Surgical Management of Complex Middle Cerebral Artery Aneurysms: An Institutional Review

Abstract

Background: Complex middle cerebral artery (MCA) aneurysms are defined as large (≥10 mm) or giant (≥25 mm) aneurysms with M2 branches arising from the aneurysm rather than M1 segments and usually require some form of reconstruction of the bifurcation. Their management is difficult and surgery is preferred over endovascular modalities because of their peculiar angioarchitecture and association with critical branch points or perforators. **Objectives:** The study was aimed at analyzing surgically managed complex MCA aneurysms and discussing characteristics not favorable for endovascular management, surgical nuances and clipping strategies, patient outcomes, and newer diagnostic modalities which help improve management. **Methods:** Nine cases of surgically operated complex MCA aneurysms were identified from January 2017 to July 2019. The aneurysm characteristics, surgical nuances, clipping strategies, patient outcomes and points not favoring endovascular management were tabulated and analyzed. **Results:** The mean maximum aneurysm diameter was 13.4 mm and the mean fundus/neck ratio was 1.6. The average microscope time was 124 min, and the most common method was clip reconstruction. The average number of clips used was 2.7 and the mean follow-up was 13 months. All patients have good postoperative outcome (Modified Rankin Score 0-2). The complete occlusion rate was 88.9% with one intraoperative voluntary residual sac which was coated. Computational fluid dynamic study results done preoperatively correlated with intraoperative findings. **Conclusions:** MCA aneurysms pose a significant challenge for endovascular treatment because of various factors such as luminal thrombi, complex angio-architecture, precarious branch/perforator locations, broad necks, and fusiform characteristics. Surgical management in experienced hands can tackle all these problems with an armamentarium of clipping techniques and bypass procedures.

Keywords: *Complex aneurysms, computational flow dynamics, FLOW 800, giant aneurysms, middle cerebral aneurysms*

Anuj Arun Bhide[1,2], Yashuhiro Yamada[1], Yoko Kato[1], Tsukasa Kawase[1], Riki Tanaka[1], Kyosuke Miyatani[1], Daijiro Kojima[1], Ahmed Sayah[1]

[1]Department of Neurosurgery, Fujita Health University Babuntane Hospital, Nagoya, Japan, [2]Department of Neurosurgery, Grant Government Medical College and Sir JJ Group of Hospitals, Mumbai, Maharashtra, India

Introduction

Middle cerebral artery (MCA) aneurysms are one of the most common aneurysms and account for about 20% of all intracranial aneurysms. Surgical management has been the standard of care for these aneurysms and has yielded high occlusion rates with minimal recurrence.[1] Large (≥10 mm–25 mm) and giant (≥25 mm) MCA aneurysms are relatively rare aneurysms and account for about 9.8% of all MCA aneurysms.[2] Although the angioarchitecture of these aneurysms make the interventional procedures either difficult or less feasible in these cases, endovascular modalities have been growing in stature since last 2 decades for the management of MCA aneurysms. There has been no direct randomized controlled study comparing the two modalities specifically for complex MCA aneurysms and the management decisions of these cases have been based on various factors such as institutional protocols, patient preferences, patient profiles, and aneurysm characteristics.

The goals of the management of these cases, by whichever means, is safe, complete obliteration of the aneurysm without compromise of the parent vessel or perforators. Endovascular coiling has been observed to be safer, with lesser immediate postoperative morbidities, albeit with higher recanalization and repeated angiographic imaging in the long term. Surgical management, although more invasive, has

Address for correspondence:
Dr. Anuj Arun Bhide, Department of Neurosurgery, Grant Government Medical College and Sir JJ Group of Hospitals, Mumbai, Maharashtra, India.
E-mail: anujbhide@yahoo.in

Access this article online

Website: www.asianjns.org

DOI: 10.4103/ajns.AJNS_5_20

Quick Response Code:

How to cite this article: Bhide AA, Yamada Y, Kato Y, Kawase T, Tanaka R, Miyatani K, *et al.* Surgical management of complex middle cerebral artery aneurysms: An institutional review. Asian J Neurosurg 2020;15:959-65.

