominent at 16-18 mm stage, and at this stage a single artery is formed by the fusion of plexiform vessels. Further, division of branches from MCA supply the cerebral hemisphere (Menshawi et al., 2015). In the developmental stage of MCA if there is early disruption before bifurcation, it leads to plexiform arterial network of the M1 segment (Yasargil, 1984). Failure of segmental fusion can result in formation of single trunk, early bifurcation, trifurcation and quadrifurcation patterns.

The duplication is defined as two arteries having different origin points and no caudal arterial junction (Lesley and Dalsania, 2004). Incomplete continuation of arterial twigs results in variation like duplicated MCA (Gunnal et al., 2019). According to Komiyama et al. (1998), duplicated MCA results because of early branching of MCA and is defined as direct bifurcation, as this arises directly from ICA. In present study, incidence of duplicated MCA was 0.7%, similar to the findings by Gunnal et al. (2019), Uchino et al. (2000) and Lee et al. (2005). The main MCA trunk was longer as compared to the duplicated MCA in the present study, which is similar to the observation of Uchino et al. (2000). Incidence was higher in females in our study. However, Uchino et al. (2000) reported higher incidence in males. Cases having both duplicated and accessory MCA are very rare and have been reported in few studies (Dong et al., 1991; Kitami et al., 1985). Distinguishing accessory MCA from duplicated MCA is challenging. Both supply the territory of MCA and have different origins, accessory is a small branch from ACA and duplicated artery is from the distal ICA (Crompton, 1962). The pattern of branching on the opposite side and level of carotid bifurcation helps in identifying the variant (Uchino et al., 2000). The

Table 6. Variations of middle cerebral artery in different studies.

Authors	Year	Population	Method	Number of cases	Variations		
					D	F	A
Uchino et al.	1999	Japan	MRA	850	2.1%	0.5%	1.17%
Gailloud et al.	2002	Switzerland	CTA	2340	-	0.4%	-
Idowu et al.	2002	Nigeria	Cadaveric	100	-	-	1%
Lee et al.	2005	Korea	MRA	34	0.8%	0.1%	0.1%
Dimmick and Faulder	2009	Australia	CTA	300	0.2-2.9%	0.17%	0.2%
Chang et al.	2011	Korea	CTA	1182	0.6%	-	-
Uchino et al.	2012	Japan	MRA	6982	0.1%	0.2%	-
Gunnal et al.	2019	Indian	Cadaveric	340	0.9%	-	2.1%
Reci	2019	North Macedonia	Cadaveric	50	2%	-	2%
Present Study	2021	India	CTA	578	0.3%	0.2%	

D-Duplicated MCA, F-Fenestrated MCA, A-Accessory MCA, CTA-Computed Tomography Angiography**,** MRA-Magnetic Resonance Angiography.

duplicated MCA provides collateral supply to frontal lobe and basal ganglia (Uchino et al., 2000), and its blockage presents with aphasia or hemiparesis. But this block can be missed in MR Angiography or CT Angiography because of presence of definitive MCA (Pressman et al., 2021). According to some authors, duplicated MCA are of two types: type I arises from ICA at the level of termination and type II originates from ICA or anterior choroidal artery (Gibo et al., 1981; Umansky et al., 1988; Kai et al., 2006). Both the duplicated MCA were of type I in the present study. Duplicated MCA along with increase in cerebral aneurysms are seen in many descriptions but mechanism is not clearly understood (Komiyama et al., 1998). Uchino et al. (2004) noted association of duplicated MCA with aneurysm in 38 cases and aneurysm was located at the origin of duplicated MCA in 15 cases. Since we have excluded the cases of aneurysm in our study, the correlations of aneurysm and this variation could not be determined.

