Neuroangiography patterns and anomalies of middle cerebral artery A Systematic review

_by_ Asra Al Fauzi

Review Article

Neuroangiography patterns and anomalies of middle cerebral artery: A systematic review

Asra Al Fauzi, Yunus Kuntawi Aji, Rudy Gunawan, Nur Setiawan Suroto

Department of Neurosurgery, Faculty of Medicine, Universitas Airlangga/Dr. Soetomo General Academic Hospital, Surabaya, East Java, Indonesia.

E-mail: *Asra Al Fauzi - asra.al@fk.unair.ac.id; Yunus Kuntawi Aji - yunus.neurosurgery@gmail.com; Rudy Gunawan - rudygunawan10@gmail.com; Nur Setiawan Suroto - setiawan.dr@gmail.com

Corresponding author:

Asra Al Fauzi,
Department of Neurosurgery,
Faculty of Medicine, Universitas
Airlangga/Dr. Soetomo
General Academic Hospital,
Jl. Mayjend Prof Dr Moestopo
6-8, Surabaya - 60286, East Java,
Indonesia.

asra.al@fk.unair.ac.id

ABSTRACT

Background: As the largest and most complex cerebral artery, the middle cerebral artery (MCA) patterns and anomalies are not fully reported. At present, there is confusion about the criteria for the different subtypes. The study of MCA patterns and anomalies is important because variants such as accessories or duplicates represent a high risk of failure during endovascular embolization or navigation during treatment for ischemic stroke. This study conducted a systematic review of studies on the neuroangiography patterns and anomalies of MCA.

Methods: We conducted a systematic review of four articles online databases and included English articles from PubMed, the Cochrane Library, Directory of Open Access Journals, and EBSCOhost.

Results: The proportion of the MCA branching pattern was 1.9% (range from 0% to 6.3%) for monofurcation, 1.0% (range from 0% to 1.4%) for tetrafurcation, 69.9% (range from 58.1% to 92.7%) for bifurcation, and 27% (ranging from 7.3% to 40.4%) for trifurcation. The proportion of MCA anomalies for accessory is 0.03% (range from 0% to 1%), duplication is 0.17% (range from 0% to 3%), and fenestration is 0.15% (range from 0% to 2%).

Conclusion: The proportions of the branching pattern and anomalies of MCA based on the systematic review are described in this study. This study is the first to systematically review the neuroangiography pattern of MCA and neuroangiography variations/anomalies of MCA in the literature.

Keywords: Anomaly, Middle cerebral artery, Neuroangiography pattern, Systematic review

INTRODUCTION

The middle cerebral artery (MCA) is the largest and most complex cerebral artery since the cerebral neocortex has developed significantly in humans.[2,29] MCA covers most of the brain hemispheres and is often exposed during surgical interventions. The MCA vascular territory includes some of the most widely used cortical areas for motor and sensory functions. The penetrating branch of the proximal MCA supplies important sites, such as the basal ganglia, descending tract, and corticospinal tract. Knowing the variations and anomalies of MCAs is important for neurosurgeons in their identification during surgical intervention to prevent damage or blockage of the two cerebral branch arteries that originate from the MCA and in assessing the contribution to perfusion of the deep MCA region.[18] To date, the diameter, length, and duplication of the cortical branch of MCA have not been widely reported. Moreover, descriptions of the origins

and possible main branches of these branches are scant in the literature. The types of bifurcation and trifurcation branching have been widely described, but other subtypes that are different from these anomalies have yet to be classified by researchers. MCA anomalies are frequently mentioned in the literature but sparsely discussed more deeply. MCA variants, such as accessory branches or their duplicates, have a high risk of misinterpretation during endovascular embolization or navigation during the treatment of ischemic stroke.[21] This study aimed to conduct a systematic review of the neuroangiography patterns and anomalies of MCA.

MATERIALS AND METHODS

The systematic review was carried out following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[11,20,24] The systematic review was intended to draw strong and broad conclusions by producing an unbiased summary of what the cumulative evidence says about a particular topic. We criticized and synthesized one or more of the literature by identifying relationships, contradictions, gaps, and inconsistencies, and exploring why. We also developed and evaluated new theories or evaluated existing theories or theories to explain how and why the individual studies fit together, providing implications for practice and policy, and outlined important quality directions for future research (for example, highlighting where evidence is lacking or poor).[3,4,6,13]

Search strategy

A literature search was carried out using the Boolean operator AND to search for literature containing all keywords and OR to search for literature containing alternative keywords. ("Middle Cerebral Artery" OR "MCA") AND ("Neuroangiography" OR "Angiography" OR "Digital Subtraction Angiography" OR "DSA") AND ("Patterns" OR "Variations" OR "Anomalies") from literature searches on PubMed, the Cochrane Library, Directory of Open Access Journals, and EBSCOhost. English literature was collected, and no time restriction was applied in the search criteria.

