Feasibility and efficacy of coil embolization for middle cerebral artery aneurysms

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Background: The anatomy of middle cerebral artery (MCA) aneurysms has been noted to be unfavorable for endovascular treatment. The purpose of this study was to assess the feasibility and efficacy of coiling for MCA aneurysms.

Methods: From January 2004 to December 2015, 72 MCA aneurysms (38 unruptured and 34 ruptured) in 67 patients were treated with coils. Treatment-related complications, clinical outcomes, and immediate and follow-up angiographic outcomes were retrospectively analyzed.

Results: Aneurysms were located at the MCA bifurcation (n=60), 1st segment (M1, n=8), and 2nd segment (M2, n=4). Sixty-nine aneurysms (95.8%) were treated by neck remodeling techniques using multi-catheter (n=44), balloon (n=14), stent (n=8), or combination of these (n=3). Only three aneurysms were treated by single-catheter technique. Angiographic results were 66 (91.7%) complete, five (6.9%) remnant neck, and one (1.4%) incomplete occlusion. Procedural complications included aneurysm rupture (n=1), asymptomatic coil migration to the distal vessel (n=1), and acute thromboembolism (n=10) consisting of eight asymptomatic and two symptomatic events. Treatment-related permanent morbidity and mortality rates were 4.5% and 3.0%, respectively. There was no bleeding on clinical follow-up (mean, 29 months; range, 6-108 months). Follow-up angiographic results (mean, 26 months; range, 6-96 months) in patients included one major and three minor recanalizations.

Conclusion: Coiling of MCA aneurysms could be a technically feasible and clinically effective treatment strategy with acceptable angiographic and clinical outcomes. However, the safety and efficacy of this technique as compared to surgical clipping remains to be ascertained.

Keywords: Coil embolization; Intracranial aneurysm; Middle cerebral artery

Introduction

The International Subarachnoid Aneurysm Trial (ISAT) data in 2002 led to a significant change in the treatment of intracranial aneurysms. Although the ISAT study had exclusively addressed ruptured intracranial aneurysms, their results were rapidly assimilated into the treatment of unruptured intracranial aneurysms [1].

However, there is still controversy about the treatment strategy for middle cerebral artery (MCA) aneurysms and surgical clipping is the preferred strategy, because MCA aneurysms are proximal to the cerebral surface and require less brain retraction to access and expose [2-4]. Moreover, endovascular coil embolization was
likely to be unfavorable because MCA aneurysms often have wide
ecks and incorporate branches. Although some recent studies
have demonstrated that endovascular embolization is equivalent
to surgical clipping for the treatment of selected MCA aneurysms,
coiling of wide-necked MCA aneurysm still remains technically
challenging [5-9].

However, newly developed devices and advanced neck-
remodeling techniques using multi-catheter, balloon, stent, or a
combination of these permit endovascular treatment (EVT) of
complex aneurysms [9-12].

The aim of this study was to retrospectively analyze the
feasibility and efficacy of EVT for ruptured and unruptured MCA
aneurysms at a center where coiling is the first option considered.

Materials and methods

From January 2004 to December 2015, EVT was performed on
72 MCA aneurysms in 67 patients. Informed written consent was
obtained from all patients in this retrospective study and approved
by the Institutional Review Board of Kosin University Gospel
Hospital (KUGH 2019-03-009).

Patient and aneurysm characteristics, angiographic and
clinical outcomes, and follow-up were evaluated by the referring
neurosurgeons and an interventional neuroradiologist. Decision
regarding treatment type (clipping versus coiling) was made
by a neurovascular team involving neurosurgeons and an
interventional neuroradiologist after completion of initial
digital subtraction angiography (DSA). In agreement with our
neurovascular team, coiling was the first-line treatment for MCA
aneurysms, unless associated with compressive hematoma
requiring immediate surgical evacuation. An experienced
interventional neuroradiologist determined the possibility of
coil embolization for MCA aneurysms, taking into consideration
their shape, size, length of the neck, and complexity. Wide-neck
aneurysms were defined as having a large neck (more than 4 mm)
or a dome-to-neck ratio less than 1.5. Complex MCA aneurysms
were defined by using particular anatomic features, including
a branch vessel arising from the aneurysm sac and wide neck
aneurysm with parent vessel incorporation.