Fenestration is the split of an artery lumen into several channels with muscularis and endothelial layers, with adventitia being shared (Parmar et al., 2005). MCA fenestration suggests the incomplete continuation of more than one arterial twigs, which merges into definitive MCA. In our study, fenestration was located in a distal segment of MCA at a distance of 12.93 mm from the origin of main trunk. In contrast, Uchino et al. (2006) reported it in a proximal segment at a distance of 4 mm from MCA trunk origin and Crompton (1962) reported it at a distance of 8 mm from main MCA trunk. The incidence of fenestration is found to be higher in cadaveric study as compared to angiographic study, because direct observation of anatomic specimens provides better visualization, while indirect observation in CTA restricts the surgical field (Gailloud et al., 2002). Recently, high incidence of MCA fenestration (5.2%) has been seen using 3D rotational angiography (Van et al., 2009).

CONCLUSION

The present study documented the variation in the branching pattern of MCA. Incidence of MCA branching pattern variations like single trunk, early bifurcation, and trifurcation in Indians is less as compared to CTA studies from other populations. This CTA study will help create a significantly more extensive database and perform more precise statistical analysis than anatomical cadaver studies. Future studies involving more patients can extrapolate the information obtained from this study to the general population. The knowledge of MCA variations will be useful for clinicians and surgeons in handling cases of intracranial aneurysms and infarcts. Also, data from this study would help surgeons minimize errors and provide the best possible outcome to the patients.

REFERENCES

ALMEIDA JP, RUIZ-TREVINO AS, SHETTY SR, OMAY SB, ANAND VK, SCHWARTZ TH (2017) Transorbital endoscopic approach for exposure of the sylvian fissure, middle cerebral artery and crural cistern: an anatomical study. *Acta neurochir*, 159(10): 1893-1907.

BRZEGOWY P, POLAK J, WNUK J, ŁASOCHA B, WALOCHA J, POPIELA TJ (2018) Middle cerebral artery anatomical variations and aneurysms: a retrospective study based on computed tomography angiography findings. *Folia Morphol*, 77(3): 434-440.

CROMPTON MR (1962) The pathology of ruptured middle-cerebral aneurysms with special reference to the differences between the sexes. *Lancet,* 280(7253): 421-425.

DIMMICK S, FAULDER K (2009) Normal variants of the cerebral circulation at multidetector CT angiography. *Radiographics*, 29(4): 1027-1043.

DONG LW, YAMADA K, OHTA T, TAKAHASHI N (1991) Ruptured intracranial aneurysm combined with multiple cerebral vessel anomalies; a case report. *No Shinkei Geka*, 19(10): 975-978.

DUDEK RW (2014) High-yield embryology. *Lippincott Williams &amp*. Wilkins, Philadelphia, pp 1-147.

EVE OO EM, SAW KE, OO HN, THAN T, THIDA K (2021) Variable anatomy of the MCA from its origin to the edge of the Sylvian fissure: A direct fresh brain study. *Sci World J*, 2021: 1-7.

GAILLOUD P, ALBAYRAM S, FASEL JH, BEAUCHAMP NJ, MURPHY KJ (2002) Angiographic and embryologic considerations in five cases of middle cerebral artery fenestration. *AJNR Am J Neuroradiol*, 23(4): 585-587.

GIBO H, CARVER CC, RHOTON AL, LENKEY C, MITCHELL RJ (1981) Microsurgical anatomy of the middle cerebral artery. *J Neurosurg*, 54(2): 151-169.

GUNNAL SA, FAROOQUI MS, WABALE RN (2019) Study of middle cerebral artery in human cadaveric brain. *Ann Indian Acad Neurol*, 22(2): 187-194.

IDOWU O, SHOKUNBI M, MALOMO A, OGUNBIYI J (2002) Size, course, distribution and anomalies of the middle cerebral artery in adult Nigerians. *East Afr Med J,* 79(4): 217-220.

JEYAKUMAR R, VEERAPANDAN R (2018) Study of anatomical variations in MCA. *Int J Sci Study*, 5(12): 5-10.