Inclusion criteria

All clinical trials, cohort prospective, retrospective, and observational mentioning patterns and variations or anomalies of MCA in neuroangiography studies were included in the study.

Exclusion criteria

All review articles or consensus statements that did not have clinical information mentioning patterns and variations or anomalies of MCA in neuroangiography studies were excluded from the study.

Data extraction

The following data were extracted from the included studies wherever available: study author(s), year, pattern, and variation or anomalies of MCA, number of samples, race, and age.

Risk of bias

Two researchers analyzed the risk of bias study using the Cochrane Collaboration's risk of bias tool and a quality assessment for observational studies based on the Newcastle-Ottawa tool according to the Cochrane Handbook for Systematic Reviews of Interventions Chapter, entitled "Assessing risk of bias in a nonrandomized study" [Tables 1 and 2] [Figure 1].[5,9,10,12,14-17,22,23,25,28,30,32]

Management and data analysis

A summary of the evidence used in data synthesis is presented in a summary form containing the characteristics of each study. Descriptive data are presented in the form of text and tables.

RESULTS

The online journal databases used in the search included PubMed (207 studies), Cochrane (17 studies), DoAJ (1 study), and EBSCO (0 study), for a total of 225 articles. Duplication screening did not reveal any duplicate articles. The screened titles and abstracts were then screened, resulting in 60 articles. The remaining 165 articles that were not related to the research topic were excluded from the study. The full texts of the 60 included articles were further screened. Forty-eight articles were excluded because further reading of the full text showed that the methodology and results did not follow the research we conducted. A total of 12 articles met the inclusion criteria of the study. The flowchart of the research literature search results is presented in [Figure 2].

Characteristics of the MCA literature

There were 12 studies included in the study, as shown in [Table 3]. Existing studies were conducted between 2011 and 2019. From all the literature, we found one article focused on discussing MCA patterns, eight articles discussed MCA anomalies, and three articles discussed both. The number of samples consisted of 20–10,927 samples. Most of the studies used MCA from patient data as a sample, and one article used cadaveric specimens. Most of the studies were performed in Western and East Asian countries. The sample age ranges varied and covered most age groups (children to adults).

Table 1: Quality ratings based on the Newcastle-Ottawa scale for observational studies.

References	Quality assessment form for cohort studies								AHRQ quality
	Selection			Comparison	Comparison	Outcome			
	Representative of the exposed cohort	Representative of nonexposed cohorts	Determination of exposure	Demonstration that the desired outcome was not available at study entry	Confounder adjustment	Outcome assessment	Quite long follow-up	Adequate of follow-up	
Cilliers, 2016[10]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Al Fauzi, 2019[14]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Ogeng'o, 2011[21]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Sadatomo, 2013[22]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Bayrak, 2011[5]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Chang, 2011[9]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Sun, 2012[24]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Uchino, 2012[26]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Hamidi, 2013[15]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Cooke, 2014[12]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Kovac, 2014[16]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good
Van Rooij, 2015[28]	Representative (*)	No explanation	Self-written report, prospective	Yes (*)	None	Self-written report	Yes (*)	Complete follow-up (*)	Good

Table 2: Characteristics of the literature.

References	Research focus	Number of sample (MCA)	Sample	Country/race	Age
Cilliers, 2016[10]	MCA patterns and anomalies	20	Cadaver	South Africa/White	No explanation
Al Fauzi, 2019[14]	MCA patterns and anomalies	554	Patient	Indonesia/Asia	Mean age 37, 3 years old
Ogeng'o, 2011[22]	MCA patterns and anomalies	288	Patient	Kenya/Black	21–90 years old
Sadatomo, 2013[23]	MCA patterns	124	Patient	Japan/Asia	20–81 years old
Bayrak, 2011[5]	MCA anomalies	395	Patient	Turkey/Europe	4–97 years old
Chang, 2011[9]	MCA anomalies	1250	Patient	Korea/Asia	No explanation
Sun, 2012[25]	MCA anomalies	4652	Patient	China/Asia	23–73 years old
Uchino, 2012[28]	MCA anomalies	3491	Patient	Japan/Asia	No explanation
Hamidi, 2013[16]	MCA anomalies	500	Patient	Turkey/Europe	2–91 years old
Cooke, 2014[12]	MCA anomalies	10.927	Patient	USA/White	No explanation
Kovac, 2014[17]	MCA anomalies	455	Patient	Serbia/Europe	Mean age 51 years old
Van Rooij, 2015[30]	MCA anomalies	140	Patient	Netherlands/Europe	27–84 years old

Figure 1: Risk assessment of bias using ROBINS-I for nonrandomized controlled trial studies.

