Ischemic Event and Risk Factors of Embolic Stroke in Atherosclerotic Cerebral Aneurysm Patients Treated with a New Clipping Technique

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Background: We would like to know the exact rate of ischemic event and the risk factors associated with embolic stroke by treatment of atherosclerotic cerebral aneurysm with a new technique. *Methods:* This is a retrospective cohort study in patients diagnosed as unruptured atherosclerotic cerebral aneurysm who underwent microsurgical clipping between January 2012 and August 2014. All intraoperative video recordings were reviewed and chosen in patients who were identified as atherosclerotic lesion on the dome, neck, or parent artery of the aneurysm. The demographic, radiographic, operative, and postoperative data were collected. The primary end point was the incidence of cerebral infarction and the neurologic outcomes using the discharge modified Rankin Scale (mRS) score at postoperation time. A statistical analysis of the factors associated with embolic stroke was done by Fisher exact and Wilcoxon rank-sum tests. The individual surgical technique was demonstrated as an illustration for use as a guide. *Results:* Among 103 atherosclerotic cerebral aneurysms, only 3 patients (2.9%) were associated with postoperative cerebral infarction and 1 of them had permanent neurologic deficit. A good mRS score (0-2) was found in 99% of patients and only 1% had a fair mRS score (3-4). A factor associated with ischemic outcome was duration of operation ($P = .046$). The differences in the atherosclerotic location showed no statistical significance. *Conclusions:* We found a very low incidence of embolic infarction after clipping of an atherosclerotic cerebral aneurysm with our new technique. Only duration of the operation time was a dependent risk factor for embolic infarction. **Key Words:** Atherosclerotic cerebral aneurysm—ischemic event—thromboembolism—hemodynamics wall shear stress.

Unruptured cerebral aneurysms (UCAs) are commonly found in the general population (.4%-6%). The number of incidental findings of UCAs has increased because of the advantages of noninvasive imaging technology. The surgery and endovascular techniques for the treatment in this type of aneurysm are still debated.[1]

The higher the prevalence of chronic diseases (ie, chronic hypertension, diabetes mellitus, hypercholesterolemia, advanced age, and smoking), the higher the prevalence of atherosclerotic or calcified aneurysms.[2] No previous studies focused on the incidence or the exact data of atherosclerotic aneurysms. They reported only the atherosclerotic type of aneurysm which was related with a poor outcome after surgery, which was more than 7.8 times higher when compared with patients who had nonatherosclerotic aneurysms.[3] The role of

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surgery in atherosclerotic aneurysm should be concerned with the aneurysmal sac that can shower emboli during manipulation or placing the clip because it can break the unstable local plaque resulting in distal arterial occlusion that leads to brain infarction. On the other hand, the outcome for this type of aneurysm treatment is not satisfied by the endovascular surgery option. Furthermore, one study showed that thromboembolic complications reached 30% of associated endovascular coiling,[4] which is more common than in the clipping technique.[5] However, surgical clipping has some limitations because of the difficulty in placement of the clip to the neck or dome of the aneurysm near calcification or an atherosclerotic plaque area. It is impossible to completely achieve adequate obliteration and avoid clip slippage. The ideal technique to solve this problem is to trap the parent artery with revascularization or make a thrombectomy of an aneurysmal thrombus with clip reconstruction. Unfortunately, these techniques usually have unfavorable outcomes.[6,7]

There are only a few studies on the incidence of ischemia and factors associated with thromboembolic events after treatment with surgical clipping, and none of the studies refer to the technique of surgery. The aim of this study is to review the ischemic events of atherosclerotic aneurysm clipping and the associated factors for embolic stroke after clipping an aneurysm. Furthermore, with the techniques proposed in this study, an aneurysm can change from an unclippable to a clippable aneurysm.

Methods

A retrospective cohort study was performed at a university hospital. The study was approved by the ethics committee of Fujita Health University, and each patient signed an informed consent before receiving the treatment. All patients who were admitted between January 2012 and August 2014 were operated on by a senior neurosurgeon (Y.K.) in the Neurosurgical Department. The operative video records of each patient were reviewed. The baseline characteristics of the patients (ie, demographic, radiographic, intraoperative, and postoperative data) were noted. The eligibility criteria were a diagnosis of unruptured atherosclerotic cerebral aneurysm, aged older than 18 years, cooperative, postoperative duration in the hospital for at least 7 days, and a computed tomography (CT) scan of the brain performed postoperatively within 24 hours. Magnetic resonance imaging (MRI) scan of the brain was performed to confirm infarction in the symptomatic patient. The ineligibility criteria were ruptured cerebral aneurysm, not cooperative for evaluation, optional procedure such as endovascular treatment or revascularization of the aneurysm, or clinical condition of cerebral infarction because of prior surgery.

