Master's Thesis of Chang Hwan Pang

Clipping versus coil embolization of unruptured middle cerebral artery aneurysm
– A single–center retrospective study involving 1366 patients over 16 years –

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Abstract

Clipping versus coil embolization of unruptured middle cerebral artery aneurysm: A single−center retrospective study involving 1366 patients over 16 years

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Abstract

Objective Even though the safety of coil embolization has been established, many institutions still prioritize surgical clipping as the primary treatment for unruptured middle cerebral artery (MCA) aneurysms. In this study, the authors conducted an analysis of the outcomes of both clipping and coiling in the context of unruptured MCA aneurysms.

Methods This study included a total of 1366 patients with 1495 unruptured middle cerebral artery aneurysms who underwent either clipping or coil embolization between January 2003 and June 2019. The medical and angiographic data were retrospectively reviewed.

Results There were 753 patients in the clip group and 676 in the coil group. The overall postoperative complication rate was 5.5% in the clip group and 3.1% in the coil group. The postoperative stroke rate was 4.1% in the clip group and 2.8% in the coil group. Major neurologic deterioration was observed in 16 (1.2%) patients, and the risk factor was the aneurysm maximum diameter (OR: 1.221, 95% CI, 1.125 to 1.325, $p < 0.001$). The retreatment rate was higher in the coil group (3.1%) than in the clip group (1.3%) ($p = 0.022$). In the clip group, a history of cerebral infarction (OR: 2.942, 95%CI 1.083 to 7.986, $p=0.034$), familial stroke history (OR: 2.155, 95% CI 1.077 to 4.312, p= 0.031) and simultaneous treatment of the MCA and other aneurysm location (OR: 4.031, 95% CI 1.777 to 9.143, p< 0.001) were identified as risk factors for postoperative complications. Early temporal branch (OR: 0.106, 95% CI 0.015 to 0.731, p= 0.023) and MCAB location (OR: 0.223, 95% CI 0.057 to 0.867, p= 0.030) were found to be protective factors. The complication rate was lower in the keyhole group (1.8%) than in the pterional group (5.4%), but the difference was not statistically significant (p= 0.057). In the coil group, the aneurysm maximum diameter was a risk factor for postoperative complications with statistical marginal significance (OR: 1.124, 95% CI, 0.998 to 1.267, p= 0.054) and for recurrence with statistical significance (OR: 1.660, 95% CI, 1.425 to 1.934). Age (OR: 0.947, 95% CI, 0.908 to 0.988, p= 0.011) and stent-assisted coiling (OR: 0.196, 95% CI, 0.056 to 0.684, p= 0.011) were protective factors for recurrence. Stent-assisted coiling did not increase the complication rate.

Conclusions For unruptured MCA aneurysm treatment, clipping was associated with a slightly higher complication rate than coiling. However there were no significant differences observed in terms of postoperative stroke rate or functional outcome between the two treatment methods. Large aneurysm size was associated with poor neurologic outcome. The rate of retreatment was higher in the coil group. It is important to conduct thorough medical and family history assessments, particularly in cases of clipping. Routine follow-up is recommended after clipping and coiling. Clipping may be a suitable recommendation for aneurysms located in the early temporal branch or middle cerebral artery bifurcation. The keyhole approach had similar or better outcomes compared with the pterional approach. The use of stents in coiling is safe and useful.

Keyword : Clipping, coil embolization, cerebral aneurysm, unruptured middle cerebral artery aneurysm
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Chapter 1. Introduction

1.1. Study Background

Intracranial aneurysm is a disease characterized by the abnormal swelling of the vascular wall, resulting from structural abnormalities such as the loss of the internal elastic lamina of the cerebral artery and rupture of the tunica media.[1] It is estimated that intracranial saccular aneurysm presents in 1 to 2% of the general population,[2] and the rupture rate of unruptured intracranial aneurysm is reported to be 0.9/100 person-year[3]. In a Korean population study, the incidence of intracranial aneurysm was 52.2 per 100,000 person-years.[4] Representative treatments for intracranial aneurysms include coiling and clipping. The field of endovascular treatment has been advancing with the introduction of techniques such as stent-assisted coil embolization, the use of flow diverters, and the development of devices like the Woven EndoBridge(WEB). The International Subarachnoid Aneurysm Trial (ISAT)[5], a prospective, multicenter, and randomized controlled study, demonstrated the efficacy and stability of coil embolization, even in cases of aneurysmal subarachnoid hemorrhage (SAH). Despite the stability and advancements in endovascular treatment for intracranial aneurysms, it is important to acknowledge that many institutions[6-11] still favor aneurysm clipping as the preferred treatment for unruptured middle cerebral artery aneurysms (MCAAs). One factor is the relative proximity of the surgical approach to the skull for MCAAs making clipping a more accessible option. Additionally, the broad neck[12] or saccular shape[13] commonly observed in MCAAs may make clipping a more suitable choice. A previous study[6] also reported higher rates of aneurysm occlusion and a lower incidences of complications with MCAA clipping.

1.2. Purpose of Research

However, there are a limited number of studies available that provide extensive data and long-term follow-up results comparing clipping and coiling for unruptured MCAAs. Therefore, in this study, we aimed to compare the outcomes of clipping and coiling for unruptured MCAAs within a single-center setting with a relatively large sample size.

Chapter 2. Body

2.1. Materials and Methods

Patient Selection

With the approval of the institutional review board of Seoul National University Hospital, we conducted a retrospective review of medical data from patients diagnosed with unruptured MCAAs between January 2003 and June 2019. The data were obtained from a single institute namely Seoul National University Hospital. The inclusion criteria for this study were as follows: 1) unruptured MCAA, 2) age $\geq$ 20 years, and 3) undergoing initial treatment for an unruptured MCAA. Patients with a history of prior treatment for MCAAs, an MCAA located above the M2 level, or ruptured aneurysms were excluded from this study. Additionally, secondary aneurysms such as traumatic or inflammatory aneurysms were excluded. Patients who received treatment other than clipping or coiling, such as clipping and bypass, trapping and bypass or endovascular treatment using a flow diverter were not included. Initially, a total of 1,605 patients were identified in the database. To ensure comparability between the clip and coil groups, all patients were matched based on sex and age, with $\pm$2 years, using the greedy method.

Clinical and radiological evaluation

Several medical conditions were considered and evaluated. These included age, sex, hypertension (HTN), diabetes mellitus (DM), hyperlipidemia (HL), heart disease, thyroid disease, autosomal dominant polycystic kidney disease (ADPKD), prehospital antiplatelet use (referring to the use of antiplatelet medication 7 days before the surgery), cerebral hemorrhage history, cerebral infarction history, familial stroke history and smoking. The functional statuses of patients were assessed using the Karnofsky performance scale (KPS) score, both before the surgery and at the last follow-up.

Preoperative digital subtraction angiography(DSA) was conducted to evaluate the maximum diameter and location of the aneurysms. The MCA aneurysm locations were classified into four groups: lenticulostriate artery (LSA), early frontal branch (EFB), early temporal branch (ETB), MCA bifurcation (MCAB) and M2 aneurysm, according to the classification proposed by ULM et al.[14] The aneurysms were further classified based on size into small (<5mm), medium (5-10 mm), large (10-25 mm), and giant (>25 mm) categories, as defined by the size criteria.[15]

Since 2011, our institution has implemented intraoperative monitoring (IOM) as a standard practice for all cases involving the clipping of unruptured aneurysms. The clipping was categorized based on the approach used, namely the pterional approach or the keyhole approach. The keyhole approach includes techniques such as superciliary supraorbital, frontolateral, and lateral supraorbital craniotomy and mini-pterional keyhole craniotomy, according to our previous study[16].

According to the Raymond-Roy classification, aneurysms were divided into Class 1, Class 2, Class 3a, and Class 3b. The degree of final occlusion was evaluated and categorized as stable occlusion (no interval change since the procedure or progressive thrombosis within the aneurysm) minor recanalization (progressive filling limited to the neck of the aneurysms) and major recanalization (aneurysm sac filling) based on the last follow-up magnetic resonance angiography (MRA) or DSA. The last follow-up image used for assessment was either the most recent imaging during patient follow-up or the image taken prior to any retreatment, if applicable.

Postoperative follow-up protocols

Prior to treatment, all patients underwent DSA, and a follow-up DSA was only performed if retreatment was deemed necessary. After surgical clipping, the need for postoperative follow-up varied depending on the extent of clip completeness. If deemed necessary, brain computed tomography angiography (CTA) was performed at 6-month and 2-year intervals. However, for patients who underwent coiling, regular MRA follow-up was conducted at 6, 18 and 36 months. If stable occlusion was confirmed, further follow-up was not needed. However, in cases of minor or major recanalization, follow-up assessments were conducted at 24-month intervals.

Definition of complications

In this study, the term “complication” was defined to include factors such as surgical site infection, thromboembolism, postoperative symptomatic cerebral infarction, postoperative intra-axial hemorrhage, and postoperative extra-axial hemorrhage that required only additional surgical intervention. The assessment of these complications was performed within the 30-day postoperative period. However, any complications that occurred between 1 and 6 months after surgery were separately documented and described. Major neurologic deterioration was defined as a significant decrease of 30 or more points in the KPS score following aneurysm treatment.

Statistical analysis

Continuous variables are presented as mean ± standard deviation (ranges) and categorical data are expressed as frequencies and percentages. Statistical analysis was performed using student's t test for continuous variables while χ^2 or Fisher' s exact tests were used for categorical variables. Logistic regression analysis was used to identify the causative variables of postoperative complications in the both clip group and coil group. Multivariable analysis was performed using the backward elimination method by including all the factors of the univariable analysis. Data are reported as ORs, 95% CIs, and two-sided p values. A value of $p < 0.05$ was considered significant. All data were analyzed using the Statistical Package for the Social Sciences (SPSS, version 20, IBM, Armonk, New York, USA).

2.2. Results

2.2.1. Clipping vs. coiling

2.2.1.1. Clipping vs. Coiling

A total of 1366 patients with 1495 MCA aneurysms were finally analyzed, and the exclusion flow chart is presented in Figure 1. There were 690 patients with 753 MCA aneurysms in the clip group and 676 patients with 742 MCA aneurysms in the coil group.

Baseline characteristics are described in Table 1. The mean follow-up duration was 35.4 ± 32.5 months (0-190 months). Specifically, that of the clip group was 27.4 ± 31.9 months (0-190 months), and that of the coil group was 43.7 ± 31.0 months (0-179 months) ($p < 0.001$).

There were no significant differences in terms of mean age, sex distribution, underlying disease, or performance scores before and after surgery between the groups. The use of prehospital antiplatelet medication was significantly higher in the coil group, with 226 patients (33.4%), than in the clip group, 148 (21.4%) ($p < 0.001$). The mean size of the aneurysm was significantly larger in the clip group (clip group, 5.4 ± 5.3, coil group, 4.7 ± 2.2; $p = 0.002$). In terms of the location of MCA aneurysms, MCA bifurcation was the most frequently treated lesion in both groups. However, the clip group had a higher proportion of MCA bifurcation, while the coil group had a higher proportion of LSA and EFB aneurysms ($p < 0.001$).

2.2.1.2. Complications and poor neurologic outcome after treatment

The overall postoperative complication rate was 4.3%, 5.5% in the clip group and 3.1% in the coil group ($p = 0.033$). Complicationd between 1-6 months were more in the clip group with statistically marginal significance (clip group: 1.7%, coil group 1.5%; $p = 0.831$). However, major neurologic deterioration was lower in both groups and there were no statistically significant differences (clip group: 1.6%, coil group: 1.4%, $p = 1.000$). Extra-axial hemorrhage was exclusively observed in the clip group, with a total of 18 patients (2.6%). The incidence of postoperative rupture was higher in the clip group, although the difference was not statistically significant (clip group: 5, 0.7%, coil group 1, 0.1%; p= 0.218). Postoperative retreatment was significantly more in the coil group (clip group 1.3%, coil group 3.1%; p= 0.022). The number of treatment cases and complication rate by year for each treatment are described in Figure 2.