MCA pattern

The MCA branching pattern is determined by the division of the main branch into smaller branches. Bifurcation and trifurcation are most commonly described, although other types have been observed and several subtypes can be identified. Eleven different types of branching can be distinguished from the literature and these include the bifurcation subtypes (medial bifurcation, lateral bifurcation, medial pseudobifurcation, and lateral pseudobifurcation), trifurcation subtypes (true trifurcation, pseudotrifurcation, and lateral pseudobifurcation), and trifurcation (true trifurcation, pseudotrifurcation, distraction trifurcation, and proximal trifurcation).[10] The prevalence of branching types is summarized in [Table 4 and Figure 3].
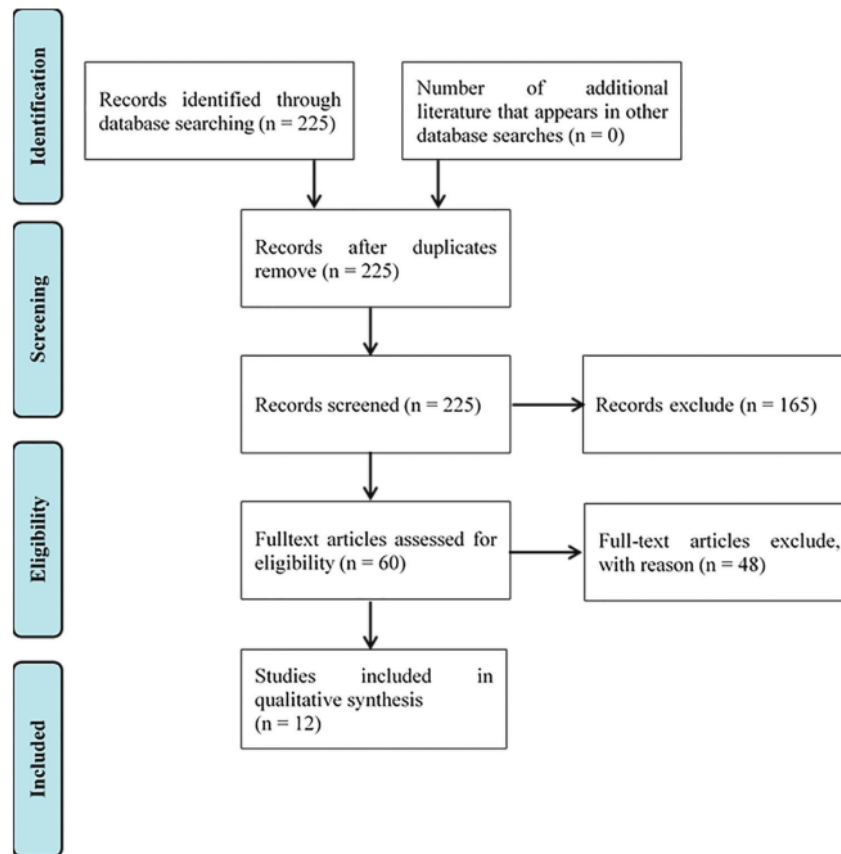
MCA anomaly

MCA anomalies occurred less frequently than other major intracranial artery anomalies.[19,21,29] This anomaly was seen in approximately 0.6–3% of the hemispheres in microanatomic studies but was less frequent during angiography.[18] MCA variations included duplication, accessory, and fenestration.[7,19,26,29] The prevalence of MCA anomalies is summarized in [Figures 4 and 5].

DISCUSSION

This research was conducted by systematically searching the entire literature on studies that reported patterns and variations/anomalies in MCA. The systematic study included 12 articles that were used for analysis of the MCA patterns.

Quality of the studies used

This systematic review obtained data from the studies using the stipulated study design. The study design used influenced the strength of the research results as levels of evidence that have a clear hierarchy. The hierarchical division began with randomized controlled trial studies as the highest quality, followed by cohort, case–control, and case series.[8] Quality assessment based on the Newcastle-Ottawa scale for observational studies showed that the quality of the entire

Figure 2: Preferred reporting items for systematic reviews and meta-analyses flow diagram.