All patients were operated on under standard techniques. After they were diagnosed as UCA from 3-dimension (3D) CT angiography (CTA), an informed consent was obtained from them and their relatives before surgery was scheduled. The patients were admitted at least 1 day before the operation and had a preoperative evaluation. Intraoperative physiologic monitoring such as motor evoke potential (MEP) or somatosensory evoke potential was applied in selected cases who had a risk of injury to small perforator arteries during surgery that could lead to a neurologic deficit. A neuroprotective anesthetic technique was chosen and the standard frontotemporal transsylvian approach was used for internal carotid artery, posterior communicating artery, anterior choroidal artery, anterior communicating artery (ACoA), and middle cerebral artery aneurysms. The other approach was the frontal interhemispheric approach for distal anterior cerebral artery or high position ACoA aneurysms. The tractionless technique was applied for exposure of brain parenchyma. Indocyanine green videoangiography (ICG-VA) with FLOW-800 software generated with infrared (ZEISS, OPMI Pentero, Germany) was used in all patients before and after clipping to check the anatomical architecture of the aneurysm and associated arteries such as the parent and perforating arteries. The patency of these arteries and the completeness of exclusion of the aneurysmal neck after clipping the aneurysm can be checked with this device. Additional software of this device, color map, and flow intensity were analyzed for blood flow dynamics which included the sequence of blood flow after aneurysm clipping in cases of suspected incomplete exclusion. Endoscope-assist microsurgery was used for anatomical safety to check before and after aneurysm clipping in case the neck or small perforator arteries could not be seen. Doppler ultrasonography was used to determine the characteristics of the blood flow after clipping of the aneurysmal sac and identify unintentional injury to small perforator or parent arteries. Postoperative CT scan of the brain was routinely performed within 24 hours to check for complications. A physical and neurologic examination was performed hourly by the attending neurosurgeon during the first day after the operation. The Glasgow coma scale score was routinely recorded on a daily basis, and the outcome evaluation was estimated by the modified Rankin scale (mRS) score on the day before discharge. For the patients who developed complications, the correctable causes were treated by medication or operation.

Ischemia or embolic stroke was defined as symptomatic or asymptomatic. Symptomatic ischemia referred to a deteriorated neurologic condition after the operation in one or more of the following conditions: hemiparesis or hemiplegia, cranial nerve palsy, decreased sensation, memory or conscious change, or all of these proved by CT and diffusion-weighted imaging form of MRI scan of the brain that showed evidence of hypodensity or

Table 1. *Modified Rankin Scale scoring system*

Score	Description
0	No symptoms at all
1	No significant disability despite symptoms; able to carry out all usual duties and activities
2	Slight disability; unable to carry out all previous activities, but able to look after own affairs without assistance
3	Moderate disability; requiring some help, but able to walk without assistance
4	Moderately severe disability; unable to walk without assistance and unable to attend to own bodily needs without assistance
5	Severe disability; bedridden, incontinent ,and requiring constant nursing care and attention
6	Dead

diffusion restriction in the distribution of a vascular territory in a size range of .2 to1.5 cm.[8] Asymptomatic ischemia or silent ischemia in this study was a diagnosis by CT scan of the brain and the patient did not have any symptoms.[9] A neurologic deficit from direct injury during surgery and not related with embolic infarction was excluded from the definition of ischemia. We measured the outcome of cerebral infarction by using the discharge mRS score which is classified into clinical symptoms with 0 to 6 points (Table 1).[10] A symptomatic UCA patient refers to any symptom related to the morphology or size of an aneurysm that directly compresses the cranial nerve or protrudes into the functional brain parenchyma. Atherosclerotic change is defined as the detection of yellowish plaque located at the dome and/or neck of an aneurysm and/or the parent artery; furthermore, we confirmed the atherosclerotic changes with ICG-VA application by the filling defect in the atheromatous calcification or the thickening of the aneurysm wall was seen (Fig 1, A,B).[11–13] The classification of the location of atherosclerotic change is designated and described in Table 2. Naming depended on the location of the plaque and it was combined if it is involved in more than one area (Fig 2). The location of atherosclerotic change might influence the effect of embolic stroke during manipulation or adjustment of the clip force around this area. The size of aneurysm was measured by the average maximal diameter in every plane of the dome from a 3D CTA image in millimeters.

The demographic data included age, sex, underlying disease (eg, diabetes mellitus, hypertension, dyslipidemia) smoking history, and symptoms of the patient. Radiographic data included the location, size (small, <7 mm; medium, 7 to 12 mm; large, 13 to 25 mm; giant, >25 mm), and the number of aneurysms. Operative data included the area of the atherosclerotic plaque, number of clippings, location of clipping, application of temporary occlusion, adjustments of the clip during operation, and time duration of the operation. Postoperation data during the duration of admission were Glasgow coma scale score (score 3 to15 described by eye opening, verbal response, and motor movement) and mRS score (good, 0-2; fair, 3-4; and severe, 5-6). On the day before discharge, the neurologic deficit and the results of a CT scan of the brain were obtained. A statistical analysis was used to measure the demographic and radiographic data, and procedural and postprocedural variable parameters. The data were interpreted by median ± interquartile range in ordinal data and analyzed by using the R program. The Wilcoxon rank-sum test and Fisher exact tests were used to analyze for nonparametric ordinal scale and nominal scale, respectively, to find the risk factors associated with ischemic outcome. Statistical significance was defined as P less than .05.

