Original Article
https://doi.org/10.5115/acb.22.242
eISSN 2093-3673
Anatomy & Cell Biology

Morphology of middle cerebral artery using computed tomography angiographic study in a tertiary care hospital

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Abstract: Increased tortuosity of vessel is associated with high incidence of plaque formation leading to atherosclerosis. Surgical procedures are done after analyzing morphology of middle cerebral artery (MCA). However, literature describing MCA morphology using computed tomography angiography (CTA) is limited, so this study was planned to determine its incidence in Indian population. Datasets of CTA from 289 patients (180 males and 109 females), average age: 49.29±16.16 years (range: 11 to 85 years), from a tertiary care hospital were systematically reviewed for morphology of MCA. Cases involving aneurysms and infarcts were excluded. Four shapes of MCA were recognized: straight, U, inverted U, and S-shaped. MCA was straight in 44% (254/578), U-shaped in 37% (215/578), S shaped in 15% (89/578) and inverted U-shaped in 3% (20/578) cases. In males, MCA was straight in 46% (166/360), U-shaped in 37% (134/360), S-shaped in 16% (58/360) and inverted U-shaped in 4% (14/360) cases. In females, MCA was straight in 42% cases (92/218), U-shaped in 37% (81/218), S-shaped in 17% (36/218) and inverted U-shaped in 4% (9/218). On comparing shape with various age groups using chi square test, U shaped ($P \leq 0.001$) and S-shaped ($P=0.003$) MCA were found to be statistically significant. The incidence of straight shape was higher in advanced age group (>60 years). Knowledge of MCA shape will be useful for clinicians and surgeons in successful endovascular recanalization. Also, this data would help surgeons during neurointerventional procedures.

Key words: Middle cerebral artery, Plaque, Aneurysm, Cerebral angiography

Received November 26, 2022; Revised January 25, 2023; Accepted April 27, 2023

Introduction

Middle cerebral artery (MCA) is conventionally divided into four segments. The first or M1 segment extends from the termination of internal carotid artery (ICA) to the genu of MCA situated at the junction of sphenoidal and operculo-insular region of the sylvian fissure [1]. It provides main supply to the cerebral hemisphere [2]. The intracranial atherosclerosis occurs in M1 segment in 25% cases [3, 4]. Certain pathological conditions like stroke also commonly affect this segment [3, 4]. The configuration of the vessel plays a major role in the development of atherosclerosis apart from the other risk factors. The plaque formation can occur in the vessel having less shear forces [5, 6]. Anatomical features of the artery like shape and bifurcation of segment are related to altered haemodynamic and may lead to the development of vascular diseases [7, 8].

Based on the available literature, MCA morphology varies from straight to U-shaped [10]. Incidence of C-shaped and arch shaped MCA is 43.1% and 64%, respectively [2, 11]. The

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superior plaques (21.7%) are more common in straight or U-shaped, whereas inferior plaques (39.9%) are common in inverted U-shaped or S-shaped arteries [10, 12].

An increased incidence of plaque formation and atherosclerosis is associated with tortuosity of vessel [9]. Analysis of vessel shape elucidates its tortuosity and is important for successful endovascular recanalization procedure [11]. In clinics, details about the shape of M1 segment carry great importance particularly at the time of neurointerventional procedures when maximum intensity projection images are viewed by 3D imaging. The morphology of MCA facilitate clinicians and surgeons in handling cases of intracranial atherosclerosis and plaques, preventing related complications, minimize errors and provide best possible outcome to the patients. Thus, it will be helpful for the clinicians to identify the shape of M1 segment [11].

A large number of cases can be explored for vessel morphology with imaging techniques [13, 14]. Han et al. used MR angiography to identify various shapes of MCA in cases from the Chinese population [2]. Apart from this, only few imaging or cadaveric studies have explored MCA morphology [10, 11]. The available literature on MCA morphology from a large sample of Indian population is lacking. Thus, this study was planned to analyze MCA shape using computed tomography (CT) angiography (CTA) in a tertiary care hospital of south India.

Materials and Methods

This descriptive Hospital Record based study was done in the Departments of Radiology and Anatomy in Jawaharlal Institute of Postgraduate Medical Education and Research, Puducherry from July 2017 to July 2020. The study was approved by Institute Human Ethics Committee of Jawaharlal Institute of Postgraduate Medical Education and Research (Ref. No. JIP/IEC/2019/421 dated 12/12/2019). Waiver of consent was given by Institutional Ethics Committee as research involves not more than minimal risk, there is no direct contact between the researcher and participant and in this study records were deidentified of patients identity.