2.2.1.3. Risk factors for complications in all patients

Univariable and multivariable analyses were conducted to identify potential risk factors in all patients. The results are summarized in Table 2. In the univariable analysis, clipping (OR: 2.464, 95% CI 1.364 to 4.449, p= 0.003) and simultaneous treatment for MCA aneurysms at other locations (OR: 6.433, 95% CI 2.191 to 18.891, p= 0.001) were risk factors for complications. On the other hand, smoking (OR: 0.309, 95% CI 0.115 to 0.827, p= 0.019), aneurysm with an ETB location (OR: 0.155, 95% CI 0.034 to 0.710, p= 0.016) and aneurysm with an MCAB location (OR: 0.290, 95% CI 0.101 to 0.836, p= 0.022) were identified as significant protective factors against complications. In the multivariable analysis, clipping (OR: 2.512, 95% CI 1.405 to 4.493, p= 0.002) and simultaneous treatment for MCA and aneurysms at other locations (OR: 6.322, 95% CI 2.213 to 18.056, p= 0.001) were risk factors for complications. Aneurysms with an ETB location (OR: 0.157, 95% CI 0.035 to 0.696, p= 0.015) and aneurysms with an MCAB location (OR: 0.304, 95% CI 0.110 to 0.844, p= 0.022) were identified as significant protective factors against complications.

2.2.1.4. Risk factors for major neurologic deterioration in all patients

Major neurologic deterioration occurred in 16 (1.2%) patients. The results are summarized in Table 3. Univariable analysis revealed that the aneurysm maximum diameter was significantly associated with a higher risk of major neurologic deterioration (OR: 1.240, 95% CI, 1.119 to 1.376, $p < 0.001$). Patients with MCAB aneurysms showed a decreased risk of major neurologic deterioration with statistical marginal significance (OR: 0.174, 95% CI, 0.029 to 1.042, $p = 0.056$). In multivariable analysis, the aneurysm maximum diameter remained a significant risk factor (OR: 1.221, 95% CI, 1.125 to 1.325, $p < 0.001$).

2.2.1.5. Rupture after treatments

Among all patients, 6 (0.4%) aneurysms ruptured after treatment, and the details are described in Table 4. Specifically, 5 (0.7%) aneurysms ruptured after clipping, and 1 (0.1%) aneurysm ruptured after coiling. The average age of the patients who experienced rupture after treatment was 45.5 ± 13.7 years (32 to 65 years), which was lower than the overall average age observed in the study population of 59.4 ± 8.8. The mean diameter of the ruptured aneurysm was 14.7 ± 9.8 mm (3.0 to 30.9 mm), which was larger than that of the overall aneurysm size of 5.1 ± 4.1 mm. For patients who underwent coiling, rupture occurred on the day after the procedure. On the other hand, for patients who underwent clipping, rupture occurred at different time intervals. One patient experienced a rupture 8 days after clipping, while the remaining patients experienced ruptures 2, 3, 4, and 7 years after the procedure. The clinical outcome following rupture was generally poor. Out of the 6 patients who experienced rupture, 2 patients died, 1 patient entered a vegetative state, and 1 patient suffered from severe disability. Only 2 of 6 patients achieved favorable outcomes after rupture. The cases of patients 3, 5, and 6 in Table 5 are described in Figures 3, 4, and 5, respectively.

2.2.1.6. Clip vs. coil for MCA-only lesions

A total of 1124 patients with 1222 MCA aneurysms were analyzed. Table 5 provides a detailed description of the treated MCA location only. There were 625 patients with 673 aneurysms in the clip group and 498 with 549 aneurysms in the coil group. The mean follow-up duration was 27.8 ± 32.4 months (0-190 months), 27.8 ± 32.4 months (0-190 months) for the clip group, and 41.8 ± 30.1 months (0-158 months) for the coil group ($p < 0.001$). In the clip group, the aneurysm size was larger (clip group: 5.2 ± 2.9 mm, coil group: 4.8 ± 2.3 mm, $p = 0.008$) and more frequently located in the MCAB ($p < 0.001$). In the coil group, the LSA location (clip group: 19 aneurysms, 2.8%, coil group 32 aneurysms, 5.8%) and the EFB location (clip group: 142 aneurysms with 21.1%, coil group 160 aneurysms with 29.1%) were more common than in the clip group. The postoperative complication rate was higher in the clip group (clip group: 4.5%, coil group: 2.8%) but different from the entire patient cohort, which was not statistically significant ($p = 0.156$). Major neurologic deficits were more common in the clip group; however, this was not statistically significant (clip group: 1.4%, coil group: 0.6%, $p = 0.564$). Extra-axial hemorrhage was observed only in the clip group in 13 patients (2.1%). Retreatment was more common in the coil group (clip group: 1.2%, Coil group: 2.9%, $p = 0.038$).

2.2.2. Clipping

2.2.2.1. *Risk factors for complications in unruptured MCAA clipping*

Univariable and multivariable analyses were performed to identify risk factors for postoperative complications after clipping of unruptured MCAA and are described in Table 6. In the univariable analysis, MCA aneurysms in the ETB location (OR: 0.104, 95% CI 0.014 to 0.759, p= 0.026) and MCAB location (OR: 0.183, 95% CI 0.043 to 0.775, p= 0.021) were identified as significant protective factors against complications. In the multivariable analysis, a history of cerebral infarction (OR: 2.942, 95% CI 1.083 to 7.986, p= 0.034), familial stroke history (OR: 2.155, 95% CI 1.077 to 4.312, p= 0.030) and simultaneous treatment of MCA and aneurysms at other locations (OR: 4.031, 95% CI 1.777 to 9.143, p= 0.001) were identified as potential risk factors for complications. MCAAs with an ETB (OR: 0.106, 95% CI 0.015 to 0.731, p= 0.023) and MCAB (OR: 0.223, 95% CI 0.057 to 0.867, p= 0.030) location were identified as protective factors against complications.

2.2.2.2. *Clipping before and after IOM*

The results before and after IOM were analyzed among 625 patients with 673 aneurysms treated with clipping only for the MCA aneurysm locations, and the details are described in Table 7. The mean follow up duration of clipping before IOM was 51.7 ± 48.4 (0–190 months), and that after IOM was 20.1 ± 20.0 months (0–97 months) (p< 0.001). In the group before IOM, the number of single MCAAs was higher (p=0.005). Hypertension, thyroid disease, prehospital antiplatelet medication use and history of cerebral infarction were more common in the group before IOM.

Hyperlipidemia and familial stroke history was more in the group after IOM. The initial and last KPS scores were higher in the group after IOM. The postoperative complication rate was not significantly different before and after IOM (group before IOM: 5.9%, group after IOM: 4.0%, p= 0.367). Major neurologic deficits were more common in the before IOM; however, there was no significant difference (group before IOM: 2.0%, group after IOM: 1.1%, p= 0.410). Intra-axial hemorrhage was more common in the group before IOM than in the group after IOM, but the difference was not statistically significant (group before IOM: 2, 1.3%, group after IOM: 2, 0.4%, p= 0.078). However, complications at 1-6 months after surgery were more common in the group before IOM (group before IOM: 3.9%, group after IOM: 0.6%, p= 0.008).

2.2.2.3. *Pterional approach vs. keyhole surgery*

Among 465 patients with MCA aneurysm after IOM, 262 patients treated with the pterional approach and 203 patients treated with keyhole surgery were compared, and the details are desbribed in Table 8. The mean follow-up duration was 21.8 ± 21.7 months (0-97 months) in the pterional group and 18.2 ± 17.7 months (0-74 months) in the keyhole group (p= 0.047). In the keyhole group, patients were older (pterional group: 58.3 ± 8.4, keyhole group: 60.8 ± 8.5, p= 0.002), and more patients had a history of cerebral hemorrhage (pterional group: 2.3%, keyhole group: 5.9%, p= 0.045), a lower initial KPS score (pterional group: 99.0 ± 4.5, keyhole group: 96.5 ± 9.4, p< 0.001) and lower last KPS score (pterional group: 98.7 ± 6.9, keyhole group: 97.1 ± 7.4, p= 0.018). The postoperative complication rate was higher in the pterional group with statistically marginal significance (pterional group: 5.4%, keyhole group: 1.8%, p= 0.057). However, major neurologic deterioration was similar in the two groups (Pterional group: 1.1%, keyhole group: 1.0%, p= 1.000). Complications between 1-6 months were more in the keyhole group without statistical significance (pterional group: 0%, keyhole group: 1.4%, p= 0.087). Postoperative SDH was observed only in the keyhole group (3 patients with 1.5%) with statistically marginal significance (p= 0.083).

2.2.3. Coiling

2.2.3.1. *Risk factors for complications in unruptured MCAA coil embolization*

Univariable and multivariable analyses were performed to identify risk factors for postoperative complications after coiling of unruptured MCAAs and they are described in Table 9. In the univariable analysis, there was no significant factor for complications. In the multivariable analysis, aneurysm maximum diameter (OR: 1.124, 95% CI 0.998 to 1.267, p= 0.054) was identified as a risk factor for postoperative complications with statistically marginal significance.

2.2.3.2. *Risk factors for retreatment after unruptured MCAA coil embolization*

Univariable and multivariable analyses were performed to identify risk factors for major recanalization after coiling of unruptured MCAAs and they are described in Table 10. In the univariable analysis, aneurysm maximum diameter (OR: 1.689, 95%

CI 1.421 to 2.008, p< 0.001) was identified as a risk factor, and age (OR: 0.944, 95% CI 0.898 to 0.993, p= 0.025) and stent-assisted coiling (OR: 0.173, 95% CI 0.047 to 0.636, p= 0.008) were identified as protective factors for major recanalization. In the multivariable analysis, aneurysm maximum diameter (OR: 1.660, 95% CI 1.425 to 1.934, p< 0.001) was identified to risk factor, and age (OR: 0.947, 95% CI 0908 to 0.988, p= 0.011) and stent-assisted coiling (OR: 0.196, 95% CI 0.056 to 0.684, p= 0.011) were identified as protective factors for major recanalization.

2.2.3.2. *Stent-assisted coiling vs coiling without stent*

Among a total of 676 patients in the coiling group, 189 patients were treated with stents and 487 patients were treated without stents; the details are described in Table 11. The mean follow-up duration of the stent group was 44.1 ± 29.2 and that of the group without stents was 40.9 ± 30.4 (p= 0.291). Hypertension was more common in the group without stents (stent group: 55.0%, group without stent: 63,9%, p< 0.001). Prehospital antiplatelet medication use was more common in the stent group (stent group: 51.3%, group without stent: 26.5%, p= 0.035). Other clinical features were not significantly different. Intraoperative events for rupture or thrombus formation were more common in the stent group (6.3%) than in the group without stents (0.8%); however, this difference was not statistically significant (p= 0.622). In the case of MCAB aneurysms, the utilization of stents was found to be more common. The aneurysm maximum diameter was significantly larger in the stent group (stent group: 5.7 ± 2.5mm, group without stents: 4.4 ± 2.0 mm, p< 0.001). Postoperative complications were 3.7% in the stent group and 2.9% in the group without stents and were not significantly different (p= 0.622). Major neurologic deterioration was more common in the stent group; however, there were no statistically significant differences (stent group: 1.6%, group without stents: 0.8%, p= 0.406).

2.3. Discussion

2.3.1. Clipping vs. coiling

We conducted a study presenting the outcomes of a relatively large number (n=1366) of patients with unruptured MCAA treated at a single institution over a long period (2003 to 2019). The complication rate was found to be higher in the clip group (5.5% in clip group vs. 3.1% in coil group, p= 0.033). However, there was no significant difference between the two groups in terms of the incidence of high-risk complications such as intra-axial hemorrhage or cerebral infarction (4.1% in clip group vs 2.8% in coil group, p= 0.236). The clinical outcomes of both groups were good in terms of KPS score and were not significantly different (clip group: 97.1 ± 9.2 vs. coil group: 96.5 ± 10.1, p= 0.243). The retreatment rate was higher in the coil group. In our institution, for MCAB or larger aneurysms, the preference is to use surgical clipping or stent-assisted coiling. Figure 2 shows an upward trend in the number of treatments for unruptured MCAA from 2003 to 2018. This can be attributed to several factors, including advancements in treatment techniques and increased awareness leading to early detection and intervention. Interestingly, despite the increasing number of treatments, we observed downward trend in the complication rates. This trend may be attributed to several factors, including the accumulation of surgical experience, expertise among the surgical team, and improved perioperative management.

