Original Article

Study of Middle Cerebral Artery in Human Cadaveric Brain

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Abstract

Background: Middle cerebral artery (MCA) is the larger terminal branch of the internal carotid artery. It travels through the Sylvian fissure on the insula. **Objective:** MCA supplies a large area of distribution than the other two cerebral arteries. Though it is so, there are very few articles in the literature describing MCA. Aim of the present work is to study the MCA regarding its origin, course, termination, branching pattern, morphometry and symmetry. **Materials and Methods:** 340 MCAs from 170 formalin preserved brains were dissected. Morphology, morphometry and symmetry of MCAs, were studied in detail and well photographed. The data collected in the study was analyzed. **Results:** Accessory MCA was found in seven specimens (2.05%). Duplicated MCA was seen in three specimens (0.88%). Aneurysm was found in three specimens (0.88%). MCA with bifurcated, trifurcated, quadrifurcated and single trunk termination was seen in 220 (64.70%), 42 (12.35%), 8 (2.35%), and in 70 (20.58%) specimens respectively. Bifurcated pattern as upper prominent trunk (type A), lower prominent trunk (type B) and both equal prominent trunks (type C) were seen in 63 (28.63%), 129 (58.63%), and 28 (12.72%) specimens respectively. Asymmetry was seen in 102 specimens (60%). Mean length and diameter of the MCA was 25.5-27.8 mm and 3 mm respectively. **Conclusion:** Awareness of these anatomical variations in branching patterns is important in neurovascular procedures. As very few Anatomical studies on MCA are there in the literature, this type of research work should be done by a number of scientists from a different region of the world in large scale.

Keywords: Anatomy, branching patterns, circle of Willis, middle cerebral artery, termination

Introduction

Middle cerebral artery (MCA) is the larger terminal branch of the internal carotid artery (ICA).[1] It supplies a large area of distribution as compare to the anterior cerebral artery (ACA) and posterior cerebral artery (PCA).[2-5] However, the MCA supplies a wider area and has more cortical branches than the other two arteries, literature does not provide detailed information on it.[5] There are very few anatomical studies on MCA describing its morphology and branching pattern in its entirety. Aim of the present work is to study the MCA regarding its origin, course, termination, branching pattern, morphometry and symmetry.

The surgical nomenclature identifies four subdivisions of MCA: M1, M2, M3, and M4. From the termination from ICA to the bi-trifurcation, this segment is also known as the sphenoidal; M2 — the segment running in the lateral (Sylvian) fissure, also known as the insular; M3 — coming out of the lateral fissure, also known as the operator; and M4 — cortical portions. The MCA runs first in the lateral cerebral fissure, then posterosuperiorly on the insula, and divides into branches.[1]

Materials and Methods

Study was done in the Department of Anatomy, Rural Medical College, PIMS, Loni. The study was started by undertaking the institutional ethical clearance (PIMS/PhD/RC/2013/28). Three hundred and forty MCA were studied on 170 formalin preserved brains of human cadavers. 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. Arachnoid mater in the interpeduncular fossa was removed carefully to expose the circle of Willis (CW). ICA at the lateral angle of the CW were identified and dissected to find out its terminal branches that is, MCA and ACA. MCA on either side were carefully dissected from its origin to its termination. Its course was traced through the lateral cerebral fissure. All the branches arising from MCA were dissected carefully. Branching pattern of MCA were seen, noted and well photographed. The arterial networks of the CW along with the MCA of both sides was carefully and delicately separated from brain tissue and pasted on the black plastic sheets for a better view. Dimensions of the MCA were measured with a vernier caliper with the least count of 0.01 mm. Thus, detailed study of these regarding morphological and morphometrical aspects were done.

Observations and Results

Origin, Course, Termination, and branching pattern was studied.

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Origin

In all specimens, MCA was the branch of ICA. It was arising in the interpeduncular fossa at the lateral angle of the CW (100%) [Figure 1a].

Accessory middle cerebral artery

Accessory MCA was found in seven specimens (2.05%). It was arising from the postcommunicating part of ACA. Out of seven specimens in five, accessory MCAs was seen in the right cerebral hemisphere and in two specimens it was in the left cerebral hemisphere [Figure 1b].

Double middle cerebral artery

Duplicated origin of MCA was seen in three specimens (0.88%). Origin was seen at the termination of ICA. It was seen in two right cerebral hemispheres, and one left cerebral hemisphere [Figure 1c].

Aneurysm

Aneurysm was seen in three specimens. (0.88%) It was seen in two right cerebral hemispheres, and one left cerebral hemisphere. A large globular aneurysm was seen at the insular portion of MCA. In two specimens, it was present at the trifurcation of the MCA. In other, it was seen at the bifurcation of the main stem of MCA at end of the first segment of MCA [Figure 1d].