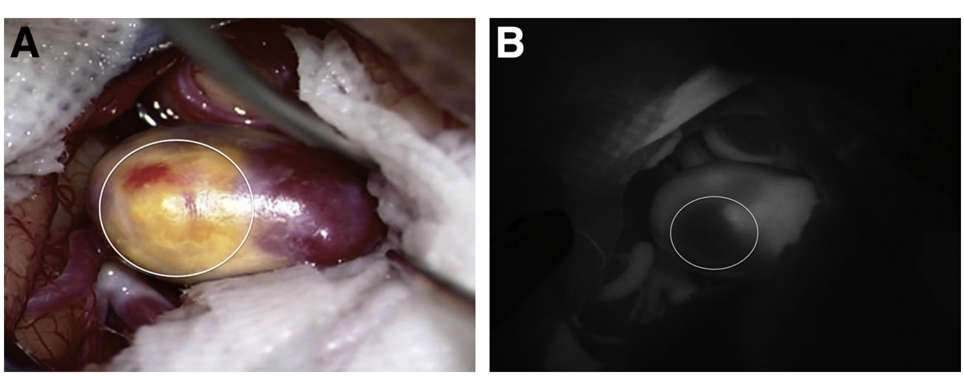

Figure 1. *Definition of atherosclerotic aneurysm that added to intraoperative yellow plaque visualization criteria. The yellow plaque of aneurysmal sac under microscopic inspection (A). Indocyanine green was administrated and revealed the filling defect area of the atherosclerotic change (B). The white circle was marked in atherosclerotic area. (Color version of figure is available online.)*

Table 2. *Classification of the definition of atherosclerotic change locations*

Part of atherosclerosis	Definition*
Dome	Sclerotic change in the aneurysmal sac just beyond the neck at least 1 mm.
Neck	Sclerotic change in the aneurysmal neck without involving the aneurysmal sac or parent vessel more than 1 mm.
Parent artery	Sclerotic change in the parent vessel not far away from the neck more than 5 mm and it does not involve the neck.

*Plus the inspection of the filling defect location from ICG-VA application.

Results

A total of 103 patients were included in this study and revealed the data in Table 3. More than half of the patients had a coexisting condition of high blood pressure and one third of them had a long history of smoking. Asymptomatic aneurysm patients were in the majority as most patients were diagnosed from image screening tests. Posterior communicating artery aneurysms were found in most patients, and the average mean aneurysmal size was less than 7 mm. Parent vessel was the most common location of atherosclerotic change and more than two thirds of the patients had the clip successfully placed at the neck area. One patient had a suitable clip placed in the aneurysmal sac. Only 3 cases (2.9%) developed ischemia after the operation, and the CT and MRI scan of the brain showed supporting evidence of cerebral infarction. The results of the study showed that 7 patients experienced both ischemia and direct injury of the essential brain during surgery that resulted in a neurologic deficit. For the 3 infarction patients, the first case was diagnosed as anterior choroidal artery aneurysm. This female patient underwent aneurysm clipping and developed cerebral infarction in the posterior limb of the internal capsule and hemiparesis was observed. Finally, the patient's neurologic deficit improved (Fig 3). In the second case, a woman was diagnosed as ACoA aneurysm and clipping was performed. She developed cerebral infarction after operation but she later had reversible hemiparesis. The last case was a male patient who was diagnosed as large M1 aneurysm, and at postaneurysm clipping, he developed weakness at his contralateral side. He still has a permanent neurologic deficit (mRS score, 2; Fig 4, A,B). Other morbidities were not from embolic stroke. One patient presented with an mRS score of 3 points from blindness in both eyes after surgery because of direct injury to the optic nerve. Two patients developed mRS scores of 2 points: the first one was hemiparesis from cerebral infarction from direct parenchymal injury and the other was an old patient who developed confusion after the operation because of adverse effects of the anesthetic drugs but improved later. None of the