The CT cerebral angiography and multiphasic contrast enhanced records, from Picture Archiving Communication System of the Department of Radiology, were used. The anatomic variation in MCA was anticipated to be around 25% in CTA [15]. Power and Sample software (W.D. Dupont and W.D. Plummer) was applied at 5% level of significance and absolute precision of 5% for calculation, and the estimated total sample for the study was 289. The conditions like occlusion, dissection, aneurysm, and vasculitis that effect the normal vascular architecture of MCA and scans in which branching pattern of MCA was not completely visible were excluded from the study.

Plain CT brain was followed by CT angiogram. CTA was done using 128-slice multidetector CT system, Siemens Somatom 64 (3 mm slices were acquired with a 128×0.6 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 10–15 seconds). Non-ionic contrast (400 mg/ml iodine) at injection rate of 4–6 ml/sec with saline flush of 40 ml was given. The CTA 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.

Bones 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. The data was recorded by anatomist under the guidance and supervision of radiologist to eliminate observer bias. The morphology of M1 segment of MCA on both the sides was noted. The statistical analysis was done using chi square test for sex, age and the two sides.

Results

The morphology of MCA was examined in 289 CTA (right: 289, left: 289). Percentage of male and female CT cerebral angiograms was 62.3% (180/289) and 37.7% (109/289), respectively. The average age of subjects was 49.29±16.16 years (range: 11 to 85 years). For convenience of analysis, the records were divided into four groups based on age, *i.e.*, group I (0–20 years), group II (21–40 years), group III (41–60 years) and group IV (61–100 years). The group I, II, III, and IV had 17 (5.9%), 67 (23.2%), 134 (46.4%), and 71 (24.5%) records, respectively.

The four shapes of MCA (Fig. 1) were recognized: "straight", "U", "inverted U", and "S". MCA was straight in 43.9% (254/578), U-shaped in 37.2% (215/578), inverted U-shaped in 3.5% (20/578) and S-shaped in 15.4% (89/578). No significant difference in shape was found on right and left