2.3.1.1 *Outcomes of treating only MCA aneurysms*

To account for the potential impact of complications arising from aneurysms in other locations, we performed a subgroup analysis specifically focusing on the treatment outcomes of MCAAs alone. In this analysis, we found no significant difference between the clip and coil groups in terms of complications when considering only MCAA treatment. This suggests that when specifically treating MCAAs only, both clip and coil approaches yield comparable outcomes in terms of complications. An Italian multicenter retrospective study[17] showed similar clinical outcomes in terms of complications but better occlusion rates for clipping than for coiling in unruptured MCAAs. A recent meta-analysis[18] suggested that clipping and endovascular treatment with advanced devices (such as Flow-diverter or Woven EndoBridge) had similar outcomes for complications and better functional outcomes after endovascular treatment. Another meta-analysis[19] suggested that unfavorable neurologic outcomes were more common after coiling (coil group: 6.5%, 95% CI 4.5 to 9.3%, clip group: 4.9%, 95% CI 3.0 to 8.1%), which is somewhat different from the findings of our study. One institution[20]-oriented “coil first” policy’s overall complication rate for the clip group was 16.7%, which was similar to that of the coil group of 20.0% ($p= 0.631$) among 148 patients with unruptured MCAAs. There was a higher complication rate; however, their favorable 6-months functional outcome of a modified Rankin Scale score of 0–2 was similar with 99.2% in the clip group, and 95.0% in the coil group ($p= 0.154$).

2.3.1.2 *Risk factors for complications and major neurologic deficits*

In our study, several risk factors for complications were identified. These included clipping itself, and simultaneous treatment of unruptured MCAA with aneurysm in other locations. On the other hand, aneurysms located in the ETB or MCAB regions were found to be relatively safe in terms of complications. These findings provide important insights into the risk factors associated with different treatment approaches according to the specific aneurysm locations.

However, the risk factors for major neurologic deficits differed from those observed for overall complications. Clipping as a treatment modality was not found to be a risk factor, and simultaneous treatment involving aneurysms in other location did not emerge as a significant risk factor. The only identified risk factor for major neurologic deterioration was a larger maximum diameter. In a study of microsurgical treatment for unruptured intracranial aneurysm[21], risk factors for persistent neurologic deficits were increasing aneurysm size and posterior circulation. The results for unruptured aneurysm treatment in a multicenter study[22] concluded that aneurysm size was associated with poor outcome in both surgical and endovascular treatment. Ogilvy et al. reported that vertebrobasilar aneurysms, age, and aneurysm size were associated with poor outcomes or death.[23] Similarly, Morgan et al.[24] reported that older age, larger size and posterior circulation location were associated with complications of a modified Rankin Scale score above 1. In a study[25] by the same author on the treatment results of MCAA surgery, aneurysm size was associated with surgical mortality and morbidity.

2.3.1.3 *Rupture after treatments*

Out of the 6 ruptured aneurysms after treatment in this study, the size distribution was as follows: 1 aneurysm was giant, 3 aneurysms were large, 1 aneurysm was medium, 1 aneurysm was small. The mean size of the aneurysms was 14.7 mm, which is much larger than the overall aneurysm size of 5.1 mm. Tsutsumi et al.[26] reported that the rate of subarachnoid hemorrhage after clipping from regrowth was 2 of 115 patients (1.7%). Their study did not mention the initial size of the aneurysms. In a study conducted by Mohmed el Beltagy et al.[27], they analyzed cases of aneurysm recurrence following successful clipping. The mean size of the aneurysms in the 9 patients was 11.9 mm, however, there was no mention or comparison of the aneurysm sizes in the entire cohort of 1016 patients. In study results of ruptured intracranial aneurysm treatment[28], the degree of aneurysm occlusion after treatment was associated with an increased risk of rerupture. The rerupture rates after treatment according to completeness were follows: complete occlusion, 1.1%; 99-91% occlusion, 2.9%; 90-70% occlusion, 3.9%; and less than 70% occlusion, 17.6% ($p < 0.0001$).

In our study, we did not conduct routine follow-up imaging after clipping. However, based on the above findings, it is evident that regular radiologic follow-up is crucial for early detection and management of any potential recurrences. Therefore, we recommend implementing a follow-up protocol that includes CT angiography or digital subtraction angiography within one week after surgery, as well as at 1 to 2 years.

2.3.2. Cliping

2.3.2.1 *Unruptured MCA aneurysm clipping*

Although the stability of coil embolization has been demonstrated, unruptured MCAA clipping remains the primary treatment option due to variable factors, such as anatomical features closer to the skull bone than other aneurysms, familiarity with Sylvian fissure dissection by neurovascular surgeons, and relatively low complication rates. According to the literature, the complication rate after surgical clipping of unruptured MCAAs ranges from 2.4% to 5.0% [25,29,30], but our result was relatively high at 5.5% (Table 1). However, the complication rate of unruptured MCAA only without aneurysms at other location was 4.5%, and that after IOM was as low as 4.0%. Morgan et al.[25] performed 280 surgical clippings on 339 unruptured MCAAs in 263 patients, and reported an overall surgical morbidity and mortality rate of 5%. Age over 60 years and aneurysm size over 12 mm were risk factors. According to clipping results for small unruptured MCAAs smaller than 5 mm[29], postoperative complications were reported in 3 out of 125 patients (2.4%) with 143 aneurysms. E. S. Nussbaum et al. reported surgical clipping results for 716 patients with 750 unruptured MCAAs, and the complication rate was 2.8%. In a study by Chung et al.[30], the complication rate of clipping among 416 patients with unruptured MCAAs was 3.6%. Lee et al.[31] reported a postoperative ischemic complication rate after clipping of unruptured MCAA of 1.9%, which is the same as our result after IOM (Table 7).

2.3.2.2 *Pterional vs. keyhole craniotomy*

In our data, overall complication rates were slightly higher in the pterional group, but the difference was not statistically significant (pterional group: 5.4%, keyhole group: 1.8%, p= 0.057). However complications at 1-6 months were observed only in the keyhole group (1.4%), without statistical significance (p= 0.087). Additionaly, postoperative SDH was observed only in the keyhole group (1.5%) and was not statistically significant (p=0.083). Sturiale et al.[32] compared 31 minipterional craniotomies and 37 pterional craniotomies for unruptured MCAAs. The results indicated that there were no significant differences in neurologic outcomes between the two surgical approaches in terms of mRS score or Glasgow Outcome Scale score. Additionally, the pterional group had a higher number of complications, which in part aligns with the findings of our study. Cha et al.[33] compared 61 patients who underwent the lateral supraorbital approach with 61 patients who underwent pterional craniotomy for unruptured cerebral aneurysms. The two groups showed similar postoperative complications (keyhole group: 4 of 61 patients, pterional group: 3 of 61 patients). These findings support the notion that keyhole craniotomy may be a viable alternative to the traditional pterional approach for the treatment of unruptured MCAAs.

2.3.2.3 *Complication risk factors for surgical clipping of unruptured MCAAs*

2.3.2.3.1 *History of cerebral infarction*

Yibing Yang et al.[34] recently conducted a study that investigated the association of postoperative cerebral infarction in Hunt and Hess grades 0–2 ruptured aneurysm patients after clipping. The findings of their study suggested that patients with a history of cerebral ischemia prior to surgery are at a high risk of postoperative cerebral infarction. The findings of our study and their results highlight the importance of considering the preoperative ischemic status of patients in the clipping of cerebral aneurysms. Further evaluation is warranted to better understand the underlying mechanisms and implications of this association.

2.3.2.3.2 *Family history of stroke*

Our data revealed that a familial history of stroke was associated with a higher risk of surgical complications. Liao D, et al.[35] reported a higher prevalence of stroke among patients with a familial history of stroke. Our previous study[4] indicated that patients with a familial history of stroke have an increased incidence of intracranial aneurysm. A familial history of intracranial aneurysm is recognized as a significant risk factor for the development and rupture of intracranial aneurysms.[36] The presence of genetic factors inherited within the family can contribute to the formation, growth, and rupture of aneurysms, making patients with a familial history of stroke more susceptible to aneurysm clipping.

2.3.2.3.3 *Treatment for aneurysms in other locations*

While it may be challenging to find specific studies that have analyzed the complications specifically when treating MCAAs along with aneurysms at other locations, it is important to consider that the treatment of multiple aneurysms in different locations can increase the complexity and potential risks of procedures. In general, the presence of multiple aneurysms at other locations, can pose challenges during treatment, including technical difficulties, longer procedural times, and increased risk of complications.

The consensus in the literature supports the notion that multiple cerebral aneurysms can pose potential risks in both the overall natural course and surgical complications. There have been two reports on aneurysm multiplicity and growth. Joseph et al.[37] reported that multiple UIAs have a high possibility of UIA growth with marginal significance in multivariate analysis (OR, 2.50; 95% CI, 0.85 to 7.53, p= 0.09). Matsumoto et al.[38] reported that multiplicity was associated with UIA growth (H.R. 5.174, 95% CI, 1.81 to 14.80, p= 0.003). A meta-study showed that in Korean and Japanese studies, the risk of SAH was higher for multiple aneurysms (OR, 2.08; 95% CI, 1.46 to 3.47)[39]. Analysis of the methodology of multiple aneurysm clipping has been performed in several recent studies, and some articles have shown one-stage clipping of multiple aneurysms is safe compared to multiple aneurysm surgeries in UIA.[40,41] One study[42] stated that the surgical risk of good clinical outcome of an mRS score ≤ 2 in multiple intracranial aneurysms (82.9%) was not lower than that of single intracranial aneurysm (93.1%) but was of statistical marginal significance (p= 0.068).

2.3.2.3.4 *Location and direction of MCA aneurysm*

Regarding more detailed MCA locations and directions, ETB direction and MCAB location aneurysms had fewer surgical complications in clipping. Marchi et al.[43] reported that the surgical risk of anterior and inferior direction MCA aneurysms (RR= 0.58, p= 0.0019) in terms of the incidence of radiologic ischemic complication rate was lower than that of posterior direction aneurysms (RR= 1.65, p= 0.046) or superior direction aneurysms (RR=1.38, p= 0.145). In ULM et al.'s study[14], the majority of LSA and EFB aneurysms exhibited a frontal direction (75% for LSA and 85% for EFB) on anterior−posterior projection of cerebral angiography. In contrast, a significant proportion of ETB aneurysms (89%) were observed in the temporal direction. Despite performing technically successful surgical clipping, it is important to recognize that there is still a potential risk of incorporating the branching artery into the clipped region.[44] In our institution, we prioritize ensuring the patency of the branching artery even if it appears to have adequate flow in the microscopic view following surgical clipping. To further validate the flow status of the branching artery, we employ additional imaging techniques such as indocyanine green angiography or Doppler ultrasound. Indeed, the location and direction of the aneurysms should be carefully considered when deciding on the appropriate treatment approach, particularly in the case of the ETB direction or MCAB location aneurysms. These specific locations have been found to have a lower risk, making surgical clipping a viable option to be considered as a primary treatment strategy. Hiroka sato et al.[45] suggested that endovascular coiling of proximal MCAAs is better than non−proximal MCAA in terms of occlusion rate. Their proximal MCAAs included LSA, EFB, and ETB location aneurysms in our study. Based on those and our studies, we suggest that surgical clipping yields favorable outcomes in terms of occlusion and lower complications for MCAB aneurysms.