Submitted: 06-Jan-2020 **Revised:** 17-Mar-2020
Accepted: 11-Jul-2020 **Published:** 19-Oct-2020

been shown to have better long-term occlusion rates with comparable patient outcomes.[3]

Large (>10 mm) and giant MCA aneurysms pose a separate challenge for surgical, endovascular, or combined management due to various features of the aneurysm such as luminal thrombi, branching at the dome or the neck, wall calcifications, and fusiform configurations. The reported rate of re-canalization and treatment related complications is high for giant and large aneurysms; however, early treatment is warranted as their rupture risk is also high.[4] This retrospective analysis was performed with the goals of highlighting the strategies, technical nuances, and advances in the surgical management of giant MCA aneurysms along with the patient outcomes.

Methods

A retrospective analysis of 3 years from January 2017 to July 2019 was performed for all cases treated for complex MCA aneurysms at Fujita Health University, Banbutane Hotkukai Hospital, Nagoya, Japan. Aneurysm characteristics such as the dimensions, size, fundus/neck ratio, status of branching vessels and perforators, exact location, and orientation were analyzed. As a protocol, discussion with the interventional neurovascular team was held at our hospital before each case. The points favoring surgical management versus endovascular were difficult access, distal locations, broad necks, dome/neck ratio <1.5, recurrent cases, fusiform architecture, critical neck perforator, and bifurcation aneurysms. We used intraoperative neuromonitoring and endoscopy assistance to visualize blind spots in all cases. The patient characteristics such as the presentations and demography were recorded. Operative videos of 9 cases classified under complex aneurysms ([1] large or giant,[2] nonsaccular,[3] recurrent) were reviewed and following surgical points were tabulated: (1) surgical time, (2) type of surgical management, and (3) number of times intraoperative indocyanine green (ICG) was performed, (4) clip repositioning after ICG, (5) n umber of fenestrated clips applied, and (6) aneurysm remnants with reason for remnant (perforator/branching/orientation) were tabulated. The intraoperative status of the aneurysm walls, which included: (1) ICG Dye intensity differences, (2) atherosclerotic changes, and (3) thin wall areas, were compared to the preoperative computational flow dynamics observations to assess possibility of this tool as a prediction for the weak spots, which may alter decision-making process in the future. We also analyzed these difficult cases to gauge why endovascular options were not feasible in each of these cases. Postoperative radiological status, i.e., the status of occlusion and distal flow were recorded. The postoperative complications, re-canalization and outcomes were analyzed first, at 4 months. A note was made of all recurrences and also of the cases treated by endovascular methods before the surgical intervention, and the aneurysm characteristics in these cases were analyzed. Surgical strategies and nuances were analyzed.

Results

Nine cases of complex MCA aneurysm were analyzed [Table 1]. Their presentation, preoperative imaging, operative findings, and postoperative discourse are discussed in detail. Observations regarding the advantages of surgical management in these cases were identified. Technical nuances and operative challenges were also highlighted. The mean maximum diameter was 13.4 mm (range 10 mm–20 mm). The mean fundus/neck ratio was 1.6 (range 1.1–3). The points favoring surgical management were difficult access, broad necks, dome/neck ratio <1.5, recurrence, fusiform architecture, or critical perforator/branch vessels associated with the aneurysms were analyzed and all these cases were considered poor candidates for endovascular treatment. Table 1 also highlights the exact reason for not preferring endovascular treatment in each case. Three cases were managed by direct clipping while eight patients were managed by clip reconstruction techniques. Two cases from our series were recurrent aneurysms, 1 coiled and the other previously clipped elsewhere. The average microscope time (from the time of dura opening to dura closure) was 124 min. Intraoperative ICG dye study was performed in each case. The number of clips varied with the size of the aneurysms (Average 2.7, range 1–6). The number of times ICG was performed and number of times clip repositioning was performed correlated with the fundus/neck ratio. There was a correlation between the surgical time and the association of perforators/branch vessels to the neck. All patients had favorable outcomes (Modified Rankin scores 0–2) at a mean clinical follow-up of 13 months (Range 4 months to 24 months). There were no postoperative complications of infarction, re-bleeding or surgical morbidity and mortality. There was documented residual sac in one case of a bifurcation aneurysm, which had been clipped and the residual neck was coated using polyglycolic acid fibers. (Neoveil, Gunze Inc., Kyoto, Japan); complete occlusion rate was 88.9%.

Case reviews

Nine complex cases were reviewed in this series. Few important cases are discussed in detail.