https://doi.org/10.5115/acb.22.242

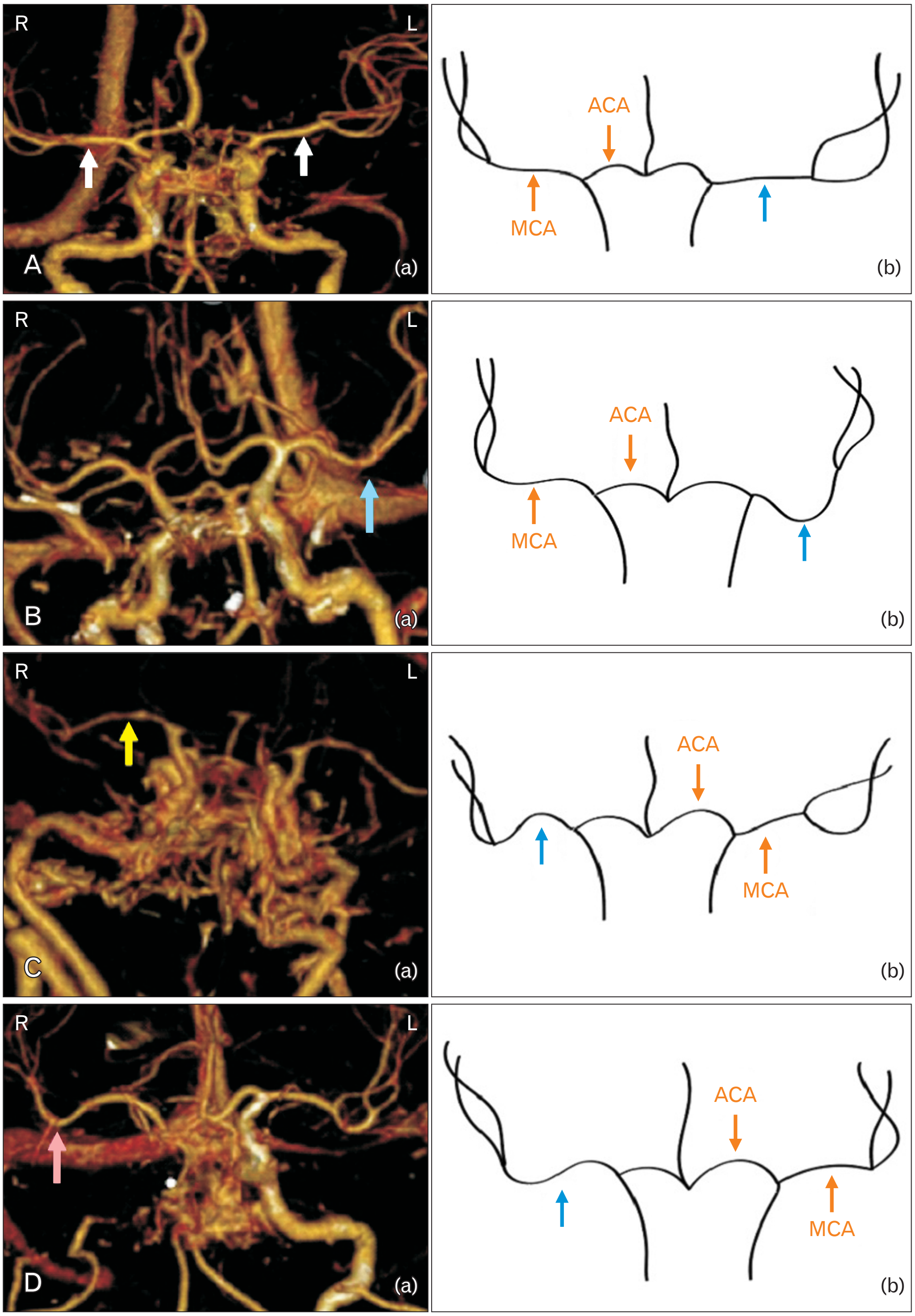

Fig. 1. VRT images (3D) and schematic diagrams showing shapes of middle cerebral artery. (A) Straight shape. (a) VRT image (3D) showing bilateral straight-shaped middle cerebral artery on both sides. White arrow: single trunk middle cerebral artery. (b) Schematic diagram showing bilateral straight-shaped middle cerebral artery on both sides. Blue arrow: single trunk middle cerebral artery. (B) U-shape. (a) VRT image (3D) showing unilateral U-shaped middle cerebral artery on left side. (b) Schematic diagram showing U-shaped middle cerebral artery on left side. Blue arrow: U-shaped middle cerebral artery. (C) Inverted U-shape. (a) VRT image (3D) showing inverted U-shaped middle cerebral artery on right side. Yellow arrow: Inverted U-shaped middle cerebral artery. (b) Schematic diagram showing inverted U-shaped middle cerebral artery on right side. Blue arrow: Inverted U- shaped middle cerebral artery. (D) S-shape. (a) VRT image (3D) showing S-shaped middle cerebral artery on right side. Pink arrow: S-shaped middle cerebral artery. (b) Schematic diagram showing S-shaped middle cerebral artery on right side. Blue arrow: S-shaped middle cerebral artery. VRT, volume rendered technique; R, right; L, left; ACA, anterior cerebral artery, MCA, middle cerebral artery.

side MCA and on comparing different shapes on right and left sides *P*-value was not statistically significant (Table 1).

In 360 specimens from males, MCA was straight in 46.1% (166/360), U-shaped in 37.2% (134/360), S-shaped in 16.1% (58/360) and inverted U-shaped in 3.9% (14/360). In females, MCA was straight in 42.2% (92/218), U-shaped in 37.1% (81/218), S-shaped in 16.5% (36/218) and inverted U-shaped in 4.1% (9/218). No significant difference in shape was found on right and left side in both the genders. On comparing different shapes in males and females (using chi square test) on both right and left sides, *P*-value was not statistically significant.

The incidence of straight shape was higher in group IV compared to other groups. However, the “U” and “S” shapes were more common in group III and I, respectively (Table 2).