Course

After origin from the lateral angle from interpeduncular fossa, MCA runs toward the posterior end of the lateral sulcus of the cerebral hemispheres. It was divided into four parts spheroidal, insular, opercular and cortical.

Termination and branching pattern

According to the termination and branching pattern, MCA is classified into four different types. These are described in Figure 2a and Table 1.

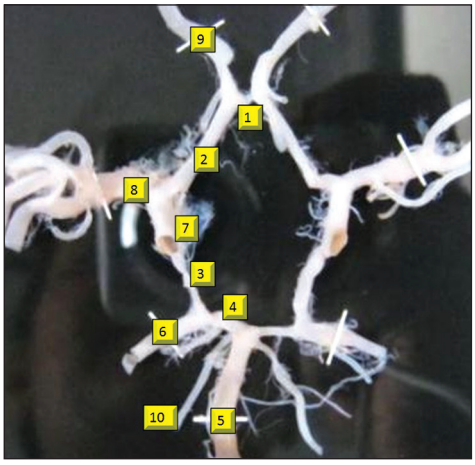

Figure 1a: Origin of MCA from ICA. ACoA = Anterior communicating artery, A1 = Precommunicating segment of anterior cerebral artery (ACA), PoCA = Posterior communicating artery, P1 = Pre-communicating segment of posterior cerebral artery (PCA), BA = Basilar artery, P2 = Post-communicating segment of PCA, ICA = Internal carotid artery, MCA = Middle cerebral artery, A2 = Post-communicating segment of ACA, SCA = Superior cerebellar artery

Terminations of MCA were observed as a normal bifurcation into M1 and M2 branches or continuation as angular artery with no trunk formation. Conventional termination of the MCA is by bifurcation as said above. Apart from this trifurcation, quadrifurcation and termination with a single trunk of MCA was also noted.

Middle cerebral artery bifurcation

Middle cerebral artery with bifurcated termination was seen in 220 specimens (64.70%) [Figure 2b]. Bilateral bifurcation of MCA was present in 55 specimens (50%). Unilateral bifurcation of MCA was present in 56 specimens (25.45%) on the left side and in 54 specimens (24.54%) on the right side.

Middle cerebral artery trifurcation

Middle cerebral artery with trifurcated termination were seen in 42 specimens (12.35%) [Figure 2c]. Bilateral trifurcation was present in three specimens (14.28%). Unilateral trifurcation was seen in 12 specimens (28.57%) on the left side, and 24 specimens (57.14%) on the right side.

Middle cerebral artery quadrifurcation

Quadrifurcated type of termination was seen in eight specimens (2.35%), four on the right side and four on the left side [Figure 2d].

Middle cerebral artery with a single main stem

When the main stem of MCA runs from its origin up to the posterior end of lateral cerebral fissure, it is referred as the complete MCA with a single trunk. In this type, no secondary trunk formation was seen. All cortical branches arise from the main single stem of MCA. It was found in 70 specimens

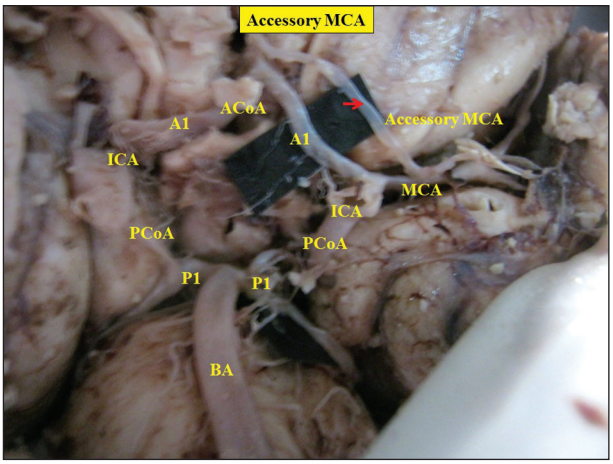

Figure 1b: Accessory MCA. Inferior view of the brain showing circulous arteriosus in the interpeduncular fossa. Red arrow is showing the accessory MCA, taking origin from ACA and running toward the lateral cerebral fissure. ACoA = Anterior communicating artery, A1 = Precommunicating segment of anterior cerebral artery (ACA), PoCA = Posterior communicating artery, P1 = Pre-communicating segment of posterior cerebral artery (PCA), BA = Basilar artery, ICA = Internal Carotid Artery, MCA = Middle cerebral artery

(20.58%) [Figure 2e]. Bilateral single stem was present in 32 specimens that is, in 16 specimens of brains (45.71%). Unilateral single stem was seen in 25 specimens (35.71%) on the left side, and in 13 specimens (18.57%) on the right side.