Inclusion criteria for this study were (1) ruptured MCA
aneurysm, (2) unruptured MCA aneurysm ≥7 mm in size, (3)
unruptured MCA aneurysm <7 mm in size with risk factors
for aneurysm rupture such as previous or family history of
subarachnoid hemorrhage (SAH), presence of lobulation or
daughter sac, increased size on follow-up study, or multiple
intracranial aneurysms, (4) patient criteria including young age,
long life expectancy, and patients’ preferred treatment modality,
or (5) recurred MCA aneurysm after coiling or clipping. The
ruptured patients group was classified according to the Hunt and
Hess grading scale (HHGS) to determine the clinical severity of
the SAH. The modified Rankin scale (mRS) score was used to
assess the clinical results recorded at each patient’s last follow-up
consultation.

1. Endovascular treatment

Antiplatelet premedication was not routinely prescribed in the
early study period. Most patients with unruptured aneurysms
were pre-medicated with dual antiplatelet therapy (aspirin 100
mg, clopidogrel 75 mg once a day) for at least 5 days prior to the
procedure according to the patients’ medical condition. But, we
did not use prophylactic antiplatelet pre-medication for patients
with acutely ruptured aneurysms.

SAH patients were treated within 24 hours after aneurysm
rupture. In all patients with unruptured aneurysm, the therapeutic
procedures were performed during a second angiography
session. Local anesthesia was administered to all of the patients
and electrocardiogram, arterial oxygen saturation, and blood
pressure were appropriately monitored. A percutaneous intra-
arterial approach was used after a standard Seldinger method
and a 6 F introducer sheath was placed in the femoral artery. The
baseline activated clotting time (ACT) was obtained before the
procedure. Then patients received systemic heparinization and a
bolus injection of 3,000 to 5,000 IU heparin just before starting
the therapeutic procedure. A booster of 1,000 IU heparin was
administered every hour to provide an ACT of longer than 250
seconds or twice the baseline ACT during the procedure.

A 6 F guiding catheter (Envoy; Cordis Endovascular, Miami
Lakes, FL, USA) was positioned in the internal carotid artery
(ICA). A 6 F Shuttle sheath was used in patients with tortuous
aortic arch and carotid artery anatomy or in cases in which
complex endovascular techniques were anticipated.

In most cases, coiling was tried first with the conventional
single-catheter technique. When a single-catheter technique failed
to make a stable coil mesh or was not suitable due to aneurysm
geometry, aneurysm neck remodeling techniques using a multi-
catheter, balloon, stent, or a combination of these were used.

Immediate angiographic results were classified according to the
Raymond classification [13]. Complete occlusion was defined
as occlusion of the entire aneurysm sac; neck remnant occlusion,
as the minimal portion of the aneurysm neck region filled with
contrast media; and incomplete occlusion, as the aneurysm dome
filled with contrast media.

Immediate clinical outcome was evaluated according to the mRS
by the neurosurgeons and the interventional neuroradiologist. All

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patients underwent non-enhanced brain computed tomography (CT) for evaluation of possible hemorrhagic complications and were monitored postoperatively at the intensive care unit.

After the procedure, 2,850 IU of low molecular weight heparin (nadroparin) were also administered subcutaneously twice or three times a day for at least 2 days. The patients with stents were medicated dual antiplatelet therapy (aspirin 100 mg, clopidogrel 75 mg once a day) for at least 6 months.

2. Follow-up angiographic and clinical outcomes
Follow-up magnetic resonance angiography or DSA was performed 6 months after the procedure. To compare immediate and last follow-up angiographic results, we defined a three-grade scale using the Raymond classification scale [13] as follows: (1) stable or improved occlusion, (2) minor recanalization demonstrating a change from class 1 to class 2 at follow-up, requiring only additional follow-up imaging, and (3) major recanalization demonstrating a change from class 1 to class 3 or from class 2 to class 3 at follow-up, which required retreatment.

Follow-up clinical outcome was assessed by the neurosurgeons according to the mRS at last follow-up. Patients were classified as having favorable (mRS, 0–2) versus unfavorable outcomes (mRs, 3–6).