In males, straight shape was observed in 28.6% cases

Table 1. Incidence of shapes of middle cerebral artery on the right and left side

No.	Shape	Side	Male (n=180)	Female (n=109)	Total (n=289)	*P*-value
1	Straight	Right	78 (43.3)	48 (44.1)	126 (43.6)	0.537
		Left	84 (46.7)	44 (40.4)	128 (44.3)	
2	U	Right	70 (38.9)	40 (36.7)	110 (38.1)	0.684
		Left	64 (35.5)	41 (37.6)	105 (36.3)	
3	Inverted U	Right	6 (3.3)	4 (3.7)	10 (3.5)	0.653
		Left	5 (2.8)	5 (4.6)	10 (3.5)	
4	S	Right	26 (14.4)	17 (15.6)	43 (14.9)	0.865
		Left	27 (15.0)	19 (17.4)	46 (15.9)	

Values are presented as number (%).

Table 2. Incidence of shapes of middle cerebral artery in various age groups

No.	Shapes	Group I (n=34)	Group II (n=134)	Group III (n=268)	Group IV (n=142)	*P*-value
1	Straight	12 (35.3)	52 (38.8)	114 (42.5)	76 (53.5)	0.046
2	U	10 (29.4)	48 (35.8)	124 (46.3)	32 (22.5)	<0.001
3	Inverted U	2 (5.9)	8 (5.9)	6 (2.2)	4 (2.8)	0.212
4	S	10 (29.4)	26 (19.4)	24 (8.9)	30 (21.1)	0.003

Values are presented as number (%).

of group I, 34.1% of group II, 44.3% of group III, 58.0% of group IV. The "U" shape was noted in 42.8% cases of group I, 38.6% of group II, 46.8% of group III, 20.0% of group IV. The "Inverted U" shape was observed in 14.3% cases of group I, 4.5% of group II, 1.3% of group III, 2.0% of group IV. The "S" shape was noted in 14.3% cases of group I, 22.7% of group II, 7.6% of group III and 20% of group IV.

In females, straight shape was observed in 40% cases of group I, 47.8% of group II, 40% of group III, 42.8% of groups IV. The "U" shape was noted in 20% cases of group I, 30.4% of group II, 45.5% of group III, 28.6% of group IV. The "Inverted U" shape was absent in group I, observed in 8.7% cases of group II, 3.6% of group III, 4.8% of group IV. The "S" shape was noted in 40% cases of group I, 13.1% of group II, 10.9% of group III and 23.8% of group IV.

Using chi square test, on comparing group I and group II (P=0.64), group I and group IV (0.26) P-value was not statistically significant while on comparing group I and group III (P=0.002), group II and group III (P=0.003), group III and group IV, group II and group IV (0.028), (P<0.001), P-value was statistically significant. On comparing shape with groups using chi square test, U shaped ($P\leq0.001$) and S-shaped (P=0.003) MCA were found to be statistically significant while straight shaped (P=0.046) and inverted U-shaped (P=0.212) were not statistically significant.

Discussion

The present study was done to evaluate the morphology of MCA in the 289 CTA records of patients from the tertiary care hospital. Four shapes of MCA were recognized: "straight, "U", "inverted U", and "S-shaped".

Proximal part of MCA is referred to as the M1 segment [16]. However, other terminologies have also been used like sphenoidal [16] and horizontal [17] segments. The M1 segment is defined in terms of brain structures in its vicinity [16]. Its origin is located lateral to the optic chiasma. It then runs laterally towards the insula and is located posterior to the anterior perforated substance [18]. M1 originates at the termination of ICA and is present at the similar level of ACA. It seems to extend laterally from ICA because of its direction and diameter. This segment concludes when the MCA trunk takes a sharp turn backwards and upwards [18].

In present study, M1 segment was straight in most of the cases (44%) similar to the other studies [18, 19]. However, in some studies, M1 segment makes a curve with concavity on the posterior aspect [16, 20]. The anterior concavity is also reported but it is less common [21].

Out of 289, MCA was U-shaped in 38% cases, inverted U-shaped in 3% cases and S-shaped in 16% cases in the current study. However, Kim et al. [10] reported higher incidence of "U", "inverted U" and "S" shapes (Table 3). In contrast, Reçi and Bexheti [11] described arch-shaped MCA in 64%,

https://doi.org/10.5115/acb.22.242

Table 3. Incidence of shapes of middle cerebral artery in various studies

Authors	Year	Population	Method	Number of cases	Shape (%)
Han et al. [2]	2014	China	MRA	419	C-shaped: 43.14 Line shaped: 38.17 S-shaped: 18.69
Kim et al. [10]	2015	Korea	MR imaging	40	S-shaped: 30 Inverted U-shaped: 27.5 Straight: 17.5 U-shaped: 15
Reçi and Bexheti [11]	2019	North Macedonia	Cadaveric study	25	Arch shaped: 64 S-shaped: 24 Straight shaped: 12
Present study	2021	India	CTA	289	Straight shaped: 44 U-shaped: 37 S-shaped: 15 Inverted U-shaped: 3

MRA, magnetic resonance angiography; MR, magnetic resonance; CTA, computed tomography angiography.