Table 3: Percentage of MCA patterns (monofurcation, bifurcation, trifurcation, and tetrafurcation).

Author	Total	Monofurcation		Bifurcation		Trifurcation		Tetrafurcation	
		Number of cases	%	Number of cases	%	Number of cases	%	Number of cases	%
Cilliers, 2016[10]	20	1	5	16	80	3	15	0	0
Al Fauzi, 2019[14]	554	0	0	322	58.1	224	40.4	8	1.4
Ogeng'o, 2011[21]	288	18	6.3	237	82.3	31	10.8	2	0.7
Sadatomo, 2013[22]	124	0	0	115	92.7	9	7.3	0	0
Total	986	19	1.9	690	69.9	267	27	10	1

included literature was good, as most studies clearly stated the patterns and variations/anomalies of MCA. The bias assessment according to ROBINS-I showed a generally low risk of bias. In one study, missing data bias and selective reporting bias were not clearly stated. The risk of other bias was generally low, given the noncomparative nature of the observational study.
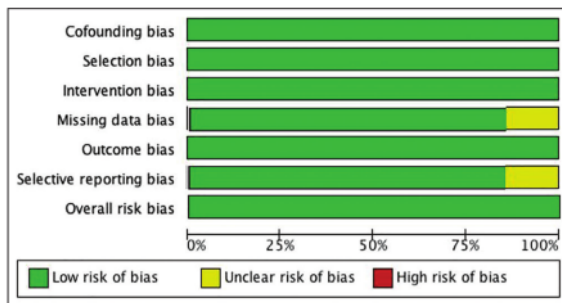
Characteristics of the studies

Based on [Tables 2 and 3], the research on MCA patterns has a diverse population: White African, Black African, East Asian, and Southeast Asian. All cases had bifurcation as the most common pattern of branching, followed by trifurcation. However, in the study by Al Fauzi *et al.*, the percentage difference between bifurcation and trifurcation was not too large.[14] This is different from the other three studies [Table 3]. This difference may be caused by factors of race/population and number of samples, as Al Fauzi *et al.* used a larger sample size than the other three studies [Table 3].

Based on [Tables 2 and 4], the entire literature, regardless of racial characteristics and different sample sizes, had a very

Table 4: Percentage of MCA anomalies (duplication, accessory, and fenestration).

Author	Total	Duplication		Accessory		Fenestration	
		Number of cases	%	Number of cases	%	Number of cases	%
Cilliers, 2016[10]	20	0	0	0	0	0	0
Al Fauzi 2019[14]	554	17	3	6	1	0	0
Ogeng'o, 2011[22]	288	5	1.7	0	0	0	0
Bayrak, 2011[5]	395	0	0	0	0	4	1
Chang, 2011[9]	1250	9	0.7	0	0	0	0
Sun, 2012[25]	4652	0	0	0	0	3	0.06
Uchino, 2012[28]	3491	0	0	0	0	3	0.09
Hamidi, 2013[16]	500	7	1.4	1	0.2	10	2
Cooke, 2014[12]	10927	0	0	0	0	10	0.09
Kovac, 2014[17]	455	0	0	0	0	1	0.2
Van Rooij, 2015[30]	140	0	0	0	0	4	2.9
Total	22,627	38	0.17	7	0.03	35	0.15

Figure 3: Proportion of bias risk assessment results using ROBINS-I for nonrandomized controlled trial studies based on the assessment for each risk of bias.

low number of MCA variations/anomalies. However, Al Fauzi *et al.* reported a greater number of duplicated MCAs than other studies, and Van Rooij *et al.* described a higher number of fenestrated MCAs.[30,31] This can be due to the smaller number of samples from the two studies compared to other studies.

MCA pattern

Eleven different types of branching can be distinguished from the literature, including the bifurcation subtypes (medial bifurcation, lateral bifurcation, medial pseudobifurcation, and lateral pseudobifurcation) and trifurcation subtypes (true trifurcation, pseudotrifurcation, distal trifurcation, and trifurcation). We classified the patterns into monofurcation, bifurcation, trifurcation, and tetrafurcation, which were the most commonly reported classifications in the literature. According to [Table 3], monofurcation was seen on average in 1.9% of cases (ranging from 0% to 6.3%), bifurcation in 69.9% of cases (ranging from 58.1% to 92.7%), trifurcation in 27% of cases (ranging from 7.3% to 40.4%), and tetrafurcation in 1.0% of cases (ranging from 0% to 1.4%). Al Fauzi's study

had the highest total number of subjects (554 cases) followed by the study by Ogeng'o (288 cases).