Case 1

A 69-year-old female was operated previously for a large MCA bifurcation clipping 3 years' back. On angiographic follow-up, it was noticed that there was gradual growth in the sacand computational fluid dynamics (CFD) analysis revealed a high pressure with low wall shear stress and multiple vector changes indicating high risk of rupture in the aneurysm [Figure 1a]. Intraoperatively, the maximum diameter was 16 mm and the neck size was 12 mm. Three clips including 2 fenestrated clips were used to reconstruct the MCA bifurcation [Figure 1b] and ICG was used to

Table 1: List of complex middle cerebral aneurysm case

Case number	Date	Age	Sex	Exact location of aneurysm	Projections	Dome/ neck ratio	Neck width (mm)	Presentation	Surgical time (microscope)	Number of clips	Fenestrated clips
1	July 7, 2017	66	Female	M1	Superior	20/18=1.1	18	1^{st}	48 months	6	5
2	September 12, 2017	76	Female	Bifurcation	Lateral	12/4=3	4	1^{st}	140 months	1	0
3	December 26, 2017	69	Female	Bifurcation	Superior	16/12=1.3	12	Recurrent - 1^{st} clipping	175 min	3+2 Old	2
4	December 27, 2017	58	Male	M1	Lateral	10/6=1.6	6	1^{st}	70 min	2	1
5	February 21, 2018	75	Female	Bifurcation	Lateral	18/11=1.6	11	Recurrent - 1^{st} clip 2^{nd} coil	146 min	2	2
6	January 21, 2019	70	Male	Bifurcation	Superior	15/12=1.2	12	1^{st}	94 min	3	1
7	April 11, 2019	80	Female	Bifurcation	Medial	10/4=2.5	4	1^{st}	139 months	2	0
8	August 6, 2019	73	Female	Bifurcation	Medial	10/7=1.4	7	1^{st}	118 months	2	0
9	December 14, 2018	80	Female	Bifurcation	Lateral	10/8=1.2	8	1^{st}	186 min	4	1

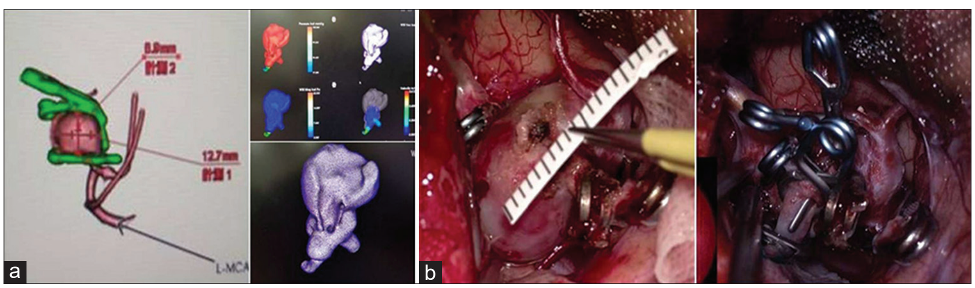

Figure 1: (a) Three-dimensional computerized tomographic reconstruction of a previously clipped (left) and computational flow dynamic study showing high pressure in the sac with vector changes at the fundus indicating high risk of rupture (right top and bottom). (b) Fenestrated clip reconstruction of the Middle cerebral artery bifurcation

evaluate the patency of the bifurcation and the associated perforators. The patient had an uneventful recovery without any neurodeficits and has not shown any recurrence at 20 m follow-up.

Case 2

A 75-year-old female, with no family history of cerebrovascular abnormalities, had a previous history of left MCA Aneurysm rupture which was treated with clipping 10 years back. Four years ago patient developed a recurrence of the MCA aneurysm and was treated with coiling. Three month ago patient had an incidental right internal carotid-posterior communicating aneurysm which was managed by clipping. During this study, the recurrence of the left MCA was observed and she was operated for clipping using the left pterional approach [Figure 2a]. The preoperative CFD identified a moderate to high pressure, with low wall shear stress with diverging vectors in the neck with alteration of streamline flow in the neck area, which indicated a high risk of rupture [Figure 2b]. Intraoperatively, the bifurcation was reconstructed using 2 fenestrated clips [Figure 2c].