Further division of bifurcated pattern

Bifurcated stem was most commonly seen termination in the present study, in 220 specimens 64.70%. This branching pattern was further divided into three patterns according to the prominence of one of the two stems.

If upper stem was more prominent than the lower stem, it was named as the type A of bifurcated pattern. If lower stem was more prominent than the upper stem, it was named as type B of bifurcated pattern. If both the stems were in equal proportion, it was termed as type C of bifurcated pattern. Type A was seen in 63 Specimens 28.63% [Figure 3a]. Type B was seen in 129 Specimens 58.63% [Figure 3b]. Type C was seen in 28 Specimens 12.72% [Figure 3c].

Table 1: Percentage of termination of MCA

Type	Termination	Specimens (number)	Percentage
Type 1	Bifurcation	220	64.70
Type 2	Trifurcation	42	12.35
Type 3	Quadrifurcation	8	2.35
Type 4	Single main stem	70	20.58

MCA = Middle cerebral artery

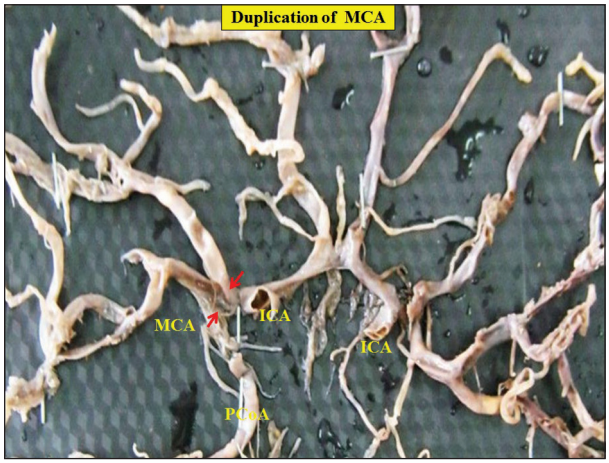

Figure 1c: Duplicated origin of MCA. Two red arrows show two MCA originating from ICA

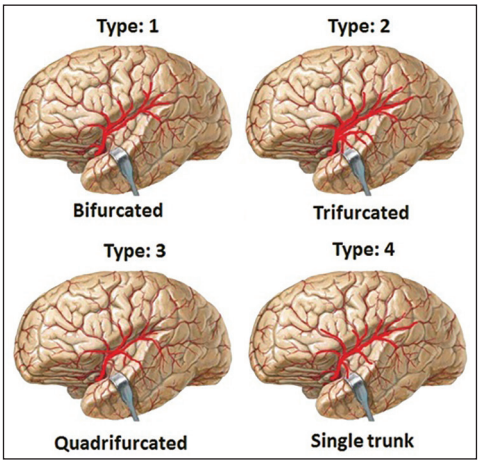

Figure 2a: Classification of middle cerebral artery according to branching termination schematic representation

Branching patterns

Branching patterns of MCA studied in detail. According to the branching pattern of MCA, origin of cortical branches differs as orbital branches, frontal branches, parietal branches, and temporal branches. There were total 10 branches arising from the MCA having few variations seen as under.

Instead of the direct origin from the main stem branches may arise from large adjacent branches. Adjacent branches take origin from a short common trunk. In most of the above-seen cortical branches, small variation were observed in their origin.

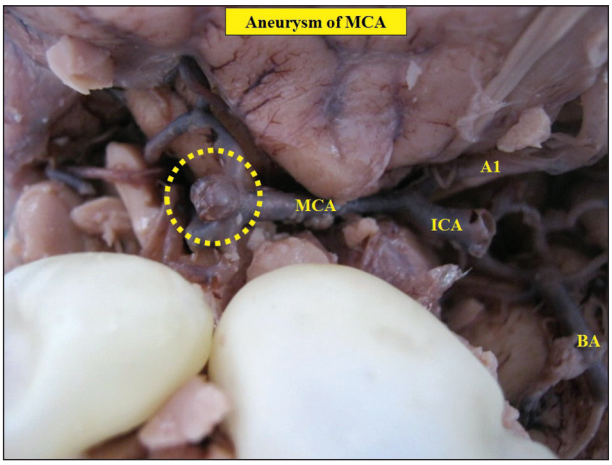

Figure 1d: Aneurysm associated with MCA. Inferolateral view of cerebral hemisphere. Dotted yellow circle shows the large globular aneurysm associated with the MCA, present at the site of bifurcated termination of MCA. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