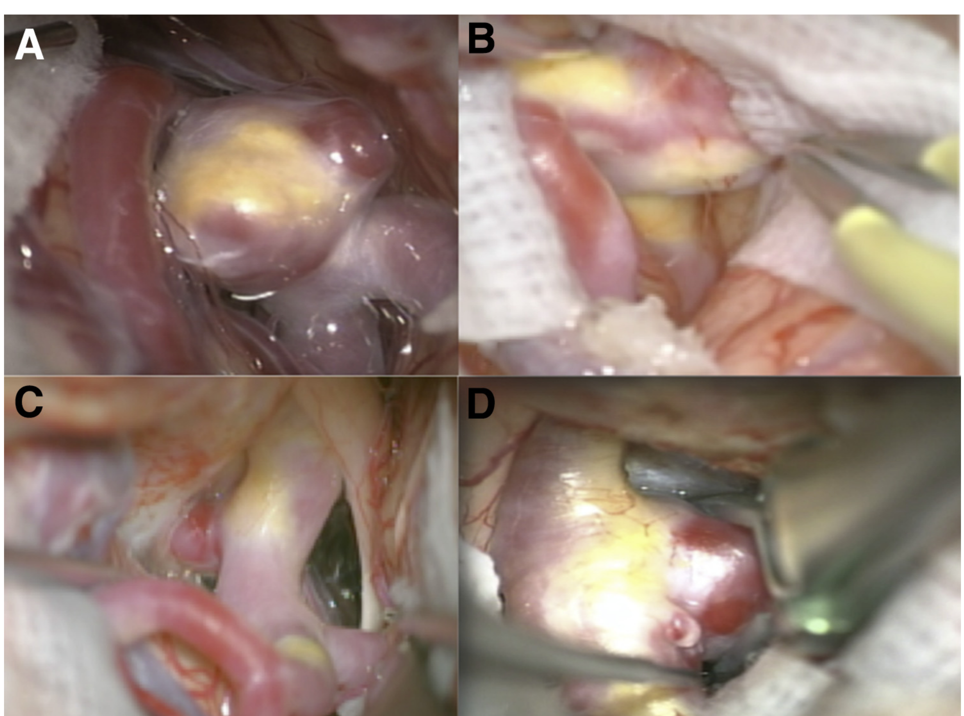

Figure 2. *Definition of atherosclerotic change at the dome (A), neck (B), parent artery (C), and neck–parent artery (D).*

Table 3. *Demographic, radiographic, procedural, and postprocedural data and univariate analysis for factors associated with infarction outcome*

Characteristic	Number (%)	*P* value
Age (y)*	65.5 (58.5-71)	.136
Sex		
Male	40 (38.8)	1
Female	63 (61.2)	1
Underlying disease		
Diabetes mellitus	3 (2.9)	1
Hypertension	54 (52.4)	.604
Dyslipidemia	15 (14.6)	.38
Smoking	33 (32)	.549
Symptomatic	14 (13.6)	.358
Location of aneurysm		
PCoA	32 (31.1)	1
MCA bifurcation	25 (24.3)	1
MCA M1	3 (2.9)	.086
ACoA	16 (15.5)	.401
Distal ACA	8 (7.8)	1
Posterior circulation	0 (0)	
Other ICA (ophthalmic, AntChoroidal)	19 (18.4)	1
Size of aneurysm		.09
Small (<7 mm)	70 (68)	
Medium (7-12 mm)	28 (27.2)	
Large (13-25 mm)	5 (4.9)	
Giant (>25 mm)	0 (0)	
Number of aneurysms*	1 (1,1)	.415
Location of atherosclerotic change		
Neck of aneurysm	48 (47)	1
Dome of aneurysm	55 (53)	1
Parent artery of aneurysm	62 (60)	1
Neck and dome of aneurysm	14 (13)	1
Neck and parent artery of aneurysm	11 (11)	1
Dome and parent artery of aneurysm	11 (11)	1
Neck, dome, and parent artery of aneurysm	13 (13)	.336
Number of clip*	1 (1,2)	.884
Readjust clip	8 (7.8)	.217
Location of clipping		
Dome	30 (29.1)	1
Neck	89 (86)	1
Temporary artery occlusion (yes)	7 (6.8)	.192
Total time of operation (min)*	299 (236,394)	.046
Duration of admission (d)*	12 (11,14)	
GCS after discharge*	15 (15,15)	
Discharge mRS score		
Good (0-2)	99 (99)	
Fair (3-4)	1 (1)	
Severe (5-6)	0 (0)	
Neurologic deficit	7 (6.8)	
CT brain (ischemia)	3 (2.9)	

Abbreviations: ACA, anterior cerebral artery; ACoA, anterior communicating artery; AntChoroidal, anterior choroidal artery; CT, computed tomography; GCS, Glasgow coma scale; ICA, internal carotid artery; IQR, interquartile range; MCA, middle cerebral artery; mRS, modified Rankin Scale; PCoA, posterior communicating artery.

*Median (IQR).

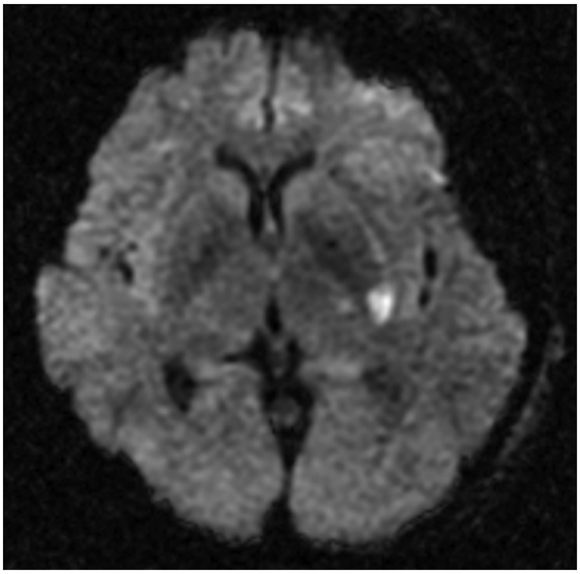

Figure 3. *DWI form of MRI scan of the brain showed the restriction area of anterior choroidal artery territory infarction after aneurysm clipping. Abbreviations: DWI, diffusion-weighted imaging; MRI, magnetic resonance imaging.*

patients developed poor outcomes (mRS score, 5-6). Two cases had a changing signal of the MEP during the operation; however, they did not have ischemic symptoms after the operations and a definite cause could not be identified. Some patients had the CT scan of the brain performed more than one time as they had complications after operation such as an infarction, and the progression of the infarction had to be determined. All patients were admitted in the hospital for at least more than 1 week, and the patients were followed for symptoms of acute complications after operation in the hospital. Some patients desired an extended time in the hospital for rehabilitation and reassurance of how to care for themselves after discharge to home.