Case 3

A 70-year-old man was incidentally diagnosed with a left MCA aneurysm during investigation for a routine headache. The aneurysm was at the bifurcation with both M2 arising from the neck and a fundus size of 15 mm with a F/N ratio of 1.25. The CFD analysis revealed a high pressure, with low wall shear stress with diverging vectors in the mid-fundus area, indicating high risk of rupture [Figure 3a]. Preclipping and postclipping intraoperative images show reconstruction using 3 clips including 1 fenestrated clip and ICG confirmation of sac obliteration and intact branch flow [Figure 3b].

Case 4

A 66-year-old female presented with headache and was diagnosed with a fusiform M1 aneurysm, with a Fundus/ Neck of 20/18 mm [Figure 4a]. Preclipping and postclipping

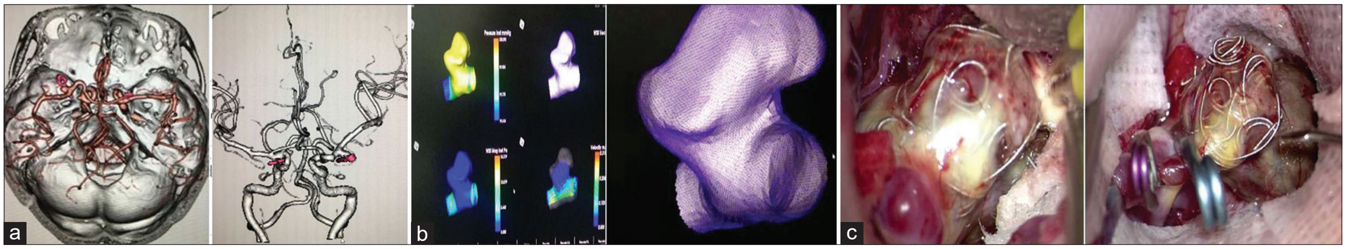

Figure 2: (a) Three-dimensional computerized tomography images showing large recurrent left middle cerebral artery aneurysm. Opposite side internal carotid aneurysm clip is seen *in situ*. Ipsilateral clip is seen with recurrent sac. (b) Computational flow dynamic studies of the same patient with recurrent sac showing moderate to high risk of rupture with moderate wall pressures (left) with divergent vectors at the neck (right). (c) Clip reconstruction using fenestrated clips with the previous coils seen in the sac

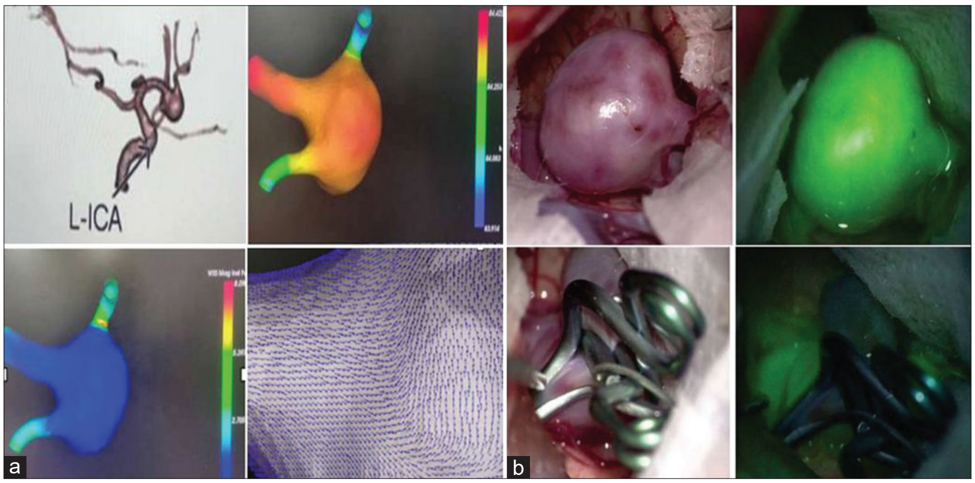

Figure 3: (a) Three-dimensional computerized tomography reconstruction images showing a middle cerebral artery bifurcation aneurysm, (left top) with computation flow dynamics showing high pressure (right top), with low wall shear stress (left bottom) with diverging vectors in the mid-fundus area (right bottom), indicating high risk of rupture. (b) Intaoperative images with video angiographic imaging which shows reconstruction using 3 clips including 1 fenestrated clip and indocyanine green confirmation of sac obliteration and intact branch flow

intraoperative images show; whole MCA had to be reconstructed using tandem fenestrated clip reconstruction technique with frequent ICG confirmation of the flow in the vessel [Figure 4b]. Preservation and conservation of the proximal neck perforator were also vital and possible with intraoperative ICG.