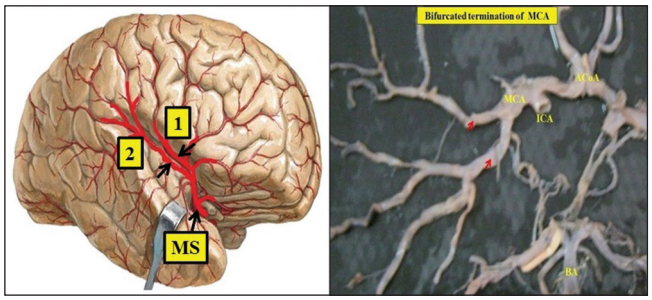

Figure 2b: Bifurcated termination of MCA. Right side shows the schematic representation of bifurcated termination of MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. 1 arrow shows upper trunk of MCA, 2 arrow shows lower trunk of MCA, MS arrow shows the main stem of MCA. Left side is the specimen found in the present study. Two arrows show the bifurcated trunks of MCA. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

It was not uniform. All cortical branches have the course in the respective cerebral sulci. Cortical branches are shown in the Figures 4a-d respectively.

Morphometry

Morphometric data of MCA was measured and tabulated in Table 2.

Length of MCA was measured from its origin to its termination from the main stem. It varies greatly from 1 to 65 mm. with the mean of 25.54 mm and 27.86 mm on right and left side respectively.

Diameter of the MCA at its middle of the main stem was measured. It was ranging from 2 to 5 mm with the mean of 3 mm.

Symmetry

In addition to morphometry, we have also studied the symmetry in the subject.

Symmetrical branching of MCA was seen in 68 brain specimens (40%) [Figure 5a] and asymmetrical branching of MCA was seen in 102 brain specimens (60%) [Figure 5b].

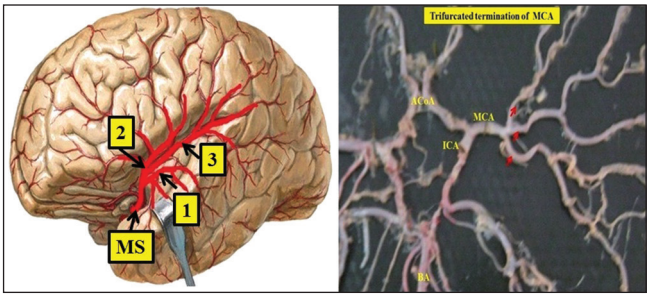

Figure 2c: Trifurcated termination of MCA. Right side shows the schematic representation of trifurcated termination of MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. 1, 2 and 3 arrows show three trunks of MCA, MS means the main stem of MCA shown by arrow. Left side is the specimen found in the present study. Three arrows show the trifurcated trunks of MCA. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

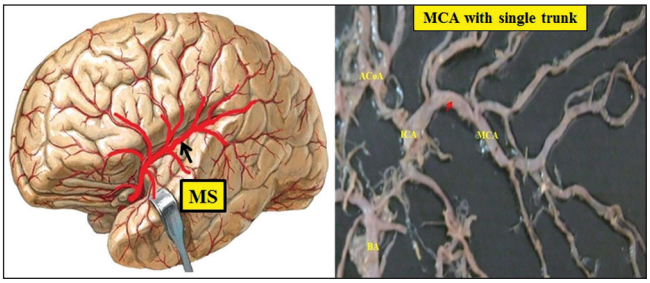

Figure 2e: MCA with a single main trunk. Right side shows the schematic representation of classical/complete MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. Arrow shows the main stem of MCA. Left side is the specimen found in the present study. Arrow shows the main stem of MCA. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

Discussion

Accessory MCA and duplicated MCA, are the most commonly seen variations involving the MCA.[6] When two vessels originate from the distal end of the ICA, the condition is called a duplicated MCA, and an anomalous vessel which originate directly from ACA is termed as accessory MCA.[7]

Table 2: Morphometry of MCA (mm)

MCA	Side	Minimum	Maximum	Average	SD
Length	Right	1	65	25.54	15.58
Length	Left	1	65	27.86	15.93
Diameter	Right	2	5	3	0.74
Diameter	Left	2	5	3	0.80

MCA = Middle cerebral artery, SD = Standard deviation

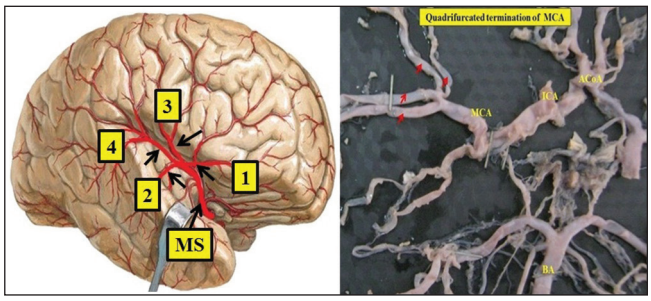

Figure 2d: Quadrifurcated termination of MCA. Right side shows the schematic representation of qudrifurcated termination of MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. 1, 2, 3 and 4 arrows show four trunks of MCA, MS means the main stem of MCA shown by arrow. Left side is the specimen found in the present study. Four arrows show the qudrifurcated trunks of MCA. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