Results
Patient and aneurysm characteristics were summarized in Table 1. The 67 patients (40 women and 27 men) ranged in age from 23 to 82 years (mean, 58.8 years). Of the 72 MCA aneurysms, 38 were unruptured in 33 patients and 34 were ruptured in 34 patients. Five patients each had two MCA aneurysms at the opposite side. Of these, one patient presented with SAH. One unruptured aneurysm was a recurred aneurysm after coil embolization. Eight (11.1%) were located in the main trunk of the artery (M1 segment), 60 (83.3%) at the first major bifurcation, and only four at the distal of M2 (5.6%). Aneurysm diameters ranged from 2 to 38.9 mm (mean, 6.8 mm) and aneurysm neck widths from 1 to 11.9 mm (mean, 3.58 mm). HHGS in the ruptured group were grade I in one, grade II in seven, grade III in 14, grade IV in eight, and grade V in four patients.

Three aneurysms were treated by the single-catheter technique. Sixty-nine aneurysms (95.8%) were treated with neck remodeling techniques using multi-catheter (n=44, Fig. 1), balloon (n=14, Fig. 2), stent (n=8, Fig. 3), or combination of these (n=3).

Immediate post-embolization control angiograms revealed complete occlusion in 66, neck remnant occlusion in five, and incomplete occlusion in one aneurysm by the Raymond

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unruptured aneurysm</th>
<th>Ruptured aneurysm</th>
<th>Total</th>
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<tr>
<td>Patients</td>
<td></td>
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<tr>
<td>Number (%)</td>
<td>33 (49.3)</td>
<td>34 (50.7)</td>
<td>67 (100)</td>
</tr>
<tr>
<td>Mean (range) age (yr)</td>
<td>59.8 (23–76)</td>
<td>57.9 (23–82)</td>
<td>58.8 (23–82)</td>
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<tr>
<td>HHGS, n (%)</td>
<td>0</td>
<td>1 (2.9)</td>
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<tr>
<td></td>
<td>1</td>
<td>7 (20.6)</td>
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<tr>
<td></td>
<td>3</td>
<td>14 (41.2)</td>
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</tr>
<tr>
<td>HHGS, Hunt and Hess grading scale; MCA, middle cerebral artery; M1, 1st segment of MCA; M2, 2nd segment of MCA.</td>
<td>8 (23.5)</td>
<td>4 (11.8)</td>
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<tr>
<th>Aneurysms</th>
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<tbody>
<tr>
<td>Number (%)</td>
<td>38 (52.8)</td>
<td>34 (47.2)</td>
<td>72 (100)</td>
</tr>
<tr>
<td>Mean (range) sac size (mm)</td>
<td>5.0 (2–11.5)</td>
<td>8.9 (2–38.9)</td>
<td>6.8 (2–38.9)</td>
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<tr>
<td>Mean (range) neck size (mm)</td>
<td>3.2 (1.5–8)</td>
<td>4.0 (1–11.9)</td>
<td>3.6 (1–11.9)</td>
</tr>
<tr>
<td>Wide neck, n (%)</td>
<td>7 (18.4)</td>
<td>10 (29.4)</td>
<td>17 (23.6)</td>
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<tr>
<td>Complex aneurysm, n (%)</td>
<td>24 (63.1)</td>
<td>16 (47.1)</td>
<td>40 (55.6)</td>
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<tr>
<td>Location</td>
<td></td>
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<tr>
<td>MCA bifurcation</td>
<td>28 (73.7)</td>
<td>32 (94.1)</td>
<td>60 (83.3)</td>
</tr>
<tr>
<td>M1</td>
<td>6 (15.8)</td>
<td>2 (5.9)</td>
<td>8 (11.1)</td>
</tr>
<tr>
<td>M2</td>
<td>4 (10.5)</td>
<td></td>
<td>4 (5.6)</td>
</tr>
</tbody>
</table>
classification. In the 38 unruptured aneurysm patients, 37 aneurysms (97.4%) demonstrated complete occlusion and only one patient (2.6%) revealed residual neck. In contrast, the group of ruptured patients showed complete occlusion in 29 (85.3%), neck remnant in four (11.8%), and incomplete occlusion in one patient (2.9%).