KADAM J, SHARMA V, BAWEJA S, SHARMA D (2018) Morphological and morphometric study of branching pattern of M2 segment of middle cerebral artery in human cadaveric brains. *J Med Sci clin Res*, 6(6): 660-665.

KAHILOGULLARI G, UGUR H, COMERT A, TEKDEMIR I, KANPOLAT Y (2012) The branching pattern of the MCA: is the intermediate trunk real or not? An anatomical study correlating with simple angiography. *J Neurosurg*, 116(5): 1024-1034.

KAI Y, HAMADA JI, MORIOKA M, YANO S, KUDO M, KURATSU JI (2006) Treatment of unruptured duplicated middle cerebral artery aneurysm: case report. *Surg Neurol*, 65(2): 190-193.

KITAMI K, KAMIYAMA H, YASUI N (1985) Angiographic analysis of the middle cerebral artery in cerebral aneurysms--its branching pattern and so-called vascular anomalies. *No Shinkei Geka*, 13(3): 283-290.

KOMIYAMA M, NAKAJIMA H, NISHIKAWA M, YASUI T (1998) MCA variations: duplicated and accessory arteries. *AJNR Am J Neuroradiol*, 19(1): 45-49.

LEE TH, KIM DH, LEE BH, KIM HJ, CHOI CH, PARK KP, JUNG DS, KIM S, MOON TY (2005) Preliminary results of endovascular stent-assisted angioplasty for symptomatic middle cerebral artery stenosis. *AJNR Am J Neuroradiol*, 26(1): 166-174.

LESLEY WS, DALSANIA HJ (2004) Double origin of the posterior inferior cerebellar artery. *AJNR Am J Neuroradiol*, 25(3): 425-427.

LUTZ T, MONNINGS P, AYZENBERG I, LUKAS C (2018) Twig-like middle cerebral artery: a seldom vessel anomaly of important relevance. *Clin Neuroradiol*, 28(3): 441-443.

MENESES MS, RAMINA R, JACKOWSKI AP, PEDROZO AA, PACHEKO RB, TSUBOUCHI MH (1997) Middle cerebral artery revascularization: anatomical studies and considerations on the anastomosis site. *Arq Neuropsiquiatr*, 55(1): 16-23.

MENSHAWI K, MOHR J, GUTIERREZ J (2015) A functional perspective on the embryology and anatomy of the cerebral blood supply. *J Stroke*, 17(2): 144-158.

OGENG'O J, NJONGO W, HEMED E, OBIMBO M, GIMONGO J (2011) Branching pattern of middle cerebral artery in an African population. *Clin Anat*, 24(6): 692-698.

OKUDERA H, KOIKE J, TOBA Y, KUROYANAGI T, KYOSHIMA K, KOBAYASHI S (1987) Fenestration of the middle cerebral artery associated with cerebral infarction. *Neurol Med Chir*, 27(6): 559-563.

OTA T, KOMIYAMA M (2021) Twig-like middle cerebral artery: Embryological persistence or secondary consequences. *Interv Neuroradiol*, 27(4): 584-587.

PAI SB, VARMA RG, KULKARNI RN (2005) Microsurgical anatomy of the middle cerebral artery. *Neurol India*, 53(2): 186-190.

PARMAR H, SITOH YY, HUI F (2005) Normal variants of the intracranial circulation demonstrated by MR angiography at 3T. *Eur J Radiol*, 56(2): 220-228.

PRESSMAN E, AMIN S, RENATI S, MOKIN M (2021) Middle cerebral artery duplication: a near miss for stroke thrombectomy. *Cureus,* 13(5): 1-4.

RECI V (2019) Morphologic Variations of End Trunks of M1 Segment of Middle Cerebral Artery. HSOA *J Alzheimer's & Neurodegener Dis*, 5(2):1-6.

RINNE J, HERNESNIEMI J, NISKANEN M, VAPALAHTI M (1996) Analysis of 561 patients with 690 MCA Aneurysms: Anatomic and clinical features as correlated to Management outcome. *Neurosurg*, 38(1):2–9.