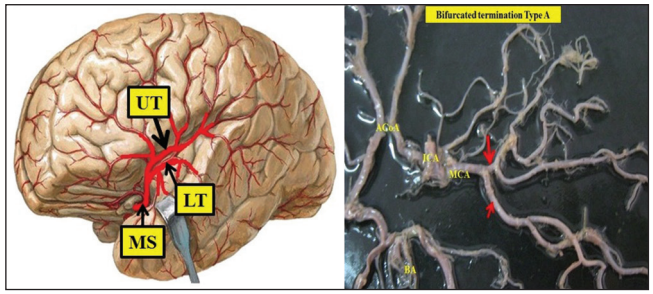

Figure 3a: Bifurcated termination type a of middle cerebral artery (MCA). Right side shows the schematic representation of bifurcated termination of MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. (1) Arrow shows upper trunk of MCA, (2) arrow shows lower trunk of MCA, MS arrow shows the main stem of MCA. Upper trunk is prominent than the lower trunk. Terminal branches angular artery and posterior parietal arteries are both arising from the upper trunk. Left side is the specimen found in the present study. Two arrows show the bifurcated trunks of MCA. Upper trunk is prominent than the lower trunk. Terminal branches angular artery and posterior parietal arteries are both arising from the upper trunk. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

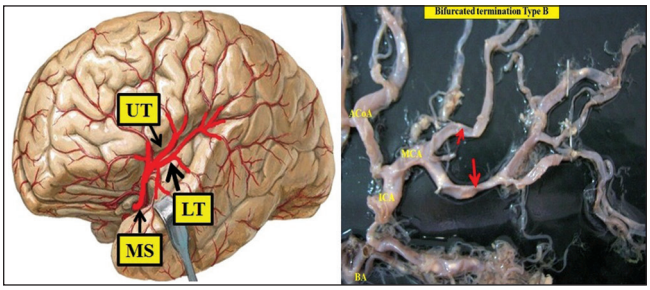

Figure 3b: Bifurcated termination type B of MCA. Right side shows the schematic representation of bifurcated termination of MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. UT arrow shows upper trunk of MCA, LT arrow shows lower trunk of MCA, MS arrow shows the main stem of MCA. Lower trunk is prominent than the upper trunk. Terminal branches angular artery and posterior parietal arteries are both arising from the lower trunk. Left side is the specimen found in the present study. Two arrows show the bifurcated trunks of MCA. Lower trunk is prominent than the upper trunk. Terminal branches angular artery and posterior parietal arteries are both arising from the lower trunk. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

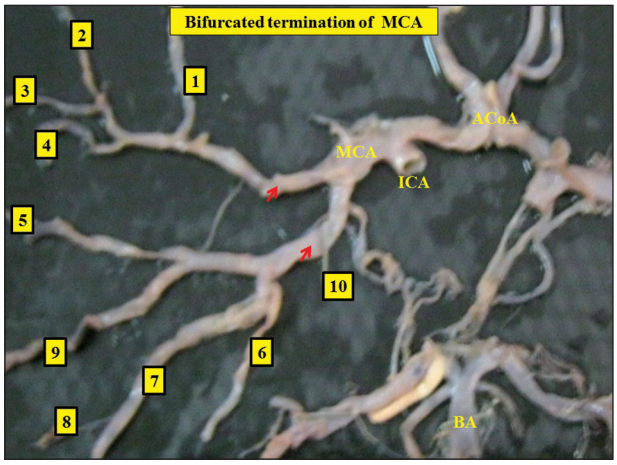

Figure 4a: Branching pattern of middle cerebral artery in bifurcated termination. 1 = Precentral artery, 2 = Central artery, 3 = Postcentral artery, 4 = Parietal artery, 5 = Anterior temporal artery, 6 = Middle temporal artery, 7 = Temporo-occipital artery, 8 = Angular artery, 9 = Lateral striate artery

Padget[8] described the normal development of the cranial arterial system. According to her study, distal primitive ICA initially divides into a large branch, the future anterior choroidal artery, and numerous small arterial twigs that will subsequently constitute the primitive ACA and MCA. Partial persistence of the arterial twigs may be responsible for variations of MCA like accessory MCA or duplicated MCA.

The small arterial twigs coalesces together to form definitive MCA. Disturbance in this formation of definitive MCA by small arterial twigs may responsible for variations in MCA.