2.3.3. Coiling

2.3.3.1 *Coiling of unruptured MCAAs*

Our immediate postoperative complete occlusion rate by Raymond-Roy Occlusion Classification was 89.8%, and the stable occlusion rate for 3-year postoperative imaging was 84.5%. Orlando M. Diaz et al.[7] reported similar results: complete or near-complete occlusion at the 6-month follow-up angiogram of the endovascular embolization group of MCAAs was 86% (73.5%-93.4%). Pflaeging et al.[20] showed 75.9% complete occlusion on 6-months angiography in 29 unruptured MCA aneurysms. Duan et al.[46] reported 81.4% of 370 coiled unruptured MCAAs.

The overall complication rate of coil embolization in our study was 3.1%, and in the case of the MCA-only aneurysm, it was slightly lower at 2.8%. Hagen et al.[47] reported that the procedure-associated good clinical outcome of an mRS score ≤ 2 was 89.9% in endovascular treatment of MCA bifurcation aneurysm. In a recent long-term follow-up study of endovascular treatment of unruptured MCAAs[46], the overall neurologic complication rate was 4.1%. Coiling of unruptured MCAAs has been associated with potential concerns regarding treatment outcomes and complications compared to intracranial aneurysms at other locations. However, in our study, it demonstrated comparable or, in part, even favorable outcomes. The rapid development of endovascular treatment methods makes it difficult to directly compare complication rates or treatment results with those of previous studies. It is important to consider various factors, including each institution's treatment outcomes and, aneurysm location and size, when determining the most appropriate treatment approaches.

2.3.3.2 *Comparison with other aneurysm locations*

Previous studies compared treatment results according to the aneurysm location. According to the Analysis of Treatment by Endovascular approach of Nonruptured Aneurysms (ATENA) study[44], intraoperative rupture or thromboembolic event were not significantly different according to the location; however, the most common site of thromboembolic events or intraoperative rupture were both MCA location. Endovascular treatment failure was higher in MCAAs (6.4%) than in internal carotid artery (2.2%), and the MCA was the most common location among anterior circulation aneurysms. According to a study analyzing rupture vs. unruptured aneurysms in the Analysis of Recanalization after Endovascular Treatment of Intracranial Aneurysms (ARETA)[39] study in a multicenter prospective cohort of 1088 patients, thromboembolic complications were higher for MCAAs (OR: 1.9, 95% CI 1.2 to 3.0, p= 0.008). Intraoperative rupture was more frequent in anterior cerebral artery and anterior communicating artery aneurysms (OR: 2.2, 95% CI 1.1 to 4.7, p= 0.03). The overall intraoperative rupture rate was 3.1%, and the MCAAs, the intraoperative rupture rate was 3.2% (7/221). This was higher than those for intradural internal carotid artery (6/338, 1.8%, p= 0.08), extradural internal carotid artery (0/13, 0.0%, p= 0.51) or vertebrobasilar (1/77, 1.3%, p= 0.50) aneurysms; however, this was not statistically significant (p= 0.97).

2.3.3.3 *Stent-assisted coiling*

Although we used stents more for the MCAB location than branched aneurysms or larger sized aneurysms, the neurologic outcomes, complications and retreatment rates were not significantly different. The overall immediate postoperative occlusion rate according to Raymond–Roy class was better in the nonstent group. However, in the last follow-up imaging, stable occlusion was more common in the stent group, and major recanalization was more common in the non-stent group. Funakoshi et al.[48] suggested that “progressive thrombosis” was higher in the stent group ($p = 0.0264$), which means that aneurysms that were incompletely coiled immediately after coil embolization could be completely obliterated at the 6-month follow-up angiography. In terms of clinical and radiological results, the use of stents is useful and safe.

2.3.3.4 *Complication risk factors for coiling of unruptured MCAAs*

2.3.3.4.1 *Aneurysm size*

Generally, a larger size UIA has a worse prognosis in terms of hemorrhage and treatment risk.[49,50] According to a study analyzing ruptured vs. unruptured aneurysm of ARETA study[39,], ruptured aneurysms showed larger maximum diameter (ruptured aneurysms: 6.3 ± 3.1 mm, unruptured aneurysms: 5.8 ± 3.9 mm, $p = 0.003$) with a smaller neck diameter (ruptured aneurysms: 3.1 ± 1.4 mm, unruptured aneurysms: 3.4 ± 2.1 mm, $p < 0.0001$). Koiso et al. found that rebleeding was more common in the group with a larger aneurysm size (≥10 mm) when SAH occurred and the mRS score was poorer; however, the relationship between poor outcome of mRS score of 3–6 and larger size was unclear when propensity score matching was performed.[51] In the ARETA[39] and ATENA[44] studies, thromboembolic complications were more common for larger aneurysms.

2.3.3.5 *Risk factors for major recanalization after coiling of unruptured MCAAs*

Our analysis focused on identifying risk factors for major recanalization rather than retreatment in the coil group. It should be noted that not all patients with major recanalization underwent retreatment, as certain factors, including subjective factors such as advanced age, presence of severe comorbidities, or patient preference, may have influenced the decision for retreatment.

2.3.3.5.1 *Aneurysm size*

Koyanagi et al.[52] suggested that the cumulative risk of retreatment was higher in the larger (≥ 10 mm) aneurysm group than in the smaller aneurysm group (log-rank p=0.02). In our previous study on anterior communicating artery aneurysms[53], recanalization was more common in the larger aneurysm group with a maximum aneurysm size over 7 mm (p <0.01). According to a recent study of endovascular treatment of unruptured MCAAs[46], the predictor of recanalization was an aneurysm size ≥ 10 mm (OR: 11.213, 95% CI, 2.127 to 59.098, p= 0.004). It is important to consider the possibility of recurrence during coiling of large unruptured MCAAs.

2.3.3.5.2 *Age*

R. Corns et al.[54] reported that younger age was a risk factor for retreatment and recurrence after coiling of ruptured intracranial aneurysms (mean age of recurrence group: 47, no recurrence group: 51, p= 0.011). In the study analyzing the retreatment rates in the ISAT of ruptured intracranial aneurysms, the mean age of retreated patients was significantly lower ($p < 0.001$). While younger age has been recognized as a risk factor for recurrence or retreatment after treatment of ruptured aneurysms, its association with recurrence or retreatment in the context of unruptured aneurysms remains less well established. Age-related changes in arterial wall properties, such as decreased vascular compliance[55], may influence the stability of coils and contribute to a lower risk of recurrence in older patients. Further research is required to elucidate this relationship.

2.3.3.5.3 *Stent-assisted coiling*

Duan et al.[46] reported a similar result: stent-assisted coiling could reduce recanalization (OR: 0.105, 95C CI, 0.023 to 0.479, p= 0.004). Progressive thrombosis may be attributed to this stability after coiling with a stent.

Limitations

There are several limitations in our study. First, this was a retrospective study. Second, although the sample size was relatively large, this study was performed at a single institution. Third, we did not assess the occlusion rate after aneurysm clipping. At our institution, we do not perform routine postoperative angiograms unless there are large remnant aneurysms after clipping or postoperative neurologic deficits unexplained by other studies. The complete occlusion rate of aneurysm clipping has already been proven in many studies, and most of them have a very good complete occlusion rate.

Chapter 3. Conclusion

Both unruptured MCAA clipping and coiling are safe in terms of functional score. While clipping may have a slightly higher overall complication rate, there is no significant difference in the occurrence of relatively high-risk complications such as intra-axial hemorrhage or symptomatic infarction compared to coiling. When treating only MCA aneurysms, both treatments showed no difference in terms of complications. A large aneurysm size may result in poor long-term neurologic prognosis.

The complication rate of keyhole approach is satisfactory compared to that of the pterional approach, but meticulous and regular postoperative follow-up is needed.

When performing MCAA clipping along with aneurysms in other location, it is crucial to exercise caution due to the potential for increased complications. Patients with a family history of stroke or a personal history of cerebral infarction may be at higher risk for complications, highlighting the importance of evaluating their medical and family history. When considering aneurysms located in the ETB or MCAB regions, clipping can be a suitable recommendation.

Stent-assisted coiling is useful and safe in terms of complications and coil stability. Larger aneurysms could have a high risk of complications and a greater likelihood of recurrence after coiling. Younger patients may have a higher probability of recurrence. Continued investigation and studies are warranted to evaluate risk factors and recurrence patterns.

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Additional Information

Competing interests

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Abstract

서론

코일색전술의 안정성이 확립되었음에도 불구하고 많은 기관에서 미파열 중대뇌동맥류에 대한 일차치료로 클립결찰술을 우선시하고 있다. 저자는 미파열중대뇌동 동맥류에대한 클립결찰술과 코일색전술의 결과를 분석하였다.

방법

2003년 1월부터 2019년 6월까지 미파열 중대뇌동맥류에대해 클립결찰술 혹은 코일색전술을 시행받은 총 1366명의 환자, 1495개의 미파열중대뇌동맥류를 분석하였다. 의무기록 혈관조영데이터를 후향적으로 검토하였다.

결과

클립 그룹에는 753명, 코일 그룹에는 676명이 포함되었다. 전체 수술 후 합병증 발생률은 클립군이 5.5%, 코일군이 3.1% 이었다. (p= 0.033) 수술 후 뇌졸중 발생률은 클립군이 4.1%, 코일군이 2.8% 로 통계적으로 유의하지 않았다. (p= 0.236) 주요 신경학적 악화는 16명 (1,2%) 에서 관찰되었으며, 동맥류의 크기가 클수록 그 위험도가 높았다. (OR: 1.221, 95% CI, 1.125 to 1.325, p< 0.001) 재치료율은 코일군이 3.1%로 클립군의 1.3%에 비해 높았다. (p= 0.022) 클리핑에서 뇌경색 병력 (OR: 2.942, 95% CI 1.083 to 7.986, p= 0.034), 뇌졸중 가족력 (OR: 2.155, 95% CI, 1.077 to 4.312, p= 0/031) 및 중대뇌동맥류와 다른 위치 뇌동맥류의 동시 치료 (OR: 4.031, 95% CI, 1.777 to 9.143, p< 0.001)가 합병증 발생의 위험인자로 확인되었다. Early temporal branch 위치 (OR: 0.106, 95% CI, 0.015 to 0.731, p= 0.023) 와 MCAB 위치 (OR: 0.223, 95% CI 0.057 to 0.867, p= 0.030)는 합병증 발생이 낮은 것으로 확인되었다. Keyhole approach 와 테리온접근법은 각각 1.8%, 5.4% 로 통계적으로 경계의 유의한 차

이가 있었다. (p= 0.057) 코일색전술에서 동맥류의 최대직경은 주요 재발의 위험인자(OR: 1.660,95% CI, 1.425 to 1.934, p< 0.001) 이자 수술후 합병증 발생의 통계적 경계성 유의성을 보이는 위험인자이었다. (OR: 1.124, 95% CI, 0.998 to 1.267, p= 0.054). 고령(OR: 0.947, 95% CI, 0.908 to 0.988, p= 0.011)과 스텐트 보조 코일(OR: 0.196, 95% CI, 0.056 to 0.684, p= 0.011)은 재발에 대한 보호인자로 확인되었다. 스텐트 보조 코일색전술은 합병증을 증가시키지 않는 것으로 확인되었다.

결론

미파열 중대뇌동맥류의 치료 중 클립결찰술은 코일 색전술에 비해 높은 합병증 발생률을 보였으나, 수술 후 뇌졸중 발생이나 신경학적 결과는 두 치료방법 간에 유의한 차이는 없었다. 미파열 중대뇌동맥류의 크기가 클수록 치료 후 신경학적 악화의 가능성이 높다. 미파열 중대뇌동맥류에 대한 치료 시 코일색전술은 클립결찰술에 비해 재치료율이 높다. 클립결찰술 시 철저한 과거력 및 가족력 평가가 중요하다. 클립결찰술 및 코일색전술 모두에서 영상의학적 경과 관찰을 권장한다. 클립결찰술은 early temporal branch 및 MCA bifurcation 위치의 동맥류에 적절한 치료법이다. Keyhole approach은 테리온접근법에 비해 합병증측면에서 나았으나 통계적으로 경계의 유의성을 보였다. 미파열 중대뇌동맥류에 대한 스텐트 보조 코일색전술은 안전하고 유용한 치료법이다.