Procedural complications occurred in 12 (16.7%) of 72 aneurysms. Six of 38 unruptured aneurysms experienced complications, including procedural aneurysm rupture (n=1) and acute thromboembolism without neurological deterioration (n=5). Two of five acute thromboembolic patients experienced symptomatic acute stroke at 6 and 10 days after treatment. Six of 34 ruptured aneurysm patients experienced complications, including asymptomatic coil migration to the distal vessel (n=1) and acute thromboembolism (n=5) which consisted of three asymptomatic embolic infarctions and two symptomatic acute strokes.

One unruptured wide-necked aneurysm (5 mm in diameter) was ruptured during stent-assisted coil embolization. The M2 branch was occluded after temporary balloon occlusion of the distal M1 and additional coil embolization for bleeding control. The final angiogram revealed nearly complete occlusion of the aneurysm sac and no flow compromise. This patient had severe

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**Fig. 1.** A 43-year-old man presented with a subarachnoid hemorrhage. (A) Anteroposterior oblique view of left internal carotid angiogram shows a wide-necked aneurysm (arrow) at the right middle cerebral artery bifurcation. (B) The aneurysm is treated with two catheter technique (arrowhead). (C) Final control angiogram reveals complete occlusion of the aneurysm (arrow) without flow compromise of the parent artery. (D) Eighteen-month follow-up angiogram shows stable, complete occlusion of the aneurysm (arrow).
Fig. 2. A 73-year-old woman with a ruptured aneurysm at the left middle cerebral artery bifurcation. (A) Anteroposterior oblique view of left internal carotid angiogram shows an elongated aneurysm (arrow). (B) The aneurysm is treated with balloon-assisted technique (arrow) due to coil protrusion into the parent artery at coil insertion into the neck portion. Immediate post-procedural radiograph (C) and angiogram (D) reveal complete occlusion of the aneurysm (arrow) without coil protrusion into parent artery. Follow-up 18-month angiogram (E) and 41-month magnetic resonance angiogram (F) show stable, complete occlusion of the aneurysm (arrow).
Fig. 3. A 52-year-old man presented with severe headache. (A) Non-enhanced brain computed tomography reveals subarachnoid hemorrhage at the left Sylvian fissure. (B) Anteroposterior oblique view of left internal carotid angiogram shows a wide-necked aneurysm (arrow) at the left middle cerebral artery bifurcation and moderate to severe vasospasm of the anterior and middle cerebral arteries (arrowheads). (C) Prior to coil embolization, angioplasty using a compliant balloon (arrow) is performed to resolve vasospasm. The aneurysm is treated with a stent-assisted technique (arrows) and immediate post-procedural radiograph (D) and angiogram (E) reveal complete occlusion of the aneurysm (arrow) and restoration of vasospasm (arrowheads). (F) A 6-month follow-up angiogram after the procedure demonstrates stable complete occlusion of the aneurysm (arrow) and well-preserved parent artery.
neurological deficits after embolization and SAH revealed on post-procedural CT. A follow-up CT the next day revealed SAH and severe brain swelling due to cerebral infarction requiring decompressive craniectomy. This patient experienced progressive infarction with hemorrhagic transformation and eventually died after 7 days.

Procedural coil migration occurred in one patient with a tiny ruptured aneurysm (2 mm in diameter) during a balloon-assisted embolization. The detached coil migrated into the distal M2 branch and on post-procedural angiogram, thrombotic occlusion was seen. After intra-arterial administration of a glycoprotein IIb/IIIa inhibitor (abciximab), acute thrombosis was lysed and the distal MCA flow was improved. At the immediate post-procedural neurological examination, patients did not show neurological differences compared to before the procedure; long-term follow-up DSA showed no flow compromise at the coil migrated distal MCA branch.

Acute thromboembolic complications occurred in five unruptured and five ruptured aneurysms in 10 patients. After intra-arterial administration of a glycoprotein IIb/IIIa inhibitor, acute thromboembolism was completely lysed in nine patients, except for one patient with a ruptured aneurysm. One patient without recanalization after a glycoprotein IIb/IIIa inhibitor injection experienced major cerebral infarction and deterioration of consciousness level after the procedure and finally expired after 3 weeks. One patient with a ruptured aneurysm and recanalization after a glycoprotein IIb/IIIa inhibitor injection presented with progressive infarction within a day and was discharged at mRS2. Two of five acute thromboembolic patients with unruptured aneurysm presented with symptomatic acute stroke at 6 and 10 days after treatment even though no neurological deterioration was revealed on immediate post-procedural neurologic examination. The patients were discharged without neurologic deficit. But, the patients visited the emergency room for acute stroke and were discharged at mRS 1 and 4.