Small arterial twig instead of contribution in the formation of MCA may remain separate and get communicated with ACA

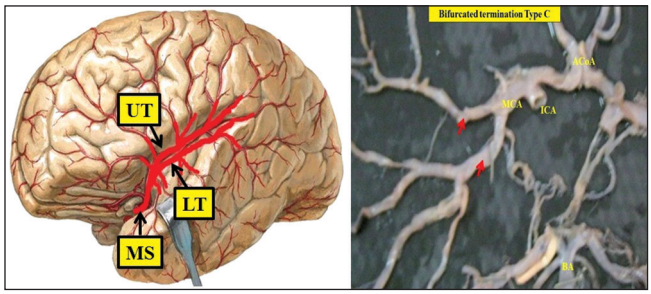

Figure 3c: Bifurcated termination type C of middle cerebral artery (MCA). Right side shows the schematic representation of bifurcated termination of MCA in the lateral cerebral fissure on the superolateral surface of the cerebrum. UT arrow shows upper trunk of MCA, LT arrow shows lower trunk of MCA, MS arrow shows the main stem of MCA. Upper and the lower trunk both are approximately having equal size. Terminal branches angular artery and posterior parietal arteries are both arising from the one of the trunk. Left side is the specimen found in the present study. Two arrows show the bifurcated trunks of MCA. Upper and the lower trunk both are approximately having equal size. Terminal branches angular artery and posterior parietal arteries are both arising from the one of the trunk. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

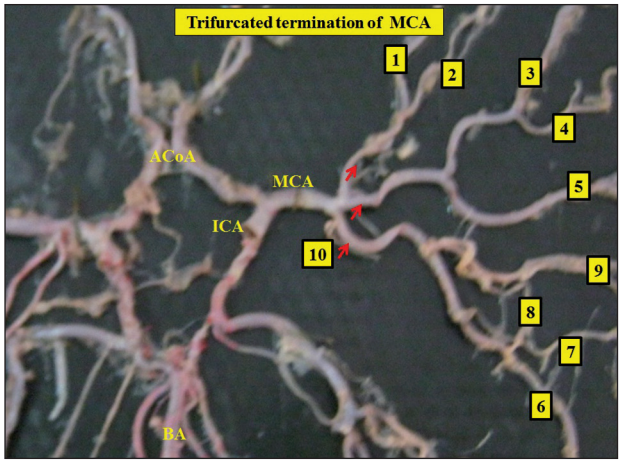

Figure 4b: Branching pattern of middle cerebral artery trifurcated termination. 1 = Precentral artery, 2 = Central artery, 3 = Postcentral artery, 4 = Parietal artery, 5 = Anterior temporal artery, 6 = Middle temporal artery, 7 = Temporo-occipital artery, 8 = Angular artery, 9 = Lateral striate artery

and may persist as an accessory MCA. If an arterial twig gets communicated with the terminal portion of ICA or anterior choroidal artery, it may persist as the duplicated MCA.

As the embryological origin of MCA is from the ACA, the accessory MCA has been regarded as the remnant of the recurrent artery of Heubner (RAH).[9-12] However, this theory is disproved because of the coexistence of both the vessels. An accessory MCA had a different course than the RAH.[7]

There are numbers of reports describing MCA. Uchino *et al*.[6] reported a case of the right accessory MCA with left MCA showing fenestration. Gibo *et al*.[2] reported a

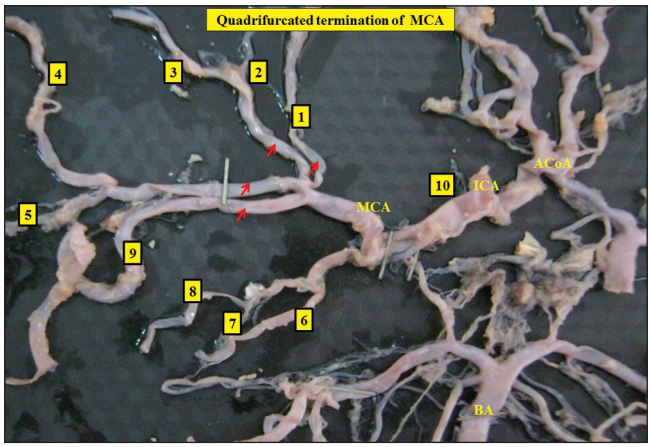

Figure 4c: Branching pattern of middle cerebral artery in quadrifurcated termination. 1 = Precentral artery, 2 = Central artery, 3 = Postcentral artery, 4 = Parietal artery, 5 = Anterior temporal artery, 6 = Middle temporal artery, 7 = Temporo-occipital artery, 8 = Angular artery, 9 = Lateral striate artery