주요어 : 클립결찰술, 코일색전술, 뇌동맥류, 미파열 중대뇌동맥류
학 번 : 2019-29067

Table of Figure and Tables

Figure 1. Inclusion and exclusion flow chart

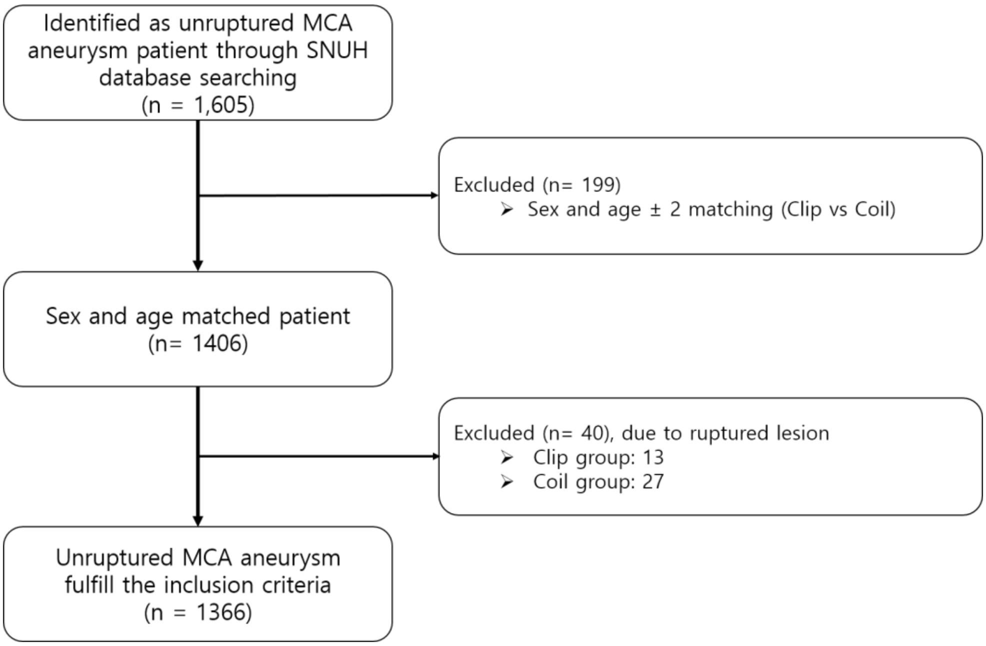

Figure 2. The number of each treatment and complication rate by year.

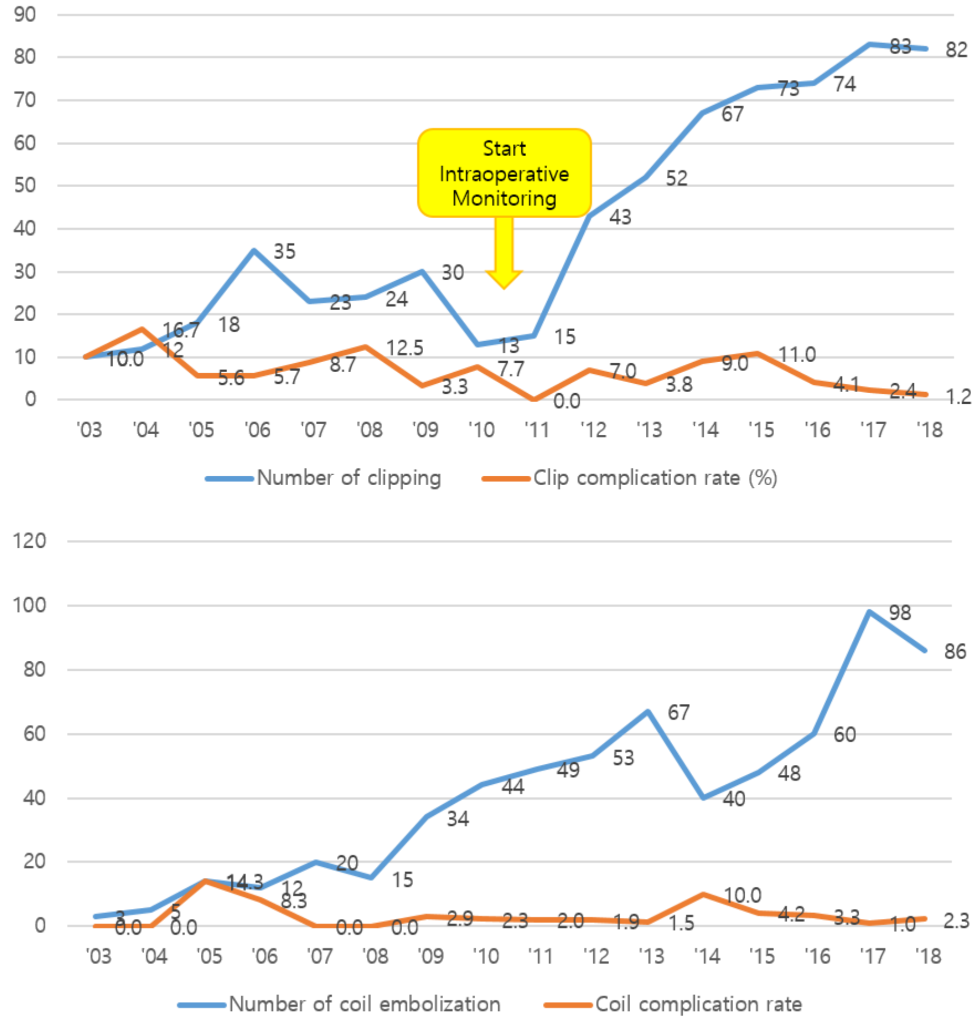

Figure 3. Representative case of rupture after clipping, patient number 3 from Table 4.

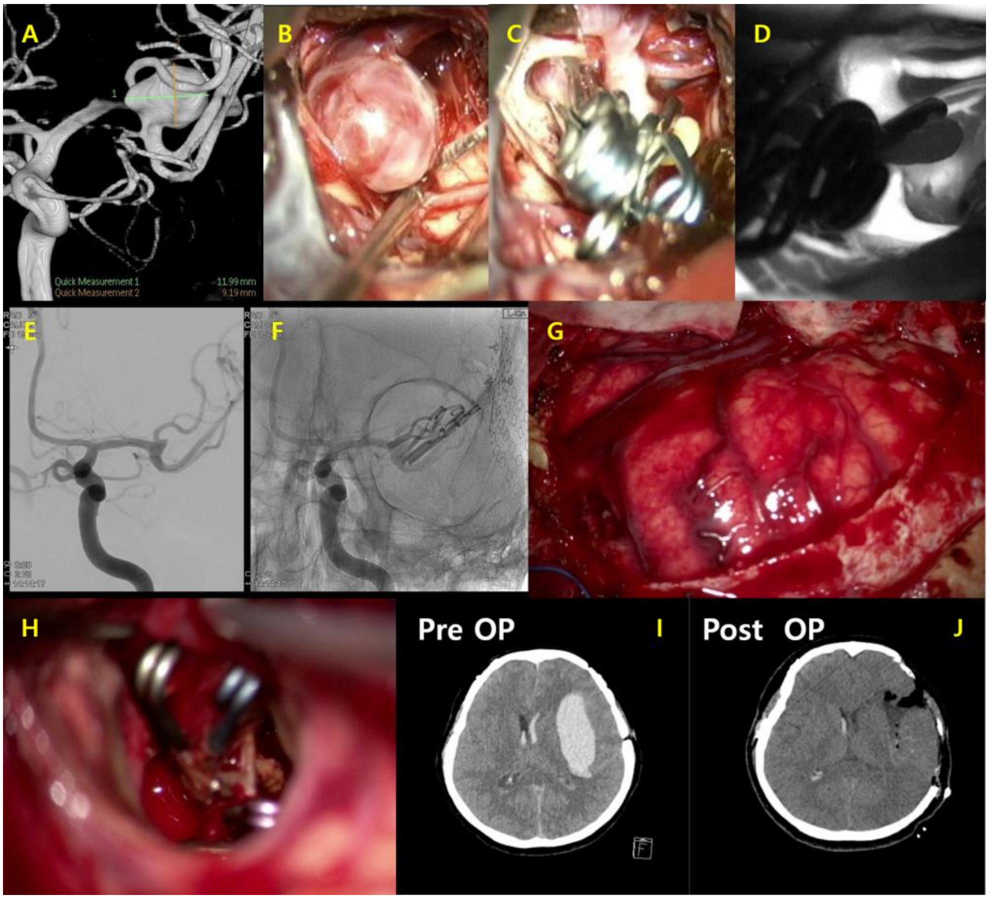

Figure legend

A: A 53-year-old female patient with a large aneurysm measuring 13.3 mm in maximum diameter. B-D: The aneurysm was surgically clipped using the pterional approach. I: Seven years later, she presented to the hospital with intracerebral hemorrhage (ICH) in the left basal ganglia. E, F: DSA revealed a remaining neck in the previously clipped aneurysm. G: Upon performing craniectomy, the patient exhibited severe brain edema. H: Active bleeding was observed upon aspiration and entry into the ICH, leading to the performance of Lt M1 trapping. J: Subsequent postoperative scans confirmed evacuation of all ICH. The patient currently exhibits right-sided hemiplegia with a KPS score of 40.

Figure 4. Representative case of rupture after clipping, patient number 5 from Table 4.

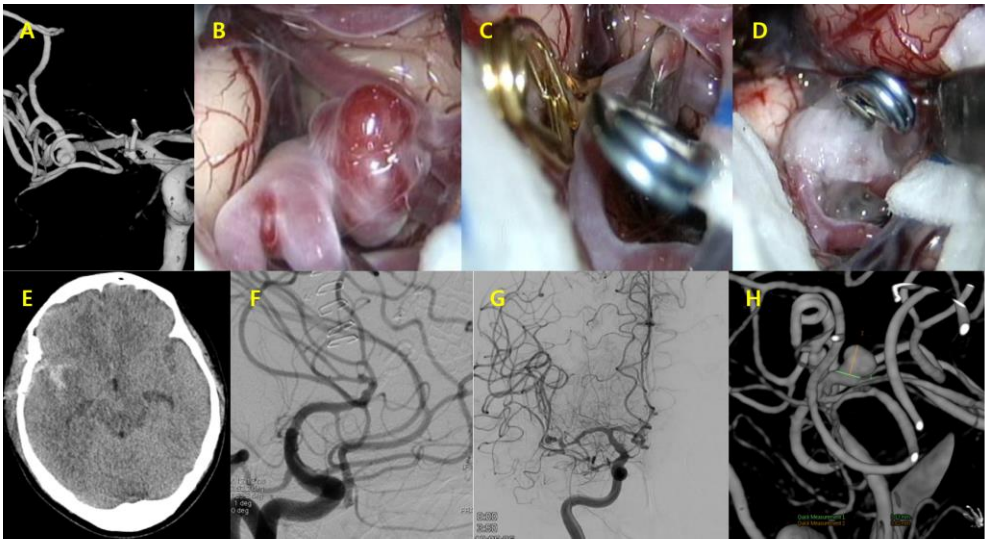

Figure legend

A: A−49−year−old female patient presented with a small aneurysm measuring 3.0 mm in maximum diameter in the right MCAB location. B−D: The aneurysm was confirmed to have bleb changes during the pterional approach and clipping. Clipping and wrapping were performed. E: On the 8th day post−operation, a CT scan revealed subarachnoid hemorrhage in the right sylvian fissure. F: DSA performed on the same day indicated the presence of a small residual neck. G, H: On the 16th day postoperation, DSA showed the formation of a pseudoaneurysm, which was subsequently treated with coil embolization. Additional coil embolization procedures were performed twice over a one−year interval due to major recanalization. On the last follow−up, the patient achieved a KPS score of 100.

Figure 5. Representative case of rupture after clipping, patient number 6 from Table 4.