S-shaped in 24% and straight-shaped in 12%. The incidence of straight shape M1 is higher in advanced age group in the present study. It is likely to be due to increase in stiffening of the vessel with age [22]. Conversely, Han et al. [2] found that there is increase in the tortuosity of the M1 segment with increase in age.

Vuillier et al. [18] described MCA as smooth, concave-curved to straight-shaped extending laterally and anteriorly. Kim et al. [10] found that straight or U-shaped MCA has more incidence of superior plaques as compared to “inverted U” or “S” shapes which have higher incidence of inferior plaques. Being present near the perforators, superior plaques are more symptomatic compared to inferior plaques [10]. In case of occlusion of proximal part due to plaques, a superficial temporal artery and MCA bypass provides blood flow to the distal MCA territory in which vessel is approached by craniotomy 6 cm above the external auditory canal. As distribution of plaque is related to the shape of M1 segment, knowing the shape of MCA would be valuable before surgery [10]. Plaques are distributed in the inner wall in a curved MCA because of disturbance in blood flow and less shear stress which due to defect in endothelial dysfunction leads to atherosclerosis [12, 23-25]. Though outer wall is more prone to higher shear stress, its plaque distribution is less despite of outer remodelling effect. Thus, before undertaking endovascular procedures, it is essential to know the tortuosity of vessel [23, 26]. We did not observe any plaques in MCA in this study.

The success of endovascular procedure is based on the anatomy of MCA [27-29]. Mechanism for this is not clear, however, haemodynamic factors and properties of the device used for endovascular procedure play a role [30, 31]. M1 segment can be reshaped by angioplasty and stenting. To avoid complications like repeat stenosis, cerebrovascular procedures are planned after complete evaluation of the configuration of the vessel [12]. The different degrees of tortuousness was seen by Han et al. [2], but the relationship of tortuosity of M1 segment with cerebrovascular disease is still doubtful [2]. Although the MCA pattern was not associated with plaque which is symptomatic, the different shapes of MCA show disparity in the frequency of symptomatic plaques. Therefore, vascular geometry leads to the growth of subcortical infarction to some extent by affecting the plaque location [10].

In a twisted vessel, centrifugal flow of blood is inclined towards the outer surface of vessel wall, thus decreasing the shear stress on the inner wall of vessel [32]. It predisposes to intimal layer thickening and formation of atherosclerosis in the inner wall of coronary or femoral arteries [9]. For endovascular procedures, tortuosity of the vessel holds a great significance as progressive risks and the success rate are clinically associated with the vessel morphology, particularly tortuosity [2]. There is deviation in the direction of blood flow at the bifurcation of MCA and significant increase in shear stress which leads to the development of aneurysms [33]. The increase in tortuosity of vessel is associated with elevated risk of aneurysm formation [34]. Also, abnormal stretching of vessel due to plaque expansion in cerebral arteriosclerosis results in aneurysm [35].

This CTA study in a tertiary care hospital of south India has shown that the most common shape of MCA is straight.

The incidence of straight shape MCA is high in advanced age group, but there is no relation of gender and shape of MCA in Indian population. The awareness of MCA shape will be useful for clinicians and surgeons in successful endovascular recanalization for plaques and other neurointerventional procedures.

The present study is retrospective in nature and dependent on the CT records available in the tertiary care hospital during the study period. The number of CT Angiograms of male patients was larger compared to that of female patients. The comparison of incidence in this study with different populations was difficult due to exclusion of aneurysm cases.

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Author Contributions

Conceptualization: US, SV, SA. Data acquisition: US. Data analysis or interpretation: US, SV, SA. Drafting of the manuscript: US, SV, SA. Critical revision of the manuscript: SV, SA. Approval of the final version of the manuscript: all authors.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

Funding

None.

Acknowledgements

I would like to express my sincere gratitude to the head of department of anatomy and radiology, JIPMER for encouraging me to conduct this study.

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