Only the duration of operation had statistical significance for the factors associated with ischemic symptoms.

Discussion

According to the best of our knowledge, this is not only the largest series review investigating the outcome of treatment in atherosclerotic UCA, and especially the risk of thromboembolism in an ischemic event, but also the first report on the technique of aneurysm clipping in this type of aneurysm. One hundred three cerebral atherosclerotic aneurysms were analyzed for the factors associated with an ischemic event after undergoing an operation using a specific clipping technique. We found very few ischemic events, and among the vascular atherosclerotic risk factors, there were no independent risk factors associated with embolic stroke outcome. There was also no increase in the incidence of ischemia despite the location of the atherosclerotic plaque, size of aneurysm, frequency of readjusting the clip, and the location of the clipping contrast which are the parameters that probably increase the risk of ischemia. The statistical analysis determined that the duration of operation was the only independent risk factor of an ischemic outcome. In our study, we found only a small number of patients (3 of 103) developed an ischemic event, which made it difficult to interpret the duration of surgery as the only independent risk factor.

The International Study of Unruptured Intracranial Aneurysm (ISUIA) revealed an increased incidence from the general population if the patients have a family history of UCA or subarachnoid hemorrhage, older age, intracranial arteriovenous malformation, coarctation of aorta, fibromuscular dysplasia, or autosomal

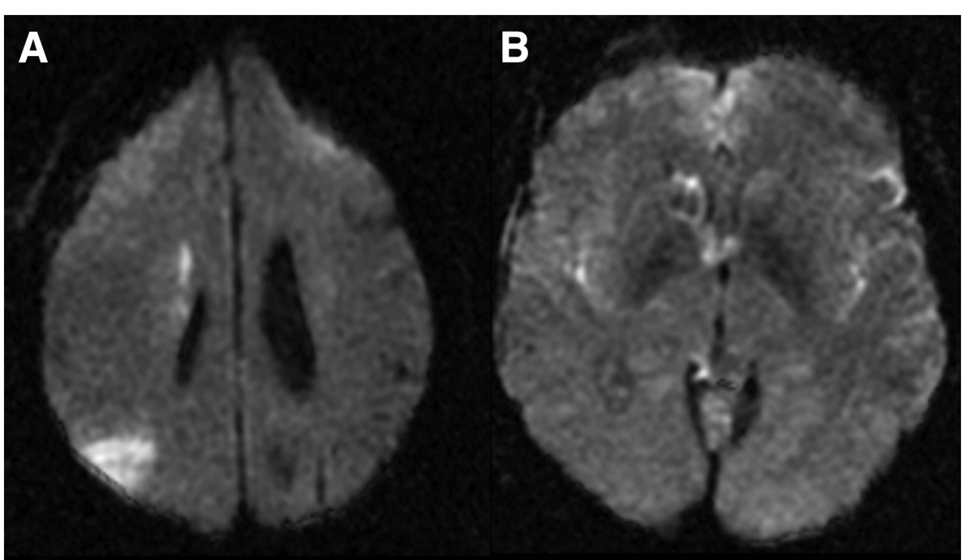

Figure 4. *Cases of large M1 aneurysm (A) and ACoA aneurysm (B) were demonstrated in infarction area after performing the surgery by DWI form of MRI. Abbreviations: DWI, diffusion-weighted imaging; MRI, magnetic resonance imaging.*

dominant polycystic kidney disease.[14,15] In patients who have a background of chronic hypertension, the pathophysiology leads to intima thickening and necrosis of the tunica media. The composition of the matrix changes and the internal elastic lamina degenerates resulting in a weakening of the arterial wall that develops into an aneurysm.[16] The risk of future rupture is very low in the asymptomatic aneurysm. There is still debate on the optimal treatment of UCAs because of a lack of prospective randomized controlled trials. According to our knowledge, the atherosclerotic plaque of an aneurysm enhances the risk of generating a shower of thrombi to the distal vascular territory that results in cerebral infarction.[17] This is a serious sequela and complication after atherosclerotic aneurysm treatment especially when we replace the clip and manipulate around the yellow plaque or thickened wall area that might squeeze the atheromatous plaque allowing it to migrate to a distal vascular area. In some situations, if the booster clip technique is used at the neck of the aneurysm, it will protrude the atheromatous thrombi and shower them and cause blockage in a distal area. Fortunately, nowadays, the incidence of cerebral infarction associated with the treatment of atherosclerotic aneurysm is low. Most reports usually mentioned stroke events related to surgical clipping in only nonatherosclerotic aneurysm. It varied between 7% and 41% and depended on several factors such as temporary occlusion and perforator artery injury from dissection or retraction.[17–19] In 1999, Ohno et al[20] reported the incidence of cerebral infarction reached 50% after treatment of atherosclerotic aneurysm with conventional clipping. Because of this poor outcome, some authors have suggested an alternative technique to first remove atheroma or sclerotic plaque then directly repair the wall of the aneurysm with a microsuture. After that, the clip was used to close the neck, which also decreased thromboembolic events.[21] Lawton et al classified the types of thrombotic aneurysm and chose the appropriate technique for each procedure. Finally, they concluded that the conventional clipping or trapping technique after revascularization had a better result than direct thrombectomy and they found that the permanent deficit and mortality rates were 7% and 6%, respectively.[6] They reported many strategies for the treatment of this aneurysm such as the incidence of neck rupture after direct clipping without opening the sac to remove the calcification. At first, they used only the compression technique with sling gauze to decrease the size of a fusiform aneurysm which was limited to direct clipping but the outcome was not so good.[22] Some aneurysms have limitations such as atherosclerotic plaque located at the neck and placement of the clip cannot be done in this area. Suitable clipping terminology was introduced to place the clip at the aneurysmal sac or dome and then wrap the neck to avoid a poor outcome of ischemia from showering the emboli.[20] They found not only a poor outcome after treatment of atherosclerosis or calcified aneurysm but it was also difficult to adequately place the clip. The clip needed readjustment or it was sometimes necessary to use multiple clips for reconstruction of the neck or formation of the parent artery or dome. That meant it probably increased the risk of injury to the small perforator arteries which were located adjacent to the aneurysm and led to cerebral infarction.[3]