Regarding M1 branch, two branches were the most frequent patterns: the anterosuperior and posteroinferior branches. The orbitofrontal, operculofrontal, and central arteries arose from the anterosuperior branches. The remaining branches originated from the posteroinferior trunk. In the case of trifurcation, orbitofrontal and operculofrontal arose from the anterosuperior trunk. The central angular, parietal, and gyrus arteries arose from the middle branches, and the temporal branches arose from the posteroinferior branches. Another variant characterized by the division of M1 into several branches may also occur, but less frequently.

For the bifurcation subtypes, medial and lateral bifurcations describe the distance of the branching from the origin of the MCA (close or further away, respectively).[10] In pseudobifurcation (also known as false bifurcation), the large cortical arteries originated from the main artery and may give the appearance of branching.

MCA branching occurred at the highest point of the insula limen, proximal to the MCA genu in 86% of cases.[2] Distal to the branching, the superior and inferior branches rotated posterosuperior to reach the insular surface. From the surface of the insula arose the MCA genu. Classically, the branching region can also be described as forming an omega pattern because of the initial divergent but later convergent routes of the MCA branch. Usually, the diameter of the artery branch near the branching was equal to the diameter of the main branch. As a result, it appeared as if there were pseudotrifurcations or pseudoquadrifurcations.

This variability in the bifurcation pattern can be demonstrated on microanatomic examination and in clinical syndromes associated with divisional occlusion. The inferior division was slightly more dominant (32%). This division covered a wider cortical area than the superior division.
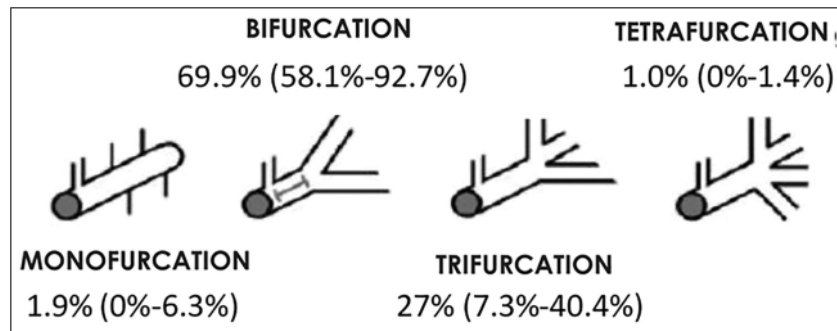
Figure 4: Percentage of middle cerebral artery pattern (monofurcation, bifurcation, trifurcation, and tetrafurcation).
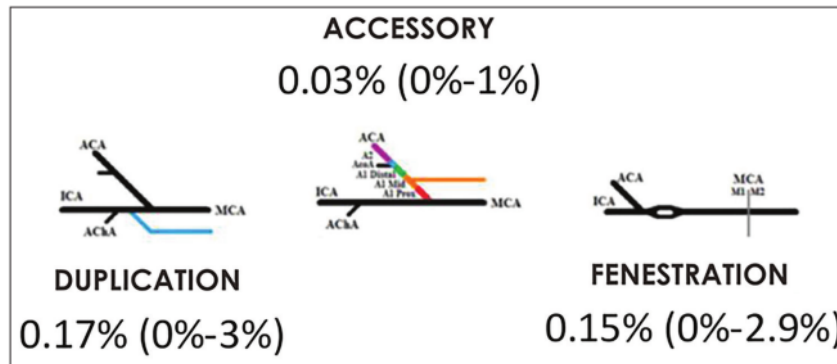

Figure 5: Percentage of middle cerebral artery anomalies (duplication, accessory, and fenestration).

In the trifurcation subtype, true trifurcation was rarely observed. In another trifurcation subtype, the MCA branching and the dominant branch further branched off to give rise to the middle branch. In pseudotrifurcation, the first and second branches were <2 mm apart. With proximal trifurcation, the most common subtype, the two branches were more than 2 mm apart. In the distal trifurcation, the two branches were more than 2 mm apart and more than a quarter of the distance between the origin of the MCA and the first. The apparent trifurcation of MCA occurred in only 12% of the hemisphere.