The rate of early post-procedural morbidity and mortality was 6.1% and 3.0% for unruptured aneurysms compared to 2.9% and 2.9% for ruptured aneurysms. As a result, over-all procedure-related permanent morbidity and mortality rates were 4.5% and 3.0% for unruptured and ruptured aneurysms, respectively. These data are summarized in Table 2.

In the final clinical grading of 33 unruptured aneurysm patients,

| Table 2. Endovascular treatment, complications, and angiographic and clinical outcomes |
|-------------------------------------------------|-----------------|-----------------|-----------------|
| Treatment methods, n (%)                        | Unruptured      | Ruptured        | Total           |
| Single catheter                                 | 1 (2.6)         | 2 (5.9)         | 3 (4.2)         |
| Multicatheter                                   | 23 (60.5)       | 21 (61.8)       | 44 (61.1)       |
| Balloon-assisted                                | 8 (21.1)        | 6 (17.6)        | 14 (19.4)       |
| Stent-assisted                                  | 4 (10.5)        | 4 (11.8)        | 8 (11.1)        |
| Combined                                        | 2 (5.3)         | 1 (2.9)         | 3 (4.2)         |
| Procedure-related complications, n (%)          |                 |                 |                 |
| Coil migration                                  |                 | 1 (2.9)         | 1 (1.4)         |
| Thromboembolism                                 | 5 (13.5)        | 5 (14.3)        | 10 (13.9)       |
| Recanalization with Reopro                      | 5 (100)         | 4 (80)          | 9 (90)          |
| Aneurysm rupture                                | 1 (2.7)         |                 | 1 (1.4)         |
| Procedure-related permanent morbidity (%)      | 6.1             | 2.9             | 4.5             |
| Procedure-related permanent mortality (%)      | 3               | 2.9             | 3               |

Clinical outcomes, n (%)                          |
Favorable (mRS, 0–2)                              | 32 (97.0)       | 20 (58.8)       | 52 (77.6)       |
Unfavorable (mRS, 3–6)                            | 1 (3.0)         | 14 (41.2)       | 15 (22.4)       |

Immediate angiographic results, n (%)             |
Complete                                         | 37 (97.4)       | 29 (85.3)       | 66 (91.7)       |
Neck remnant                                     | 1 (2.6)         | 4 (11.8)        | 5 (6.9)         |
Incomplete                                       | 1 (2.9)         |                 | 1 (1.4)         |

Follow-up angiographic results, n (%)             |
Stable or improved                               | 18 (90.0)       | 10 (83.3)       | 28 (87.5)       |
Major recanalization                             | 1 (5.0)         | 1 (3.1)         |                 |
Minor recanalization                             | 1 (5.0)         | 2 (16.7)        | 3 (9.4)         |

mRS, modified Rankin scale.
two symptomatic acute stroke patients were discharged at mRS 1 and 4 respectively. One patient improved to mRS 3. None of the surviving patients had any deterioration of functional neurological outcomes (mRS, 0-2).

Thirty-four patients with ruptured aneurysm were discharged with mRS 0 in seven patients, mRS 1 in 10 patients, mRS 2 in three patients, mRS 3 in two patients, mRS 4 in one patient, mRS 5 in four patients, and mRS 6 in seven patients. Therefore, there were 20 patients in the favorable outcome group (mRS, 0–2) and 14 patients in the unfavorable outcome group (mRS, 3–6). Seven patients were hospitalized with HHGS IV or V and severe cerebral hemorrhage at the time of visit. They were mostly elderly and expired with severe cerebral hemorrhage and other systemic complications including pneumonia and multiple organ damage.

Clinical follow-up was available only in 12 of 34 ruptured patients because 22 patients were transferred to another hospital, died or outpatient visits were impossible. Thirty-two aneurysms in 31 of the 45 patients who could visit as outpatients at least once at 6 to 24 months (mean, 26 months; range, 6-96 months) received follow-up angiography. Follow-up angiographic results revealed 1 major and 3 minor recanalizations. One major recanalization aneurysm was re-treated by coiling with no complications.