The options for treatment in this type of aneurysm are still being debated. The complete obliteration of the aneurysm from clip and endovascular coiling was only 72% and 28% of the cases, respectively.[5] The prevalence of thromboembolic event associated with endovascular treatment of UCA is still high.[4] It is not safe for treatment by endovascular technique because of the high rate of recurrence and incomplete obliteration of the aneurysmal sac. Our institute prefers the operation treatment rather than the endovascular treatment. We found the incidence of infarction was lower than that in a previous study.[20] Recently, in a discussion of the hemodynamics of an aneurysm, they established a theory related to wall shear stress. They found that the increased relative residence time of blood flow (stagnant blood flow) and low wall shear stress played a role in the incidence of a change in the atherosclerotic area from calculations in a computational fluid dynamics simulation model.[23] However, in another study, aneurysms that initiated with rapid growth were found in areas of high wall shear stress.[24] From this knowledge, we can predict the natural course of an atherosclerotic aneurysm especially at the point of sclerotic change and it may help the surgeon decide how to adequately manage an incomplete obliteration of the residual neck because of sclerotic change. The preoperative imaging usually cannot predict the atherosclerotic plaque of aneurysm before operation. We must directly face the yellowish plaque and consider the location in the intraoperative field. Therefore, it is very difficult at that time to judge how to suitably place the clip to prevent emboli migration and obtain maximal exclusion of the aneurysm. Unstable plaque is very weak and easily migrates because of the force of the clip compression or manipulation around the plaque. In some cases, because the location of the plaque is incorporated in the neck and dome and there is no area for placement of the clip, it necessary to perform a dome clip to decrease the risk of rupture in the future. We should leave some part of yellowish plaque because the risk of aneurysmal growth in this area is very low according to the low wall shear stress theory. This is the strategic treatment of this type of aneurysm.

In our study, this specific technique of clipping was introduced in all patients. Based on the aim of the treatment to restore the neurologic function and obtain maximal obliteration of the aneurysm, we used this concept for this technique, "Touch only the reddish area and avoid touching the yellowish plaque." One clip to several clips and various types of clips were used (Sugita, Mizuho, Japan) such as straight, angled, or fenestrated type. We applied several techniques such as formation, booster, or compression clipping for exclusion in large aneurysmal necks. For example, if the aneurysmal neck had multiple sites of atherosclerotic plaque that limited the placement of the clip at the neck, the clip was applied in a different direction by using the formation clipping technique (see Appendix for technical notes). A dome clip or suitable clip was also considered for complete obliteration of an aneurysm. In all patients, many assistive devices such as ICG-VA with FLOW 800 software, endoscope-assist microsurgery, MEP, and intraoperative microvascular Doppler ultrasonography were used to check the completeness of obliteration of the aneurysm and patency of the small perforator and parent arteries after clipping. Readjustment of an aneurysm clip was performed in cases of incomplete aneurysm exclusion or small arteries were not patent after clipping. The main point of this review was not only a study of the incidence and risk factors associated with embolic stroke but also the application of techniques in the atherosclerotic aneurysm that was categorized as "complex aneurysm," which usually needs other techniques such as revascularization, trapping procedures, thrombectomy, or hypothermic circulatory arrest. However, it was not necessary to use these procedures as simpler procedures were used instead, which changed an unclippable aneurysm to a clippable aneurysm and had an excellent outcome. This technique was established in this study for the first time.

There were some limitations in this study. First, we had a small population in a single center. Second, MRI scan of the brain could not be used to prove ischemic results in asymptomatic ischemic patient because it is the investigation of choice to detect acute brain infarction and CT scan of the brain is not sensitive enough to detect cerebral infarction. The accuracy of the outcome in brain infarction may be missing especially in cases diagnosed as silent infarction. Third, the source of the emboli could not be determined before surgery. The outcome of infarction from a thromboembolic event might not be precise. Fourth, measuring the outcome was performed only in acute complications because follow-up on a long-term basis was not possible for the large number of patients in our setting. Fifth, we should compare a non–atherosclerotic group with an atherosclerotic group. Last, the computational fluid dynamics model may be helpful to study the wall shearing stress in atherosclerotic areas as it would help to predict aneurysmal growth.