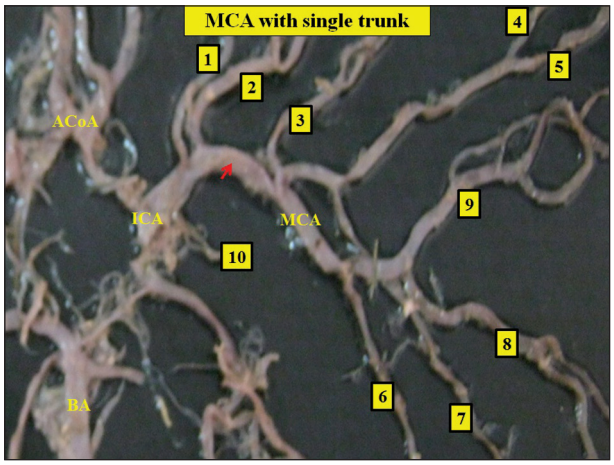

Figure 4d: Branching pattern of middle cerebral artery with a single main trunk. 1 = Precentral artery, 2 = Central artery, 3 = Postcentral artery, 4 = Parietal artery, 5 = Anterior temporal artery, 6 = Middle temporal artery, 7 = Temporo-occipital artery, 8 = Angular artery, 9 = Lateral striate artery

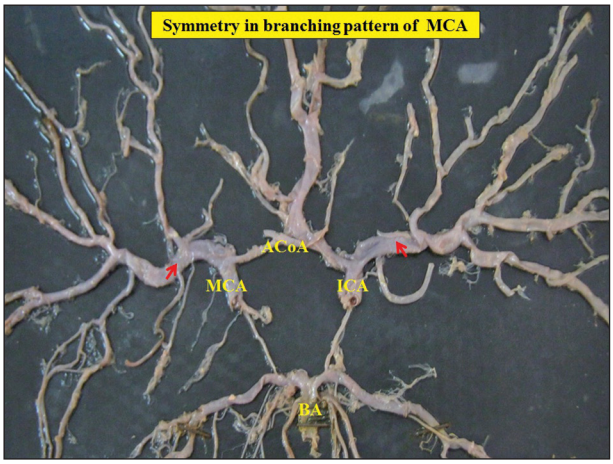

Figure 5a: Symmetrical branching of MCA. Right and left sided MCA shows symmetry in the branching pattern. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

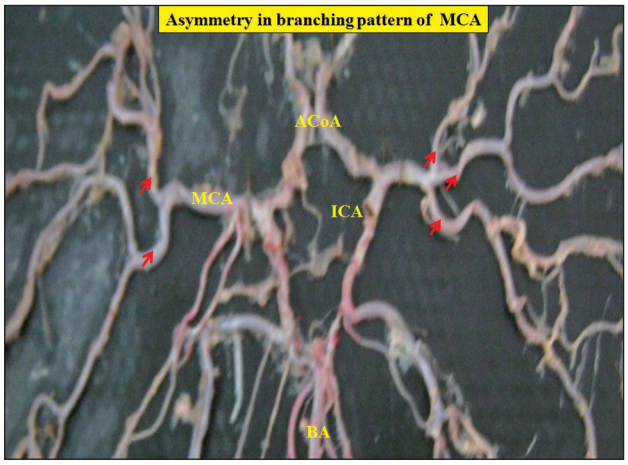

Figure 5b: Asymmetrical branching of MCA. Right-sided MCA is bifurcated shown by two arrows. Left sided MCA is trifurcated shown with three arrows. ACoA = Anterior communicating artery, ICA = Internal carotid artery, MCA = Middle cerebral artery, BA = Basilar artery

case associated with both variations that is, duplication and one accessory MCA. Jain[13] reported one case of bilateral duplication of MCAs in 300 brains. Dong *et al*.[14] reported a case with left MCA duplication, right accessory MCA and ACA fenestration.

It is said that true accessory MCAs originate from the A2 segment of the ACA An accessory MCA and a duplicated MCA both are simply additional outward buds of the ICA or ACA.[11] Yamamoto *et al*.[15] postulated that true accessory MCAs are residual congenital arteries and double MCA (DMCA) is a variant of the normal branching of the MCA.

Some authors have suggested that the DMCA are of two types as per their origin. Type 1 originates from the ICA at the exact level of its termination, type 2 from ICA or anterior choroidal artery.[2,12,16] In the present study DMCA was of type 1 seen in 0.88%.

Teal *et al*.[7] further classified two types of accessory MCAs based on the origin of variant vessels, which can be proximal (type 1) or distal (type 2) segments of the ACA.[2]

In present study accessory MCAs were found in 2.05%, so further classification into different types was not done. As per the classification of Teal *et al*. Accessory MCA found in the present study was type 2. That is, true Accessory MCA. It was taking origin from the postcommunicating segment of ACA.

There are different studies on the frequency of accessory and duplicated MCAs. The reported frequencies of accessory MCAs and duplicated MCAs were compared with the present study in Table 3.