**Discussion**

Ausman was the first neurosurgeon to advocate EVT of cerebral aneurysms as a first option treatment in 1997. In his experience, 50% of aneurysms were suitable for EVT [14]. Unlike coiling of other cerebral aneurysm locations, the success rate of MCA clipping was initially low at the beginning. In 1999, Regli et al. [2] reported on a consecutive series of 30 patients with 34 unruptured MCA aneurysms. Of the 34 aneurysms evaluated, only two (6%) were successfully obliterated with endovascular coil embolization. In 32% of the cases, EVT was attempted but abandoned, and in the remaining 62%, surgery was considered the best therapeutic choice. In this series, 94% of the unruptured MCA aneurysms were treated with surgical clipping. Until recently, EVT for MCA aneurysms showed a higher procedural failure rate and inconsistent results compared with EVT application to aneurysms at other sites [2,6-8,15,16].

MCA aneurysms have been traditionally considered not ideal for coiling because of their unfavorable anatomic features, including a wide neck and partial incorporation of one or both M2 branches [17]. Although the ISAT and some reports [18,19] have confirmed that EVT was equal or superior to clipping for all aneurysms regardless of their location, the treatment of MCA aneurysms, which accounted for 14% of aneurysms, is still controversial [20]. Recently, with the development of interventional devices and technologies, various neck remodeling endovascular techniques have attempted to treat MCA aneurysms with complex morphologic features. Even if EVT technology has advanced recently, neurovascular surgeons still seem to prefer clipping to coiling for MCA aneurysms. Suzuki et al. [15] reported a consecutive series of 115 patients with MCA aneurysms in which only 40% of patients were treated with coiling. Similarly, another recent study of 152 MCA aneurysms reported that 32.6% of the MCA aneurysms were either not considered for EVT or sent to surgery after EVT was attempted [16].

However, the selection rate for EVT of MCA aneurysms did not appear to be due to the difficulty of treating aneurysms via this technique. It seems that the difference is between medical institutions that consider MCA aneurysm embolization to be the first treatment modality and institutions that still believe surgery is the predominant treatment modality for MCA aneurysms. For example, there are some centers where embolization is the first treatment option considered [7,10]. In contrast, some institutions have applied very stringent criteria to select MCA aneurysm patients who will be treated with EVT. Raftopoulos et al. [4] chose EVT only when the ratio of neck to sac was less than 1:3. Our neurovascular team considered EVT as the first treatment modality for MCA aneurysms. Although almost all MCA aneurysms (95.8%) were treated with neck remodeling techniques, the technical success rate of EVT was 100% in this study. EVT for MCA aneurysms could be a technically feasible treatment strategy.

One major concern about EVT for MCA aneurysms is procedure-related complications. Choi et al. [21] compared the outcomes of clipping and coiling and evaluated the benefits of clipping for 178 ruptured and unruptured MCA aneurysms. Inclusion criteria for coiling were very strict and only 25 of 178 MCA aneurysms were treated by coiling. In their study, a multidisciplinary neurovascular team decided the treatment strategy (observation, clip, or coil) after discussion. If they expected there would be no definite benefits between the two treatment options (clip or coil) in terms of patient outcome and perioperative complications, they primarily chose microsurgical clipping. EVTs were considered in some selected cases that lacked complexity such as a relatively small neck (≤4 mm), large dome-to-neck ratio (>1.5), no incorporated branches in angiographic findings, clinically ruptured aneurysms with a high Hunt-Hess grade and/or use of medications such as warfarin. In the surgical group, perioperative complications occurred in 17 patients (11.1%). However, in the strictly selected EVT group, eight patients (32%) experienced procedural complications (25% in the
ruptured group and 35% in the unruptured group). Therefore, the complication rate for MCA embolization may seem to be high. However, most of the complications included five asymptomatic embolic infarctions observed on diffusion magnetic resonance (MR) imaging and one asymptomatic intraprocedural aneurysm rupture. Furthermore, there were no cases of procedure-related morbidity and mortality in the EVT group. Their results suggested that EVT for MCA aneurysms in selected patients can be effectively performed but the complication rate is not negligible.