Discussion

Complex MCA aneurysms are defined as having large (10–24 mm in diameter) or giant (diameter ≥25 mm) size or non-saccular morphology (fusiform, dissecting, or serpentine) or are recurrent. These aneurysms have been classified as complex based on the fact that most of these cases have M2 branches arising from the aneurysm sac rather than M1 segments.[4] Large (≥10 mm in diameter) and giant (≥25 mm in diameter) MCA aneurysms are not uncommon in clinical practice and account for 9.8% of all MCA aneurysms.[2] Patients with complex MCA aneurysms may present incidentally of with mass effect, rupture, seizures, or infarction and may have a high mortality rate when they rupture.[5-8] These aneurysms have a significantly higher rupture rate. Unruptured Cerebral Aneurysm Study of Japan[9] reported that the annual rupture rates of large and giant MCA aneurysms were 4.11% and 16.87%, respectively. In addition, ISUIA (International Study of Unruptured Intracranial Aneurysms)[10] determined that the 5-year cumulative rupture rates for patients without a history of subarachnoid hemorrhage (SAH) who had aneurysms located at the internal carotid artery, anterior communicating, or anterior cerebral artery, or MCA were 14.5% for aneurysms with a diameter of 13–24 mm and 40% for aneurysms with a diameter of ≥25 mm.[9,10] Hence, the management of these cases is desired promptly after diagnoses.

Complex MCA aneurysms are traditionally considered as poor candidates for endovascular treatment because generally they have neck width 4 mm or more, dome neck ratios <1.5, inadequate endovascular access, have unstable thrombi or have arterial branches incorporated in aneurysm neck.[11] After the International Subarachnoid Aneurysm trial trial,[12] there has been a surge of endovascular management of all types of MCA aneurysms and newer devices and advancement in technology keep on growing the ever expanding scope for these procedures.[12] The Barrow ruptured Aneurysm Trial study[13] however found that aneurysm obliteration rates were significantly lower and retreatment rates significantly higher in the patients undergoing coiling than in those undergoing clipping over

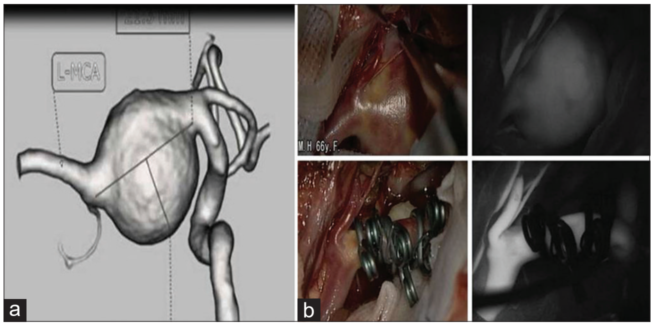

Figure 4: (a) Three-dimensional computerised tomographic reconstruction shows a fusiform M1 aneurysm. (b) Intraoperative images showing the clip reconstruction technique of the entire fusiform sac, with frequent intra-operative angiographic confirmation

longer duration of the follow-up.[13] In a recent meta-analysis comprising of all MCA aneurysms was performed after analyzing 37 publications for the management of MCA aneurysms. Their observations were that occlusion rates were higher at a 94.2% mean (C/I 87.6%–97.4%) in the 11 studies comprising of 626 patients in the clipping arm as compared to a mean of 53.2% (C/I 45.0%–61.1%) in the coiling arm which included 18 studies and 759 patients. The study also calculated that 97.9%(C/I 96.8%–98.6%) had favorable outcomes (Modified Rankin Score 0-2) after analyzing 22 studies with 2404 cases in the clipping group, while the favorable functional outcomes were comparable in the analysis of 22 studies with 826 patients at 95.1% (C/I 93.1%–96.5%) in the coiling arm. The conclusions of this study were that the surgical management of MCA aneurysms results in a better disease free status with comparable functional outcomes.[14] A large study comparing coiling versus clipping in 101 consecutive patients found that the maximum re-canalization rates after coiling among all intracranial aneurysms, were for MCA aneurysms.[15] Another study comparing the two modalities specifically for un-ruptured MCA aneurysms found that micro-surgical clipping appears to be the most efficient and safest way in treating MCA aneurysms and the two major angio-anatomical factors for failure of endovascular procedures were: Dome/neck ratio of 1.5or less, and an arterial branch (usually the proximal M2 segment) originating from the aneurysm neck. However, all these analysis was made irrespective of the size and angio-architecture of the aneurysms and not specific to complex cases.