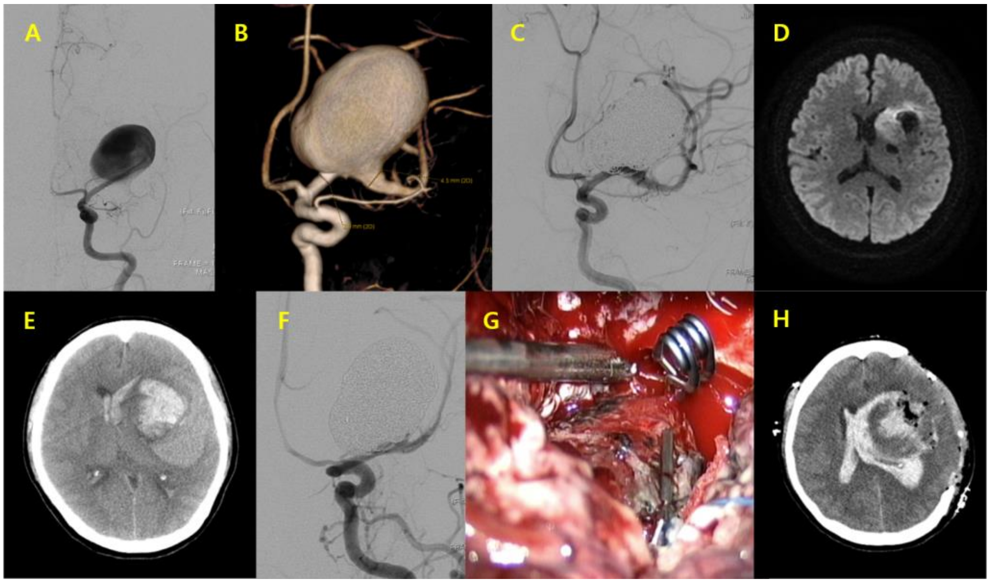

Figure legend

A, B: A 46−year−old female with giant MCA aneurysm measuring 30.9 mm in maximum diameter. C. The patient underwent stent−assisted coiling as treatment. D: Following the procedure, diffusion restriction of the left basal ganglia was observed on MRI. E: Unfortunately, aneurysm rupture occurred the day after the initial treatment. F: Additional coil embolization was performed to address the rupture. G, H: Despite further treatments, including decompressive craniectomy and aneurysm clipping, the patient’s condition did not improve, and unfortunately, she passed away.

Table 1. Baseline Characteristics

		Clip= 690	Coil= 676	Total= 1366	P-value
Clinical features					
Age (mean ± SD, years)		59.3 ± 8.9	59.5 ± 8.8	59.4 ± 8.8	.686
Female sex		481 (69.7%)	469 (69.4%)	950 (69.5%)	.894
Hypertension (n, %)		407 (59.0%)	415 (61.4%)	822 (60.2%)	.364
Diabetes mellitus (n, %)		86 (12.5%)	85 (12.6%)	171 (12.5%)	.951
Hyperlipidemia (n, %)		282 (40.9%)	291 (43.1%)	573 (41.9%)	.415
Heart disease (n, %)		53 (7.7%)	58 (8.6%)	111 (8.1%)	.543
Thyroid disease (n, %)		28 (4.1%)	34 (5.0 %)	62 (4.5%)	.388
Prehospital antiplatelet medication (n, %)		148 (21.4%)	**226 (33.4%)**	374 (27.4%)	< .001
ADPKD (n, %)		12 (1.7%)	23 (3.4%)	35 (2.6%)	.052
History of cerebral infarction (n, %)		41 (5.9%)	29 (4.3%)	70 (5.1%)	.166
History of cerebral hemorrhage (n, %)		23 (3.3%)	32 (4.7%)	55 (4.0%)	.188
Stroke familial history (n, %)		203 (29.4%)	192 (28.4%)	395 (29.9%)	.678
Smoker		104 (15.1%)	101 (14.9%)	205 (15.0%)	.946
Initial KPS score (mean ± SD)		97.2 ± 8.0	96.6 ± 9.4	96.9 ± 8.7	.169
Last KPS score (mean ± SD)		97.1 ± 9.2	96.5 ± 10.1	96.8 ± 9.6	.243
The number of treated aneurysm	1	**581 (84.2%)**	449 (66.4%)	1030 (75.4%)	< .001
	2	82 (11.9%)	**190 (28.1%)**	272 (19.9%)	
	3 or more	27 (3.8%)	**37 (5.5%)**	64 (4.8%)	
Treated lesion	MCA only	**625 (90.6%)**	498 (73.7%)	1123 (82.2%)	< .001
	MCA and other location	65 (9.4%)	**178 (26.3%)**	243 (17.8%)	
Previously treated other aneurysms		53 (7.7%)	54 (8.0%)	107 (7.8%)	.833
Complication					
Complications (n, %)		**38 (5.5%)**	**21 (3.1%)**	59 (4.3%)	.033
Complications 1-6 month (n, %)		11 (1.6%)	3 (0.4%)	14 (1.0%)	.056
Major neurologic deterioration (n, %)		9 (1.3%)	7 (1.0%)	16 (1.2%)	.803
Post OP intra-axial hemorrhage or symptomatic infarction (n, %)		28 (4.1%)	19 (2.8%)	47 (3.4%)	.236
Post OP symptomatic infarction (n, %)		21 (3.0%)	12 (1.8%)	33 (2.4%)	.158
Intra-axial hemorrhage (n, %)		8 (1.2 %)	10 (1.5%)	15 (1.3%)	.642
Extra-axial hemorrhage (n, %)		**18 (2.6%)**	**0 (0.0%)**	18 (1.3%)	< .001
Aneurysm					
		Clip= 753	Coil= 742	Total= 1495	P-value
Aneurysm maximum diameter (mean ± SD, mm)		5.4 ± 5.3	4.7 ± 2.2	5.1 ± 4.1	.002
Small < 5mm (n, %)		407 (54.1%)	494 (66.6%)	901 (60.3%)	
Medium 5 - 10mm (n, %)		308 (40.9%)	229 (30.9%)	537 (35.9%)	
Large 10 - 25mm (n, %)		36 (4.8%)	18 (2.4%)	54 (3.6%)	
Giant ≥ 25mm (n, %)		2 (0.3%)	1 (0.1%)	3 (0.2%)	
Locations (n, %)	LSA	23 (3.1%)	38 (5.1%)	61 (4.1%)	< .001
	EFB	154 (20.5%)	212 (28.6%)	366 (24.5%)	
	ETB	89 (11.8%)	85 (11.5%)	174 (11.6%)	
	MCAB	**448 (59.6%)**	378 (50.9%)	826 (55.3%)	

M2 (n, %)	38 (5.1%)	29 (3.9%)	67 (4.5%)	
Post OP Rupture (n, %)	5 (0.7%)	1 (0.1%)	6 (0.4%)	.218
Retreatment (n, %)	**10 (1.3%)**	**23 (3.1%)**	33 (2.2%)	.022

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, OP: Operation, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 2. Univariable and multivariable analysis for complication in all patients

Univariable analysis				
Variables	OR	95% CI		P value
Clipping (Ref. Coiling)	2.464	1.365	4.449	.003
Age	.722	.382	1.365	.316
Female sex (Ref. male sex)	.975	.944	1.008	.137
Hypertension	1.514	.801	2.862	.202
Diabetes mellitus	1.105	.505	2.417	.803
Hyperlipidemia	1.327	.744	2.364	.338
Heart disease	.575	.186	1.777	.336
Prehospital antiplatelet medication	1.274	.618	2.628	.512
Thyroid disease	1.288	.365	4.552	.694
ADPKD	.459	.058	3.663	.463
History of cerebral infarction	1.776	.616	5.122	.288
History of cerebral hemorrhage	.570	.067	4.854	.607
Stroke familial history	1.518	.861	2.676	.149
Smoking	.309	.115	.827	.019
Previously treated other aneurysm	.179	.022	1.435	.105
Initial KPS score	1.001	.964	1.039	.964
MCA and other location	6.433	2.191	18.891	.001
The number of treated aneurysm	.525	.248	1.109	.091
Aneurysm maximum diameter	1.057	.983	1.137	.135
Location (Ref. LSA)				.023
EFB	.550	.185	1.638	.283
ETB	.155	.034	.710	.016
MCAB	.290	.101	.836	.022
M2	.720	.169	3.068	.657
Multivariable analysis				
Variables	OR	95% CI		P value
Clip (Ref. Coil)	2.512	1.405	4.493	.002
The number of treated aneurysm in one surgery	.487	.234	1.013	.054
MCA and other location	6.322	2.213	18.056	.001
Previously treated other aneurysm	.169	.023	1.251	.082
Stroke familial history	1.619	.933	2.811	.087
Smoking	.496	.208	1.179	.112
Location (Ref. LSA)				.030
EFB	.552	.193	1.576	.267
ETB	.157	.035	.696	.015
MCAB	.304	.110	.844	.022
M2	.677	.167	2.749	.586

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 3. Univariable and multivariable analysis for major neurologic deteriorations in all patients

Univariable analysis				
Variables	OR	95% CI		P value
Clipping (Ref. Coiling)	1.260	.413	3.844	.685
Age	1.008	.943	1.078	.815
Female sex (Ref. male sex)	.467	.094	2.333	.354
Hypertension	1.913	.434	8.421	.391
Diabetes mellitus	1.630	.410	6.481	.487
Hyperlipidemia	1.518	.471	4.897	.485
Heart disease	1.612	.330	7.866	.555
Prehospital antiplatelet medication	1.456	.371	5.709	.590
Thyroid disease	2.171	.259	18.182	.475
ADPKD	3.260	.318	33.395	.320
History of cerebral infarction	1.484	.160	13.762	.728
History of cerebral hemorrhage	2.527	.225	28.399	.453
Stroke familial history	1.120	.350	3.578	.849
Smoking	1.261	.212	7.513	.799
Previously treated other aneurysm	1.002	.095	10.587	.998
Initial KPS score	1.075	.955	1.210	.230
MCA and other location	1.888	.312	11.414	.489
The number of treated aneurysm	1.077	.360	3.221	.894
Aneurysm maximum diameter	1.240	1.118	1.376	.000
Location (Ref. LSA)				.255
EFB	.468	.074	2.939	.418
ETB	.169	.013	2.280	.181
MCAB	.174	.029	1.042	.056
M2	.605	.044	8.349	.708

Multivariable analysis				
Variables	OR	95% CI		P value
Aneurysm maximum diameter	1.221	1.125	1.325	< .001
Hypertension	2.769	.762	10.070	.122

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 4. Details of the patients with postoperative rupture

Patient number	Age (years)	Sex	Treatment method	Year of Surgery	Initial KPS score	Last KPS score and Clinical outcomes		Period from surgery to rupture	Aneurysm maximum diameter	Aneurysm location	Underlying disease	Possible mechanism
1	32	M	Clip	2006	100	0	Death	2 years	17.2 mm	LSA	None	Growth after clip slippage in the residual aneurysm
2	65	F	Clip	2011	100	100	No disability	4 years	6.6 mm	MCAB	None	Growth of residual aneurysm
3	53	F	Clip	2012	100	40	Severe disability	7 years	13.3 mm	EFB	HTN, HL	Growth of residual aneurysm
4	28	M	Clip	2012	100	20	Vegetative state	3 years	16.6 mm	MCAB	HTN, DM, HL, Heart disease	Growth of residual aneurysm
5	49	F	Clip	2014	100	100	No disability	8 days	3.0 mm	MCAB	HL	Pseudoaneurysm formation around clipped artery
6	46	F	Coil (stent)	2014	100	0	Death	next day	30.9 mm	LSA	None	NA

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 5. Clip vs coil in MCA only lesions