Conclusion

The atherosclerotic plaque aneurysm is difficult to judge for treatment. Both endovascular and surgical treatments are debatable. The worse complication of surgical clipping is cerebral infarction from showering of the emboli. Surgical treatment of this aneurysm depends on the location of the atherosclerosis. We should avoid manipulating or touching the sclerotic areas to avoid occluding the neck of the aneurysm by the clip if there is yellow plaque. We should change the type of operation to another such as revascularization and then occlude the parent artery. However, this procedure also has a very high risk of complications. Endovascular surgery has several limitations including recurrent aneurysmal growth or thromboembolic event. Surgical clipping is the main technique for treatment. A new technique for clipping was introduced to avoid placing a clip in the yellow area to decrease the incidence of ischemia and leave some areas of yellow plaque. We can follow up the aneurysmal growth because this area presents with a very low wall shear stress force. Good outcomes were observed in the patients of this study after this technique was performed. This new technique of clipping usually changed the concept of unclippable to clippable aneurysm using a simple procedure with a low rate of morbidity. This technique also used a short time for the operation and avoided the revascularization procedure.

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Appendix

Technical notes

As a special technique for clipping an atherosclerotic UCA, we propose this concept, "avoid compressing the clip at the yellowish sclerotic area and obliterate only the reddish area with complete aneurysm exclusion at the neck or dome." In the first step of the technique, a preoperative 3D CTA was performed in every patient to study the anatomy of the aneurysm which included the parent artery, small perforator arteries, and normal brain tissue. The second step was the intraoperative procedure. Accessory devices such as a microscope with ICG-VA were applied in every case. Other devices were used but it depended on the special circumstance such as an MEP monitor in cases that had a risk of small perforator artery injury during surgery. Endoscope-assisted and Doppler ultrasonography were used in cases where the parent or perforator arteries could not be seen before clipping and they usually helped to confirm the blind corners of surgery. The standard frontotemporal approach with sylvian dissection was approached for anterior circulation system aneurysms, but the interhemispheric approach was used for distal anterior cerebral artery aneurysms or high position ACoA aneurysms. The following were the 4 basic stages of clipping: (1) before application of a clip, (2) selection of a clip, (3) application of a clip, and (4) after clipping. Before the application of a clip, the aim was clear: visualization of the neck and structure surrounding the aneurysmal area. A plan was made to place a clip that would result in saving the vital structures and yet have the ability to change the technique during the operation to suit the circumstance at that time. The "Sugita" clip was selected and was available in various designs such as straight, angled, L-shaped, or fenestrated clip. The blade holding force was designed specifically for each type of clip. For the application of a clip, there were many techniques that followed the strategies of clipping. These techniques are tentative clipping, multiple clipping (tandem and counterclockwise techniques), formation clipping (branch artery or parent artery formation), booster clipping, shank clipping, compression clipping, and rotation advance. Finally, after clipping, the position of the clip was checked. Patency of perforator arteries and the parent artery and the complete neck clipping were checked by endoscope-assisted microsurgery or by ICG-VA.

As previously mentioned, the location of atherosclerosis is very important concerning the type of treatment because it determines how to choose the adequate clip type or proper technique in the clipping. We demonstrated the technique of "suitable clipping" as shown in Figures 5 and 6.