Several authors have described their experiences in the management of complex MCA aneurysms [Table 2]. Park *et al*.[1] evaluated 106 large and giant MCA aneurysms, with a mean size of 15.3 mm (±7.1). Ten (9.4%) of their cases were giant aneurysms (≥25 mm). MCA bifurcation (n = 84; 79.2%) was the most common site of the aneurysm followed by the MCA trunk (n = 18; 17.0%) and distal MCA (n = 4; 3.8%). The clipping group included 88 aneurysms (83.0%); 82 were treated by neck clipping and 6 by aneurysm thrombectomy with clip reconstruction. The bypass group included 12 aneurysms (11.3%). The endovascular treatment group included 6 aneurysms (5.7%); 4 were treated by stent-assisted endovascular coiling and 2 by endovascular coiling without stent assistance. Small residual lesions were observed in 26 cases in their series at follow-up imaging, of which, 7 required re-treatment. (4 in the endovascular treatment group, 2 in the clipping group, and 1 in the bypass group). Favorable Neurological outcomes were achieved in 93 patients (87.7%) in their series at follow-up. Poor outcomes were significantly higher in the giant aneurysm group than in the large aneurysm group (4/10 [40%] vs. 9/96 [9.4%]; P = 0.011) at 6 months after neurosurgical treatment. In addition, poor outcomes were significantly higher in the SAH group than in the un-ruptured group (8/31 [25.8%] vs. 5/75 [6.7%]; P = 0.011).[1]

Xu *et al*.[16] evaluated 20 complex MCA aneurysms with a mean size of 19 mm comprising of 5 prebifurcation, 4 bifurcation, and 11 postbifurcation cases. Of all 20 aneurysms treated, 5 (25%) were managed with clip reconstruction, 1 (5%) by clip wrapping, 4 (20%) by proximal occlusion or trapping, and 10 (50%) by vascular bypass. Overall, their bypass patency rate was 90% on follow-up angiography. Postoperatively, 19 of 20 aneurysms (95%) were completely occluded. The mean follow-up period was 18 months (range, 1–36 months). Overall, good outcomes (mRS score 0–2) was observed in 90% (n = 18) of patients at the last follow-up.[16]

Zhu *et al*.[4] evaluated 58 cases of complex MCA aneurysms including ruptured and un-ruptured cases. They managed 8 cases with direct clipping, 25 cases with clip reconstruction and 25 cases with indirect aneurysm occlusion which included trapping/resection with various bypass techniques. They achieved a complete occlusion rate of 81.4% (48 cases) with a graft patency rate of 95.2% at an average radiological follow-up of 32 months (range 3–70). Fifty-two cases (88.1%) had favorable neurological outcomes (Glasgow outcome score ≥4) at a mean clinical follow-up of 38 (range 3–97) months.[4]

Huang *et al*.[17] evaluated 11 cases of giant aneurysms managed via endovascular treatment. Eight (7 un-ruptured and 1 ruptured) were managed by stent-assisted coiling (4-complete occlusions, 2-partialocclusion, and 1-residual) and 4 fusiform cases at M2 were managed by parent artery occlusion. One patient in their series had a relapse at a mean follow-up period of 13.5 m which required further treatment. The mean Glasgow outcome scale was 4.5 and the mean Modified Rankin score was 1 at the mean follow-up.[17]

Mantilla *et al*.[18] studied a meta-analysis of 12 studies (244 patients) regarding management of MCA aneurysms using flow diversion. The mean fundus size was 8.2 mm with 23.7% prebifurcation and 76.3% bifurcation and post bifurcation cases. The mean occlusion rate was 78.7% (95%