		Clip = 625	Coil = 499	Total = 1124	P-value
Clinical features					
Age (mean ± SD, years)		59.1 ± 8.9	59.4 ± 8.8	59.2 ± 8.9	0.555
Female sex		431 (69.0%)	337 (67.5%)	768 (68.3%)	0.652
Hypertension (n, %)		359 (57.4%)	307 (61.5%)	666 (59.3%)	0.179
Diabetes mellitus (n, %)		79 (12.6%)	64 (12.8%)	143 (12.7%)	0.928
Hyperlipidemia (n, %)		254 (40.6%)	215 (43.1%)	469 (41.7%)	0.429
Heart disease (n, %)		48 (7.7%)	41 (8.2%)	89 (7.9%)	0.740
Thyroid disease (n, %)		26 (4.2%)	27 (5.4%)	53 (4.7%)	0.322
Prehospital antiplatelet medication (n, %)		130 (20.8%)	166 (33.3%)	296 (26.3%)	< 0.001
ADPKD (n, %)		11 (1.8%)	15 (3.0%)	26 (2.3%)	0.230
History of cerebral infarction (n, %)		33 (5.3%)	21 (4.2%)	54 (4.8%)	0.483
History of cerebral hemorrhage (n, %)		21 (3.4%)	16 (3.2%)	37 (3.3%)	1.000
Stroke familial history (n, %)		186 (29.8%)	148 (29.7%)	334 (29.7%)	1.000
Smoker		89 (14.2%)	72 (14.4%)	161 (14.3%)	0.932
Initial KPS (mean ± SD) score		97.5 ± 7.4	97.0 ± 8.6	97.3 ± 8.0	0.262
Last KPS (mean ± SD) score		97.5 ± 8.8	96.6 ± 9.9	97.1 ± 9.3	0.142
The number of treated aneurysm	1	**580 (92.8%)**	449 (90.0%)	1029 (91.5%)	0.052
	2	37 (5.9%)	**47 (9.4%)**	84 (7.5%)	
	3 or more	8 (1.3%)	3 (0.6%)	11 (7.0%)	
Previously treated other aneurysms		46 (7.4%)	29 (5.8%)	75 (6.7%)	0.337
Complication					
Complications (n, %)		28 (4.5%)	13 (2.8%)	42 (3.7%)	0.156
Complications 1-6 month (n, %)		9 (1.4%)	3 (0.6%)	12 (1.1%)	0.245
Major neurologic deterioration (n, %)		8 (1.3%)	4 (0.8%)	12 (1.1%)	0.564
Post OP intra-axial hemorrhage or symptomatic infarction (n, %)		20 (3.2%)	12 (2.4%)	32 (2.8%)	0.474
Post OP symptomatic infarction (n, %)		16 (2.6%)	6 (1.2%)	22 (2.0%)	0.130
Intra-axial hemorrhage (n, %)		4 (0.6%)	7 (1.4%)	11 (1.0%)	0.232
Extra-axial hemorrhage (n, %)		**13 (2.1%)**	0 (0.0%)	13 (1.2%)	0.001
Aneurysm					
		Clip= 673	Coil= 549	Total= 1222	P-value
Aneurysm maximum diameter (mean ± SD, mm)		5.2 ± 2.9	4.8 ± 2.3	5.1 ± 2.7	0.008
Small < 5mm (n, %)		361 (53.6%)	658 (65.2%)	719 (58.8%)	
Medium 5 - 10mm (n, %)		279 (41.5%)	175 (31.9%)	454 (37.2%)	
Large 10 - 25mm (n, %)		31 (4.6%)	15 (2.7%)	46 (3.8%)	
Giant ≥ 25mm (n, %)		2 (0.3%)	1 (0.2%)	3 (0.2%)	
Location (n %)	**LSA**	19 (2.8%)	32 (5.8%)	51 (4.2%)	< 0.001
	EFB	142 (21.1%)	160 (29.1%)	302 (24.7%)	
	ETB	71 (10.5%)	56 (10.2%)	127 (10.4%)	
	MCAB	409 (60.8%)	279 (50.8%)	688 (56.3%)	
	M2	32 (4.8%)	22 (4.0%)	54 (4.4%)	
Post OP Rupture (n, %)		5 (0.7%)	1 (0.2%)	6 (0.5%)	0.235
Retreatment (n, %)		8 (1.2%)	**16 (2.9%)**	24 (2.0%)	0.038

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, OP: Operation, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 6. Uni- and multivariable analysis for complication of clipping

Univariable analysis				
Variables	OR	95% CI		P value
Age	.980	.940	1.023	.360
Female sex	.603	.253	1.435	.253
Hypertension	1.733	.722	4.160	.219
Diabetes mellitus	1.872	.749	4.678	.180
Hyperlipidemia	1.179	.544	2.555	.677
Heart disease	.436	.089	2.123	.304
Antiplatelet	1.058	.408	2.743	.908
Thyroid disease	1.113	.221	5.600	.897
ADPKD	1.848	.207	16.504	.582
History of cerebral infarction	3.201	.892	11.488	.074
History of cerebral hemorrhage	1.081	.113	10.374	.946
Previously treated other aneurysms	.291	.033	2.603	.270
Stroke familial history	2.016	.961	4.230	.064
Smoking	.295	.084	1.030	.056
Initial KPS score	1.022	.969	1.077	.433
IOM applied	.596	.264	1.346	.213
MCA and other location	4.006	.976	16.441	.054
The number of treated aneurysm	1.189	.521	2.713	.682
Aneurysm maximum diameter	1.019	.915	1.135	.731
Location (Ref. LSA)				.031
EFB	.480	.110	2.088	.328
ETB	.104	.014	.759	.026
MCAB	.183	.043	.775	.021
M2	.356	.046	2.730	.320

Multivariable analysis				
Variables	OR	95% CI		P value
History of cerebral infarction	2.942	1.083	7.986	.034
Stroke familial history	2.155	1.077	4.312	.030
MCA and other location	4.031	1.777	9.143	.001
Location (Ref. LSA)				.044
EFB	.511	.126	2.073	.348
ETB	.106	.015	.731	.023
MCAB	.223	.057	.867	.030
M2	.332	.048	2.282	.262

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale,: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 7. MCA clipping before and after application of IOM

Clip MCA only		Before IOM = 152	After IOM = 473	Total = 625	P-value
		Clinical features			
Age (mean ± SD, years)		58.3 ± 9.7	59.3 ± 8.6	59.1 ± 8.9	0.231
Female sex (n, %)		106 (69.7%)	325 (68.7%)	431 (69.0%)	0.841
The number of treated aneurysm	1 (n, %)	**147 (96.7%)**	433 (91.5%)	580 (92.8%)	0.005
	2 (n, %)	2 (1.3%)	35 (7.4%)	37 (5.9%)	
	3 or more (n, %)	3 (2.0%)	5 (1.1%)	8 (1.3%)	
Approach	Pterional (n, %)	85 (55.9%)	262 (55.4%)	347 (55.5%)	0.337
	Keyhole (n, %)	67 (44.1%)	203 (42.9%)	270 (43.2%)	
	Bilateral Keyhole (n, %)	0 (0.0%)	8 (1.7%)	8 (1.3%)	
Previously treated other aneurysms (n, %)		9 (5.9%)	37 (7.8%)	46 (7.4%)	0.481
Intraoperative rupture event (n, %)		3 (2.0%)	5 (1.1%)	8 (1.3%)	0.410
Hypertension (n, %)		99 (65.1%)	260 (55.0%)	359 (57.4%)	0.030
Diabetes mellitus (n, %)		17 (11.2%)	62 (13.1%)	79 (12.6%)	0.578
Hyperlipidemia (n, %)		42 (27.6%)	212 (44.8%)	254 (40.6%)	< 0.001
Heart disease (n, %)		12 (7.9%)	36 (7.6%)	48 (7.7%)	0.863
Thyroid disease (n, %)		13 (8.6%)	13 (2.7%)	26 (4.2%)	0.004
Prehospital antiplatelet medication (n, %)		43 (28.3%)	87 (18.4%)	130 (20.8%)	0.011
ADPKD (n, %)		2 (1.3%)	9 (1.9%)	11 (1.8%)	1.000
History of cerebral infarction (n, %)		18 (11.8%)	15 (3.2%)	33 (5.3%)	< 0.001
History of cerebral hemorrhage (n, %)		2 (1.3%)	19 (4.0%)	21 (3.4%)	0.126
Stroke familial history (n, %)		29 (19.1%)	157 (33.2%)	186 (29.8%)	0.001
Smoker (n, %)		19 (12.5%)	70 (14.8%)	89 (14.2%)	0.594
Initial KPS score (mean ± SD)		96.2 ± 8.1	97.9 ± 7.1	97.5 ± 7.4	0.019
Last KPS score (mean ± SD)		95.6 ± 12.5	98.1 ± 7.1	97.5 ± 8.8	0.022
		Complication			
Complications (n, %)		9 (5.9%)	19 (4.0%)	28 (4.5%)	0.367
Complications, 1-6 months (n, %)		6 (3.9%)	3 (0.6%)	9 (1.4%)	0.008
Major neurologic deterioration (n, %)		3 (2.0%)	5 (1.1%)	8 (1.3%)	0.410
Post OP intra-axial hemorrhage or symptomatic infarction (n, %)		8 (5.3%)	12 (2.5%)	20 (3.2%)	0.112
Post OP symptomatic infarction (n, %)		4 (2.6%)	9 (1.9%)	13 (2.1%)	0.528
Intra-axial hemorrhage (n, %)		2 (1.3%)	2 (0.4%)	3 (0.5%)	0.078
Extra-axial hemorrhage (n, %)		4 (2.6%)	9 (1.9%)	13 (2.1%)	0.528
		Aneurysm			
		Before IOM = 157	After IOM = 516	Total = 673	P-value
Aneurysm maximum diameter (mean ± SD, mm)		5.6 ± 4.1	5.1 ± 2.5	5.2 ± 2.9	0.126
Small < 5mm (n, %)		81 (51.6%)	280 (54.3%)	361 (53.6%)	0.532
Medium 5-10mm (n, %)		66 (42.0%)	213 (41.3%)	279 (41.5%)	
Large 10-25mm (n, %)		9 (5.7%)	22 (4.3%)	31 (4.6%)	
Giant ≥ 25mm (n, %)		1 (0.6%)	1 (0.2%)	2 (0.3%)	
Location (n, %)	LSA	6 (3.8%)	13 (2.5%)	19 (2.8%)	0.243
	EFB	41 (26.1%)	101 (19.6%)	142 (21.1%)	

ETB	18 (11.5%)	53 (10.3%)	71 (10.5%)	
MCAB	87 (55.4%)	322 (62.4%)	409 (60.8%)	
M2	5 (3.2%)	27 (5.2%)	32 (4.8%)	
Post OP Rupture (n, %)	1 (0.6%)	4 (0.8%)	5 (0.7%)	1.000
Retreatment (n, %)	3 (1.9%)	5 (1.0%)	8 (1.2%)	0.398

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, OP: Operation, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 8. Pterional approach vs keyhole surgery for MCA only aneurysm, after application of IOM