Grellier *et al*. described monofurcation as branching after insula limen, although monofurcation can also be called when there was no major branching.[10] Tetrafurcation occurred when the forks form four trunks, and pseudotetrafurcation occurred when the inferior trunk and superior trunk branch off again near the initial branching.

MCA anomaly

MCA anomalies occurred less frequently than other major intracranial artery anomalies.[19,21,29] MCA variations included duplication, accessory, and fenestration.[7,19,26,29]

According to [Figure 5], duplication was seen on average in 0.17% of cases (range from 0% to 3%), accessories were seen on average in 0.03% of cases (range from 0% to 1%), and fenestration was observed on average in 0.15% of cases (ranged from 0% to 2.9%). Cooke's study had the highest total number of subjects, with 10.927 cases, followed by Sun's study, with 4652 cases.

MCA typically arose from ICA as a single artery. In some cases, two MCAs arose from the ICA, such as an accessory MCA or a duplicate MCA.[29] Teal *et al*.[27] described two vessels originating from the distal end of the ICA as duplicate MCAs. Accessory MCA was described as an artery originating from the A1 ACA segment, either from the proximal A1 or the junction of A1 and A2.[26] Accessory MCA usually runs parallel to the main MCA in the Sylvian vallecula, and its anastomosis with the primary MCA is extremely rare.

Previous angiography and anatomical studies have shown a prevalence of 0.2–2.9% of duplicated MCAs and 0.3–4.0% of accessory MCA. The occurrence of MCA duplication and accessory MCA variants depended on the modality used (reduced by DSA compared to the autopsy, computed tomography scanning angiography, or magnetic resonance

imaging angiography). MCA duplication was almost twice as common as an accessory MCA. In addition to the modality used to detect it, variations in their occurrence may also occur as these two variants were often confused with each other and with other and with more common variants, such as branching or trifurcation of the initial M1 segment.

The types of MCA variations were usually classified according to the descriptions presented by the Teal and Abanou groups. Abanou *et al.* classified MCA accessories into three types.[1] Type 1 arises from the ICA terminal segment and is now called a duplicate MCA; Type 2 is proximal to A1, and Type 3 originates from the A1-A2 Heubner artery junction with an extensive cortical supply.[26] Uchiyama *et al.*[29] distinguished accessory and duplicate MCAs by their terminal distribution, with duplicated MCAs supplying the anterior temporal lobe and accessory MCAs supplying the anterior frontal lobe. There are two types of accessory MCAs, either from proximal joints A1 or A1-A2.

Fenestration is when blood vessels have a common origin, split into two channels, and then recombine. Fenestration (window) refers to the focal opening in the artery (not duplicated in the origin of M1).[19] A penetrated MCA emerges as a single vessel from the ICA and feeds the MCA region, but deviates and regroups along its path.[18] This fenestration can be either a small slit-like fenestration or a large convex-like area; the small slit-like fenestration is the most common. MCA fenestration was usually observed in the M1 segment, although it can also occur in the M2 segment. Three subtypes of M1 segment fenestration were defined: proximal, intermediate, and distal.

MCA fenestration was rare. Proximal M1 segment fenestration was the most common. Gailloud *et al.*[15] reported a high frequency of associated early TpA branching from the inferior limb of the MCA fenestration segment. Several previous studies noted that TpA often appeared as an early temporal branch associated with fenestration. They hypothesized that MCA fenestration occurred when the initial TpA branching failed MCA primitive arterial tissue fusion.[10,18,19,29]

This study was limited by its observational analytic nature and the lack of supplementation data in the form of individual data by all included studies. Race/population and sample size can affect the percentage of branching patterns obtained, and a small number of samples could have increased the findings on one of the MCA anomalies, challenging the reliability of the numbers reported, whereas studies using a large sample size would have a low percentage of MCA variation/anomaly.

Nevertheless, this study is the first to systematically review the neuroangiography pattern of MCA and neuroangiography variations/anomalies of MCA in the literature.

CONCLUSION

Based on the studies included in this systematic review, the proportion of MCA branching patterns included 1.9% (range from 0% to 6.3%) monofurcation, 1.0% (range from 0% to 1.4%) tetrafurcation, 69.9% (range from 58.1% to 92.7%) bifurcation, and 27% (ranging from 7.3% to 40.4%) trifurcation. Accessory anomalies represented 0.03% (range from 0% to 1%), duplication 0.17% (ranges from 0% to 3%), and fenestration 0.15% (ranges from 0% to 2.9%) of the reported MCA anomalies.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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