Table 2: Literature review of management of complex MCA aneurysms

Study	Modality	Study size	Mean size	Distribution	Management	Mean follow-up	Recurrence/ occlusion rates	Favorable outcome
Alreshidi *et al*. 2018	Clipping	626/2404	All MCA		Clipping		94.20%	97.90%
	Coiling	759/826	All MCA		Coiling		53.20%	95.10%
Park *et al*. 2017	Clip + coil	106	15.3 mm	MCA bifurcation; (79.2%) MCA trunk (17.0%) and distal MCA (3.8%)	82 clipping + 6 Clip recon 12 bypass Coiling		2 1 4 Total 7	87.70%
Xu F *et al*. 2018	Clipping	20	19 mm	5 prebifurcation, 4 bifurcation and 11 postbifurcation cases	5 (25%) clip reconstructio1 (5%) by clip wrapping 4 (20%) by proximal occlusion or trapping, 10 (50%) by vascular bypass	18 months	95%	88.10%
Zhu *et al*. 2013	Clipping	58			8 direct clipping 25 clip reconstruction 25 cases indirect aneurysm occlusion techniques	32 months (radiological) and 38 months (clinical)	81.4% (48 cases)	52 cases (88.1%)
Huang *et al*. 2015	Coiling	11			8 stent assisted coiling 3 parent Artery Occlusion	13.5 months	1 recurrent/ occliusion rate not available	Favourable in all
Cognazzo F *et al*. 2017 Meta analysis	Flow-diversion	12 studies 244 aneurysms	8.2 mm	23.7% prebifurcation 76.3% bifurcation and M2	Flow diversion		78.70%	92.70% Mortality=2%
Current study	Clipping	9	13.4 mm	2 (22.2%) prebifurcation 7 (77.8%) bifurcation	3 direct Clipping, 8 clip rconstruction	13 months	88.90%	100%

MCA – Middle cerebral artery

CI, 67.8%–89.7%) with a 12-month median duration. The overall rate of good outcome was 92.7% (C/I 86.4–99.1) with 2% mortality. The incidence of symptoms (ischemic stroke in the MCA territory) related to M2 at branch occlusion and diminished flow was 2.7% (95% CI, 0.4%–5%) and 2.6% (95% CI, 0.1%–5.1%), respectively.[18]

Because of the diversity of aneurysm morphology and the location and hemodynamic differences among patients, tailored surgical treatment is required for each individual case. Techniques such as aneurysm trapping or resection and arterial reconstruction play a pivotal role in treating these formidable lesions. Various newer clipping strategies have been used for the management of these complex aneurysms. Strategies such as "Picket Fence" clipping technique,[19] suction decompression assisted clipping[20] and "Mass Reduction" Clipping Technique.[21] However, aneurysm trapping/resection and various bypass strategies like EC-IC bypass, IC-IC bypass, and ICA sacrifice + EC-IC bypass have been described as an invaluable tool in the armamentarium for the management of complex cases which cannot be managed by pure clipping strategies.[1,4,16,22]

Our experience in this regard was that with careful selection of clipping techniques, clip size and architecture, use of multiple fenestrated clips and repeated ICG analysis can avoid requirement for vascular bypass procedures completely. In our study, all cases except one could be managed by direct clipping with or without reconstruction. One case required clip plus coating however, there was no requirement for bypass revascularization. Fenestrated clips play an important role in these cases as large perforators or branch vessels sometimes arise precariously close to the sac. Fusiform variety of aneurysms can be managed by clip reconstruction of the involved wall and CFD analysis can play a vital role in this regard in identification of the pathological wall in these cases. Surgical management leads to overall good results in these complex aneurysms which are not favorable in morphology for endovascular management currently available. Some studies involving use of flow diverter have shown promise in the fusiform cases, but lack of randomized trials, expertise and risks of residual sacs/re-canalization still favor surgery in these cases.

Conclusions

MCA aneurysms pose a significant challenge for endovascular treatment because of various factors such as luminal thrombi, complex angioarchitecture, precarious branch/perforator locations, broad necks, and fusiform characteristics. Surgical management in experienced hands can tackle all these problems with an armamentarium of clipping techniques and bypass procedures. Complete exposure of all proximal, distal and perforator vessels is essential to plan the strategy for clip application in these cases. The average surgical time and exposure to anesthesia is not very long and multiple intra-operative ICG dye fluorescence studies and use of fenestrated clips add to the safety and efficacy of surgery. Computational flow dynamic studies using specialized software can help gauge which aneurysms have high risk of rupture and also anticipate weak spots in the sac or the neck. The neurological outcomes after surgery in these complex aneurysms are comparable with endovascular treatment and various studies have cited a better long-term disease-free rate with surgery.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot bechrological order guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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