		Pterional= 262	Keyhole= 203	Total = 465	P-value
Clinical features					
Age (mean ± SD, years)		58.3 ± 8.4	60.8 ± 8.5	59.4 ± 8.5	**0.002**
Female sex (n, %)		171 (65.3%)	148 (72.9%)	319 (68.6%)	0.078
The number of treated aneurysm	1	248 (94.7%)	185 (91.1%)	433 (93.1%)	0.311
	2	12 (4.6%)	16 (7.9%)	28 (6.0%)	
	3 or more	2 (0.8%)	2 (1.0%)	4 (0.9%)	
Previously treated other aneurysms		21 (8.0%)	17 (8.4%)	38 (8.2%)	0.889
Hypertension (n, %)		150 (57.3%)	105 (51.7%)	255 (54.8%)	0.235
Diabetes mellitus (n, %)		39 (14.9%)	22 (10.8%)	61 (13.1%)	0.200
Hyperlipidemia (n, %)		121 (46.2%)	88 (43.3%)	209 (44.9%)	0.542
Heart disease (n, %)		19 (7.3%)	17 (8.4%)	36 (7.7%)	0.653
Thyroid disease (n, %)		6 (2.3%)	7 (3.4%)	13 (2.8%)	0.452
Preoperative antiplatelet use (n, %)		50 (19.1%)	38 (18.7%)	88 (18.9%)	0.921
ADPKD (n, %)		5 (1.9%)	4 (2.0%)	9 (1.9%)	1.000
History of cerebral infarction (n, %)		8 (3.1%)	7 (3.4%)	15 (3.2%)	0.811
History of cerebral hemorrhage (n, %)		6 (2.3%)	12 (5.9%)	18 (3.9%)	**0.045**
Stroke familial history (n, %)		94 (35.9%)	61 (30.0%)	155 (33.3%)	0.186
Smoker (n, %)		39 (14.9%)	30 (14.8%)	69 (14.8%)	0.974
Initial KPS score (mean ± SD)		99.0 ± 4.5	96.5 ± 9.4	97.9 ± 7.2	**< 0.001**
Last KPS score (mean ± SD)		98.7 ± 6.9	97.1 ± 7.4	98.0 ± 7.2	**0.018**
Complication					
Complications (n, %)		15 (5.4%)	4 (1.8%)	19 (3.8%)	0.057
Complications, 1-6 months (n, %)		0 (0.0%)	3 (1.4%)	3 (0.6%)	0.087
Major neurologic deterioration (n, %)		3 (1.1%)	2 (1.0%)	5 (1.1%)	1.000
Post OP intra-axial hemorrhage or symptomatic infarction (n, %)		9 (3.4%)	4 (1.8%)	13 (2.8%)	0.342
Post OP symptomatic infarction (n, %)		7 (2.5%)	4 (1.8%)	11 (2.2%)	0.762
Intra-axial hemorrhage (n, %)		4 (1.4%)	0 (0.0%)	4 (0.4%)	0.133
Other intracranial hemorrhage (n, %)		4 (1.5%)	4 (2.0%)	8 (1.7%)	0.733
Post OP subdural hematoma (n, %)		0 (0.0%)	3 (1.5%)	3 (0.6%)	0.083
Post OP epidural hematoma (n, %)		1 (0.4%)	1 (0.5%)	2 (0.4%)	1.000
Remote cerebellar hemorrhage (n, %)		3 (1.1%)	0 (0.0%)	3 (0.6%)	0.260
Aneurysm					
		Pterional= 278	Keyhole= 222	Total= 500	P-value
Aneurysm maximum diameter (mean ± SD, mm)		5.2 ± 2.6	5.0 ± 2.2	5.1 ± 2.4	0.547
Small < 5mm (n, %)		153 (55.0%)	117 (52.7%)	270 (54.0%)	0.869
Medium 5-10mm (n, %)		114 (41.0%)	95 (42.8%)	209 (41.8%)	
Large 10-25mm (n, %)		10 (3.6%)	10 (4.5%)	20 (4.0%)	
Giant ≥ 25mm (n, %)		1 (0.4%)	0 (0.0%)	1 (0.2%)	
Location (n, %)	LSA	6 (2.2%)	7 (3.2%)	13 (2.6%)	0.908
	EFB	52 (18.7%)	45 (20.3%)	97 (19.4%)	
	ETB	28 (10.1%)	22 (9.9%)	50 (10.0%)	
	MCAB	176 (63.3%)	138 (62.2%)	314 (62.8%)	
	M2	16 (5.8%)	10 (4.5%)	26 (5.2%)	
Post OP Rupture (n, %)		4 (1.4%)	0 (0.0%)	4 (0.8%)	0.133
Retreatment (n, %)		3 (1.1%)	2 (0.9%)	5 (1.0%)	1.000

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, OP: Operation, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation

Table 9. Uni- and multivariable analysis for complication of coiling

Univariable analysis				
Variables	OR	95% CI		P value
Age	.961	.909	1.016	.165
Female sex	1.301	.459	3.686	.620
Hypertension	1.358	.488	3.780	.558
Diabetes mellitus	.304	.038	2.413	.260
Hyperlipidemia	1.909	.722	5.045	.192
Heart disease	1.422	.272	7.446	.677
Preoperative antiplatelet medication	1.319	.424	4.105	.632
Thyroid disease	1.408	.172	11.521	.750
ADPKD	.000	0.000		.998
History of cerebral infarction	.000	0.000		.998
History of cerebral hemorrhage	.000	0.000		.998
Stroke familial history	1.202	.447	3.232	.715
Smoker	.216	.025	1.885	.166
Initial KPS score	.975	.927	1.025	.318
MCA and other location	2.052	.776	5.431	.148
Maximum diameter	1.116	.979	1.272	.101
Location (Ref. LSA)				.500
EFB	.585	.093	3.668	.567
ETB	.265	.019	3.601	.318
MCAB	.509	.088	2.943	.450
M2	1.819	.193	17.112	.601
Stent-assisted coiling	1.219	.440	3.380	.704

Multivariable analysis				
Variables	OR	95% CI		P value
Aneurysm maximum diameter	1.124	.998	1.267	.054

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch

Table 10. Uni- and multivariable analysis for major recanalization after coiling

Univariable analysis				
Variables	OR	95% CI		P value
Age	.944	.898	.993	.025
Female sex	.682	.244	1.902	.464
Hypertension	1.253	.483	3.249	.643
Diabetes mellitus	.338	.043	2.675	.304
Hyperlipidemia	1.228	.478	3.158	.670
Heart disease	1.836	.324	10.412	.492
Prehospital antiplatelet medication	.571	.134	2.424	.447
Thyroid disease	.000	0.000		.998
ADPKD	1.295	.216	7.749	.777
History of cerebral infarction	.000	0.000		.998
History of cerebral hemorrhage	1.139	.120	10.788	.910
Stroke familial history	1.034	.392	2.725	.946
Smoker	.950	.259	3.487	.938
Initial KPS score	1.006	.947	1.069	.846
MCA and other location	1.411	.536	3.714	.486
Maximum diameter	1.689	1.421	2.008	< .001
Location (Ref. LSA)				.656
EFB	.838	.153	4.590	.839
ETB	.265	.021	3.388	.307
MCAB	.473	.088	2.554	.384
M2	.000	0.000		.998
Stent-assisted coiling	.173	.047	.636	.008
Multivariable analysis				
Variables	OR	95% CI		P value
Age	.947	.908	.988	.011
Aneurysm maximum diameter	1.660	1.425	1.934	< .001
Stent-assisted coiling	.196	.056	.684	.011

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch

Table 11. Aneurysm coiling Stent vs not

		Stent (N=189)	Without stent (N=487)	Total (N=676)	P-value
Clincal features					
Age (mean ± SD, years)		60.0 ± 8.2	59.2 ± 9.1	59.4 ± 8.8	0.444
Female sex (n, %)		141 (74.6%)	328 (67.42%)	469 (69.4%)	0.077
Hypertension (n, %)		104 (55.0%)	311 (63.9%)	415 (61.4%)	0.035
Diabetes mellitus (n, %)		21 (11.1%)	64 (13.1%)	85 (12.6%)	0.520
Hyperlipidemia (n, %)		83 (43.9%)	208 (42.7%)	291 (43.0%)	0.796
Heart disease (n, %)		12 (6.3%)	46 (9.4%)	58 (8.6%)	0.223
Thyroid disease (n, %)		6 (3.2%)	28 (5.7%)	34 (5.0%)	0.238
Prehospital antiplatelet medication (n, %)		97 (51.3%)	129 (26.5%)	226 (33.4%)	< 0.001
ADPKD (n, %)		6 (3.2%)	17 (3.5%)	23 (3.4%)	1.000
History of cerebral infarction (n, %)		10 (5.3%)	19 (3.9%)	29 (4.3%)	0.405
History of cerebral hemorrhage (n, %)		7 (3.7%)	25 (5.1%)	32 (4.7%)	0.546
Stroke familial history (n, %)		53 (28.0%)	139 (28.5%)	192 (28.4%)	0.925
Smoking (n, %)		21 (11.1%)	80 (16.4%)	101 (14.9%)	0.092
Initial KPS score (mean ± SD)		97.9 ± 6.2	96.6 ± 9.3	97.0 ± 8.6	0.069
Last KPS score (mean ± SD)		96.6 ± 11.5	96.7 ± 9.2	96.6 ± 9.9	0.911
Follow up duration (mean ± SD)		44.1 ± 29.2	40.9 ± 30.4	41.8 ± 30.1	0.291
Previously treated other aneurysm (n, %)		11 (5.8%)	43 (8.8%)	54 (8.0%)	0.211
MCA and other location (n, %)		48 (25.4%)	129 (26.5%)	177 (26.2%)	0.846
The number of treated aneurysm (n, %)	1	122 (64.6%)	327 (67.1%)	449 (66.4%)	0.795
	2	56 (29.6%)	134 (27.5%)	190 (28.1%)	
	3 or more	11 (5.8%)	26 (5.3%)	37 (5.5%)	
Intraoperative event (Rupture or thrombus formation) (n, %)		12 (6.3%)	15 (3.1%)	27 (4.0%)	0.077
Complication					
Complications (n, %)		7 (3.7%)	14 (2.9%)	21 (3.1%)	0.622
Complications, 1-6 months (n, %)		2 (1.1%)	1 (0.2%)	3 (0.4%)	0.190
Major neurologic deterioration (n, %)		3 (1.6%)	4 (0.8%)	7 (1.0%)	0.406
Post OP intra-axial hemorrhage or symptomatic infarction (n, %)		3 (1.6%)	7 (1.4%)	10 (1.5%)	1.000
Post OP symptomatic infarction (n, %)		5 (2.6%)	7 (1.4%)	12 (1.8%)	0.331
Intra-axial hemorrhage (n, %)		2 (1.4%)	3 (0.8%)	5 (1.0%)	0.622
Aneurysm					
		Stent (N=198)	Non-stent (N=544)	Total (N=742)	p-value
Location (n, %)	**LSA**	5 (2.5%)	33 (6.1%)	38 (5.1%)	< 0.001
	EFB	48 (24.2%)	164 (30.1%)	212 (28.6%)	
	ETB	10 (5.1%)	75 (13.8%)	85 (11.5%)	
	MCAB	129 (65.2%)	249 (45.8%)	378 (50.9%)	
	M2	6 (3.0%)	23 (4.2%)	29 (3.9%)	
Aneurysm maximum diameter (mean ± SD, mm)		5.7 ± 2.5	4.4 ± 2.0	4.7 ± 2.2	< 0.001
Small < 5mm (n, %)		87 (43.9%)	407 (74.8%)	494 (66.6%)	
Medium 5-10mm (n, %)		106 (53.5%)	123 (22.6%)	229 (30.9%)	
Large 10-25mm (n, %)		4 (2.0%)	13 (2.4%)	17 (2.3%)	
Giant ≥ 25mm (n, %)		1 (0.5%)	1 (0.2%)	2 (0.3%)	
Raymond-roy class (n, %)	1	176 (88.9%)	490 (90.1%)	666 (89.8%)	< 0.001
	2	6 (3.0%)	25 (4.6%)	31 (4.2%)	
	3a	10 (5.1%)	14 (2.6%)	24 (3.2%)	
	3b	6 (3.0%)	15 (2.8%)	21 (2.8%)	
Last Post OP imaging (n, %)	Stable occlusion	173 (87.4%)	452 (83.4%)	625 (84.5%)	0.179
	Minor recanalization	21 (10.6%)	63 (11.6%)	84 (11.4%)	

	Major recanalization	4 (2.0%)	27 (5.0%)	31 (4.2%)	
Retreatment (n, %)		4 (2.0%)	19 (3.5%)	23 (3.1%)	0.306
Post OP Rupture (n, %)		1 (0.5%)	0 (0.0%)	1 (0.1%)	0.267

ADPKD: Autosomal dominant polycystic kidney disease, KPS: Karnofsky Performance Scale, OP: Operation, MCA: Middle cerebral artery, LSA: Lenticulostriate, EFB: Early frontal branch, ETB: Early temporal branch, MCAB: MCA bifurcation