Double middle cerebral artery's themselves have no clinical significance. However, a rare aneurysms have been reported at the origin of the DMCA.[10,18,19]

Some authors states that an accessory MCA takes part in collateral blood supply to the territory of the main MCA and partly compensate for its occlusion, thus leading to an improved prognosis in patients with disease of this vessel.[11,12]

According to Cekirge *et al*.[20] cerebral aneurysms are encountered more frequently in specimens with anatomic variations, such as an accessory MCA; however, the reason for this association is still vague. In the present study, we could not found any relation between accessary MCA with aneurysm.

Middle cerebral artery supplies a wider area and has more cortical branches than that of the ACA and PCA. In spite of a large territory of distribution and complex branching, the literature does not provide detailed information on the interrelations of those branches and their influence on terminal branching pattern of MCA, this issue is debatable.

The most interesting part of the MCA is the site of trunk separation and origin of the cortical branches from this point, and associated aneurysms are most interesting pathologies in relation to MCA.[21,22] Terminations found in the present study were compared with the previous study in Table 4.

According to Grays spheroidal segment, is defined as M1 segment with course from its origin from ICA up to the separation of the main trunk. The conventional understanding is that the main trunk is separated into two trunks, that is, the superior and inferior trunks.[5] In the present study, MCA with a single trunk was found second most common in 20.58%.

Except the case reports on accessory MCA and its duplication, very few anatomical studies have described the termination and branching pattern of MCA. In the present study, the termination and branching pattern of MCA is described in detail.

Table 3: Comparison of accessory MCA and duplicated MCA in percentage

Authors	Accessory MCA	Duplicated MCA
Present study	2.05	0.88
Takahashi *et al*.[17]	2.9	0.2
Umansky *et al*.[12]	4	0.3
Uchino *et al*.[6]	1.2	2.1

MCA = Middle cerebral artery

Few findings of the present study were compared with the previous studies in Table 5. Findings are comparable to a little extent. In all of these studies, dominance of inferior trunk was most commonly observed.

Several authors have given importance to point of bifurcation that is, point of separation of MCA into two trunks. After this point of separation, the artery may separate into three (trifurcation), four (quadrifurcation), and multifurcation trunk, etc. Intermediate trunk is the middle trunk in the case of trifurcation.[2,12,30] Kahilogullari *et al*. proposed a new way of classification made in relation to the terminology of the intermediate trunk.[5] Despite the MCA's complex structure, variations are less commonly observed than in the othertwo arteries.[5,11,12]

Keeping this in view, the MCA was studied in detail and classified in four different types as bifurcated, trifurcated, quadrifurcated MCA and MCA with no trunks or single main trunk as per the termination.

In the present study dimensions of MCA were compared with the previous studies. Mean diameter found by the previous study was 3.35 mm. In the present study, it was 3 mm. Mean length of MCA found by Umansky *et al*.,[12] Yasargil and Fox,[22] and Pai *et al*.[26] was 15.1-15.7 mm, 14-16 mm and 20 mm respectively. While in the present study mean length of MCA was having little higher value of 25.5-27.8 mm. this difference may be because of the high incidence of single main trunked MCA (with a larger length). The present study proposed that the length of the MCA varies highly.

For the sake of interest present study had noted the symmetry and asymmetry of the MCA. It is surprising to note that the MCAs supplying two cerebral hemispheres in the same brain were with different branching patterns seen in 60% specimens of the present series. Symmetry as such has no clinical significance, but asymmetry itself may be an indication of variability in functional ability of two sides of the brain. Assessment of symmetry is the most neglected part and rarely described in the literature.

Conclusion

Awareness of these anatomical variations in branching patterns is important in neurovascular procedures. As very

Table 4: Comparison of percentage and occurrence of different patterns of termination of MCA in different populations

Authors	Year	Population	Bifurcation	Trifurcation	Quadrifurcation	One trunk
Present study	2014	Indian	64.70	12.35	2.35	20.58
Ogeng'o *et al*.[23]	2011	Kenyan	82.3	10.8	0.6	6.3
Vvuiller *et al*.[24]	2008	French	73	9	—	17
Tanriover *et al*.[25]	2003	American	88	12	0	0
Pai *et al*.[26]	2005	Indian	80	20	—	-
Kulenovic *et al*.[27]	2003	Croatian	70	30	—	-
Idowu *et al*.[28]	2002	Nigerian	81	13	—	-

MCA = Middle cerebral artery

Table 5: Comparison of dominant trunk of MCA in percentage

Author	Year	Dominant superior trunk	Dominant inferior trunk	Equally dominant 2 trunks
Present study	2014	28.63	58.63	12.72
Türe *et al.*[29]	2000	35	50	15
Kahilogullari *et al.*[5]	2012	20	55	25

MCA = Middle cerebral artery

few anatomical studies on MCA are there in the literature, this type of research work should be done by a number of scientists from a different region of the world in large scale.

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