SADATAMO T, YUKI K, MIGITA K, IMADA Y, KUWABARA M, KURISU K (2013) Differences between middle cerebral artery bifurcations with normal anatomy and those with aneurysms. *Neurosurg Rev*, 36(3): 437-445.

SERRADOR JM, PICOT PA, RUTT BK, SHOEMAKER JK, BONDAR RL (2000) MRI measures of middle cerebral artery diameter in conscious humans during simulated orthostasis. *Stroke*, 31(7): 1672-1678.

SHALOM D, TREVISAN M, MALLELA A, NUNEZ M, GOLDSCHMIDT E (2021) Brain folding shapes the branching pattern of the MCA. *PLoS One*, 16(1): 0245167.

SHAPIRO M, RAZ E, NOSSEK E, CHANCELLOR B, ISHIDA K, NELSON PK (2020) Neuroanatomy of the middle cerebral artery: implications for thrombectomy. *J Neurointerv Surg*, 12(8): 768-773.

TANRIOVER N, KAWASHIMA M, RHOTON AL JR, ULM AJ, MERICLE RA (2003) Microsurgical anatomy of the early branches of the MCA: morphometric analysis and classification with angiographic correlation. *J Neurosurg*, 98(6): 1277-1290.

TEAL JAMESS, RUMBAUGH CALVINI, BERGERON RTHOMAS, SEGALL HERVEYD (1973) Anomalies of the MCA: Accessory artery, duplication, and early bifurcation. *AJR Am J Roentgenol*,18(3): 567-575.

TURE U, YASARGIL M, AL-MEFTY O, YASARGIL D (2000) Arteries of the insula. *J Neurosurg*, 92(4): 676-687.

UCHINO A, KATO A, TAKASE Y, KUDO S (2000) MCA variations detected by magnetic resonance angiography. *Eur Radiol*, 10(4): 560-563.

UCHINO M, KITAJIMA S, SAKATA Y, HONDA M, SHIBATA I (2004) Ruptured aneurysm at a duplicated middle cerebral artery with accessory middle cerebral artery. *Acta Neurochir*, 146(12): 1373-1375.

UCHINO A, TAKASE Y, NOMIYAMA K, EGASHIRA R, KUDO S (2006) Fenestration of the MCA detected by MR angiography. *Magn Reson Med Sci,* 5 (1): 51-55.

UCHINO A, SAITO N, OKADA Y, NAKAJIMA R (2012) Duplicate origin and fenestration of the MCA on MR angiography. *Surg Radiol Anat,* 34(5): 401-404.

UMANSKY F, DUJOVNY M, AUSMAN JI, DIAZ FG, MIRCHANDANI HG (1988) Anomalies and variations of the middle cerebral artery: a micro anatomical study. *Neurosurg*, 22(6P1-P2): 1023-1027.

VAN ROOJI S, VAN ROOJI W, SLUZEWSKI M, SPRENGERS M (2009) Fenestrations of intracranial arteries detected with 3D rotational angiography. *AJNR Am J Neuroradiol*, 30(7): 1347-1350.

VUILLIER F, MEDEIROS E, MOULIN T, CATTIN F, BONNEVILLE J, TATU L (2008) Main anatomical features of the M1 segment of the middle cerebral artery: a 3D time-of-flight magnetic resonance angiography at 3T study. *Surg Radiol Anat*, 30(6): 509-514.

WANG GX, YU JY, WEN L, ZHANG L, MOU KJ, ZHANG D (2016) Risk factors for the rupture of middle cerebral artery bifurcation aneurysms using CT angiography. *PLoS One*,11(12): 0166654.

YASARGIL MG (1984) Microsurgical anatomy of the basal cisterns and vessels of the brain, diagnostic studies, general operative techniques and pathological considerations. *Thieme Publishing Group,* Microneurosurg, volume I Stuttgart Germany, pp 1-371.