Generally, complications during EVT were stratified into three groups: (1) thromboembolic complications, (2) parent artery occlusion, and (3) aneurysm perforation [22]. But, it is not easy to analyze EVT complications compared to the complications of surgery. Because complications were determined by the neurointerventionalist who performed the procedure, there are many other factors that can or cannot be classified as complications.

The first reason is that EVT cases have not been analyzed yet and there are not enough to compare to clipping cases. The next reason is that the definition of EVT complications is vague and unclear. In the case of asymptomatic embolic infarction, institutions which perform MR diffusion after the procedure report it as a complication. But, it is not a complication at institutions that do not perform MR diffusion after the procedure.

In addition, aneurysm rupture during clipping is not classified as a complication. This is probably because most of them are controllable in the surgical field and do not cause other serious symptoms. Unlike clipping, aneurysm ruptures during embolization may cause serious symptoms and may lead to death or disability. However, many cases of intraprocedural rupture can be treated asymptotically. Therefore, it is unclear if asymptomatic rupture should be classified as a complication.

Most of the complications in this study were thromboembolism. We thought at first this was related to antiplatelet premedication. Thromboembolic complications occurred mainly in patients who did not receive premedication. In the early days of attempting unruptured MCA coiling, premedication was not administrated.

The second cause of thromboembolism was related to selection criteria and the endovascular technique. We performed EVT as a first treatment for MCA aneurysms regardless of their morphological complexity. Most cases (95.8%) could by treated by neck-remodeling techniques using multiple catheters, balloon, or stent. These complex procedures using multiple intravascular devices were known to be a cause of thromboembolic complications [23].

Lastly, we performed the procedure with the goal of complete occlusion. Therefore, immediate angiographic outcomes revealed complete occlusion in 66 cases (91.7%) by the Raymond classification. Trying complete occlusion of an aneurysm may be likely to increase the incidence of thromboembolic complications during the procedure. Quadros et al. [7] prioritized prevention of thromboembolic complications during MCA aneurysm coiling. They did not treat with a complex, neck-remodeling technique in many cases and left the neck portion of the aneurysms to reduce the rate of thromboembolic complications.

Fortunately, thromboembolism could be prevented or resolved with administration of antiplatelet premedication or glycoprotein IIb/IIIa inhibitors. In this study, thromboembolism occurred in 10 patients. Although two patients experienced immediate post-procedural symptomatic ischemic events, procedural thromboembolism was completely lysed with intra-arterial administration of glycoprotein IIb/IIIa inhibitor. Therefore, like intraprocedural aneurysm rupture, it is unclear that the asymptomatic procedural thromboembolism should be classified as a complication.

Another major concern is the recurrence rate after coiling for MCA aneurysms [7]. Immediate angiographic complete occlusion was known to an important factor for decreasing recurrence rate after coiling [24]. Brinjikji at al. [22] reported in a review article of 12 series that post-operative complete occlusion was 82.4% and follow-up results of 758 aneurysms demonstrated that 70 (9.3%) had a minor recurrence not requiring re-treatment and 73 (9.6%) had major recanalization requiring retreatment. Overall angiographic stability or progression to better obliteration was reported in 81% of patients undergoing follow-up angiography. However, in our series, immediate angiographic outcomes were 91.7% complete occlusion; only one major recanalization (3.1%) was detected on follow-up angiography. We thought that this follow-up angiographic outcome might be related to complete occlusion immediately after the procedure.

There are some limitations in this study. First, this is a retrospective study and included a small number of MCA aneurysm cases at only one institution. Second is patient selection bias. As mentioned above, EVT is a first treatment option for MCA aneurysms in this study regardless of aneurysm morphological complexity. Considering improved operator experience and devices, our result may not represent the general situation of MCA coiling in this era because our cases were collected over 10 years.

Coil embolization of MCA aneurysms could be a technically feasible and clinically effective treatment strategy with acceptable angiographic and clinical outcomes. In the future, increased operator experience, improved new devices, and various neck-
remodeling techniques might greatly increase the feasibility and efficacy of MCA aneurysm coiling. However, the safety and efficacy of this technique as compared to surgical clipping remains to be determined.

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Conflicts of interest

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

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