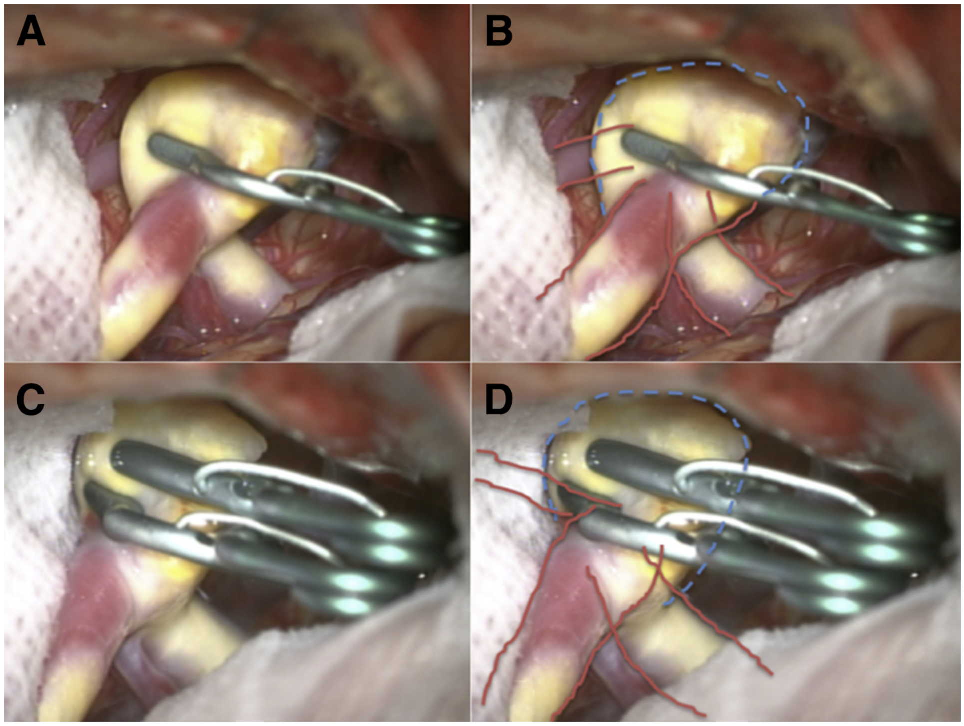

Figure 5. *Case of MCA bifurcation aneurysm, (A) demonstrated using fenestrated clip place at the neck of aneurysm located between the yellowish plaque. (C) showed the neck of aneurysm was reconstructed with an additional straight clip. Finally, we left some area of the yellowish plaque for prevention of thromboembolic event. Blue dashed line refers to the border of aneurysmal sac, and the red bold line refers to the parent artery (B and D). Abbreviation: MCA, middle cerebral artery. (Color version of figure is available online.)*

Summary of the clipping techniques:

1. Exceptionally straight or angled clip, the fenestrated and supplementary clips are necessary to apply in most cases of atherosclerotic type of cerebral aneurysm.
2. Avoid the use of temporary clips in the yellowish sclerotic area of the parent artery because it might lead to ischemia from emboli showering.
3. Avoid placing the clip on the yellowish area of an aneurysmal dome or neck because not only they produce a thromboembolic event to the distal territory of the vessels but slippage of the clip is also easy.
4. Avoid placing the booster clip if it is unnecessary in the situation because it can squeeze emboli into the distal vascular territory.
5. The straight type of clip is used as the standard device for exclusion of a neck aneurysm. Other types of clips are designed for other purposes. The fenestrated clip type is used for formation of the parent vessels or sparing of the small vessels arising near the neck or dome and unable to directly clip with a straight type of clip. A fenestrated clip is used in cases when an atheromatous thickened wall cannot be completely closed.
6. The ideal target of treatment is complete aneurysmal neck closure with a clip. However, in some situations when a neck clip cannot be used because of either limited space to place the clip or atherosclerotic change, the dome of the aneurysm is the optional technique for closure.
7. The blade of the clip should be near the aneurysm neck.
8. A supplementary clip can be applied in an area where the residual area of an aneurysm is identified.
9. A re-enforcement technique can be applied in cases when the blade of the clip does not tightly compress at the neck/optimal area.
10. The clipping of an aneurysm in this study is not perfect for closure at the neck and a part of the aneurysm is left open because of a change in the atherosclerotic area. However, other types of clips were used to reconstruct for closing and fortunately, because the wall shear stress in this area is very low, the rate of aneurysmal growth in the future is also very low.

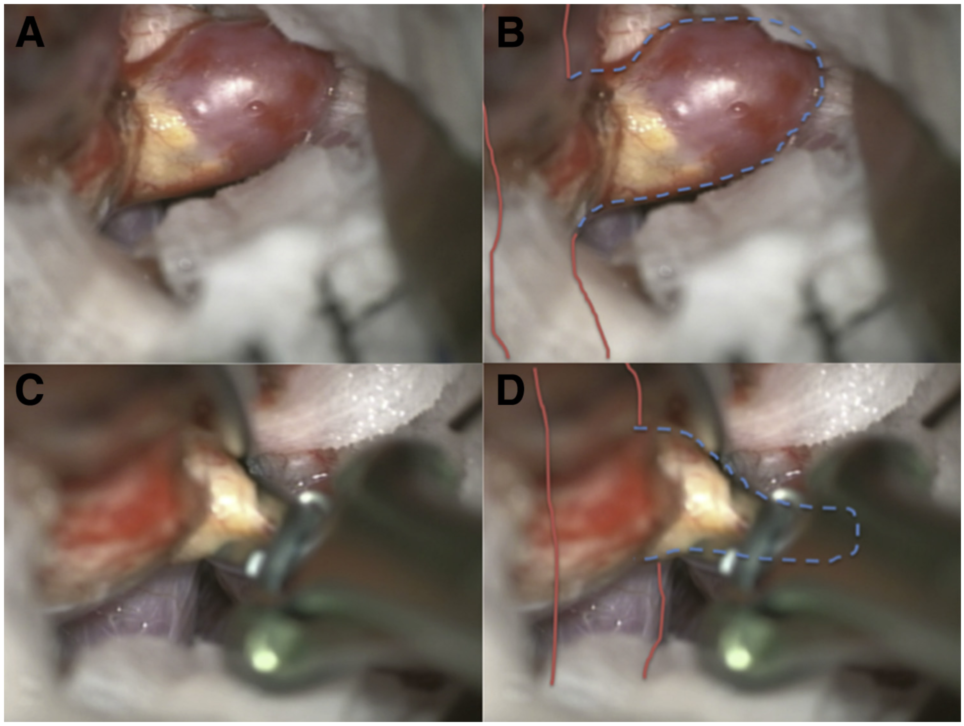

Figure 6. *Case of PCoA aneurysm with atherosclerotic plaque of the neck (A). The clip was placed in the reddish area beyond the neck area, and this technique is called "suitable clipping" (C). Blue dashed line represents the border of the aneurysm sac, and the red bold line represents the parent artery (B and D). Abbreviation: PCoA, posterior communicating artery. (Color version of figure is available online.)*