Potential Risks and Limited Indications of the Supraorbital Keyhole Approach for Clipping Internal Carotid Artery Aneurysms

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BACKGROUND: **Internal carotid artery (ICA) aneurysm may be a good target for supraorbital keyhole clipping. We discuss the surgical indications and risks of keyhole clipping for ICA aneurysms based on long-term clinical and radiologic results.**

METHODS: **This was a retrospective analysis of 51 patients (aged 35–75 years, mean 62 years) with ICA aneurysms (mean 5.8 ± 1.8 mm) who underwent clipping via the supraorbital keyhole approach between 2005 and 2017. Neurologic and cognitive functions were examined by several methods, including the modified Rankin Scale and Mini-Mental Status Examination. The state of clipping was assessed 1 year and then every few years after the operation.**

RESULTS: **Complete clipping was confirmed in 45 patients (88.2%), dog-ear remnants behind the clip persisted in 4 patients, and wrapping was performed in 2 patients. Mean duration of postoperative hospitalization was 3.4 ± 6.9 days. The mean clinical follow-up period was 6.6 ± 3.2 years. The overall mortality was 0, and overall morbidity (modified Rankin Scale score ≥2 or Mini-Mental Status Examination <24) was 3.9%. Completely clipped aneurysms did not show any recurrence during the mean follow-up period of 6.3 ± 3.1 years, but the 2 (3.9%) aneurysms with neck remnants showed regrowth.**

CONCLUSIONS: **The risk of neck remnant behind the clip blade is a drawback of supraorbital keyhole clipping. The surgical indication requires preoperative simulation and careful checking of the clip blade state is essential.**

INTRODUCTION

The development of less-invasive clipping techniques remains desirable. The keyhole strategy is less invasive in experienced hands with or without endoscopy,[1-11] but application to the clipping of unruptured cerebral aneurysms (UCAs) carries the risk of serious complications, and therefore neurosurgeons should be cautious about adopting this method. However, little is known about the surgical indications and limitations of keyhole clipping for internal carotid artery (ICA) aneurysms based on long-term clinical and radiologic results.[10,12,13]

Keyhole clipping has been performed in our facility for subsets of UCAs in the anterior circulation since July 2005, to achieve less-invasive surgery, and the long-term clinical and radiologic results for anterior communicating artery (AcomA) aneurysms[1] and middle cerebral artery (MCA) aneurysms[2] already have been reported. The supraorbital keyhole approach also was adopted to clip a subset of unruptured supraclinoid ICA aneurysms. ICA aneurysms may be good targets for supraorbital keyhole

Key words
- Clipping
- Internal carotid artery
- Keyhole surgery
- Unruptured cerebral aneurysm

Abbreviations and Acronyms
3D: 3-Dimensional
AcomA: Anterior communicating artery
AntChoA: Anterior choroidal artery
BDI: Beck Depression Inventory
CT: Computed tomography
CTA: Computed tomography angiography
DSA: Digital subtraction angiography
DWI: Diffusion-weighted imaging
HAM-D: Hamilton Depression Scale
HDS-R: Revised Hasegawa Dementia Scale
ICA: Internal carotid artery
ISUIA: International Study of Unruptured Intracranial Aneurysms
MCA: Middle cerebral artery
MMSE: Mini-Mental Status Examination
MRI: Magnetic resonance imaging
mRS: Modified Rankin Scale
NIHSS: National Institutes of Health Stroke Scale
PcomA: Posterior communicating artery
UCA: Unruptured cerebral aneurysm

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clipping,[4,5,13-15] but we carefully examined the surgical indications using computer simulation with 3-dimensional (3D) computed tomography angiography (CTA) and sometimes digital subtraction angiography (DSA), and strictly limited the indications for keyhole clipping because of the diversity of the ICA aneurysm complex.

The present study describes the surgical results of supraorbital keyhole clipping for 51 cases of unruptured ICA aneurysms selected according to our surgical indications and reports the long-term clinical and radiologic follow-up data, including postoperative cognitive and mental states. The indications and limitations of keyhole clipping for various locations of ICA aneurysms, namely ICA-posterior communicating artery (PcomA) aneurysm, ICA-anterior choroidal artery (AntChoA) aneurysm, ICA bifurcation aneurysm, and ICA paraclinoid aneurysm, are also discussed.

MATERIALS AND METHODS

This retrospective study is based on review of the medical records of patients treated at our institutions. The institutional ethics committees approved this study, and written informed consent was obtained from all patients.

Patients and Aneurysms

A total of 564 unruptured aneurysms were treated by surgical clipping in our institutions between July 2005 and January 2017. Among these, 155 aneurysms were located on the ICA and 51 of these 155 (32.9%) were clipped via the supraorbital keyhole approach through eyebrow skin incision by the senior operator (K.M.). These 51 unruptured supraclinoid ICA aneurysms (right/left 26:25) occurred in 27 female and 24 male patients aged 35–75 years (mean 62 ± 10 years). All patients were free of neurologic symptoms except for 2 with oculomotor palsy (National Institutes of Health Stroke Scale [NIHSS] score 1), but all patients were totally independent in daily life without critical comorbidity or frailty.[16] Locations of the ICA aneurysms treated by keyhole mini-craniotomy and standard craniotomy, and the rates of keyhole clipping in each location are listed in Table 1. Largest diameter of the aneurysms treated by keyhole clipping was 2–10 mm (5.8 ± 1.8 mm) and bleb was present in 13 aneurysms. Multiple cerebral aneurysms (11 aneurysms) were present in 10 patients, of which 4 aneurysms were treated simultaneously and 7 aneurysms were not treated and followed up.

Preoperative Computer-Assisted Simulation and Evaluation of Indications for Keyhole Surgery

The supraorbital keyhole mini-craniotomy has a diameter of 25–30 mm, so unruptured ICA aneurysms of less than 10-mm diameter are the main candidates for the keyhole surgery. Preoperative planning is based on 3D CTA with contrast medium. Data are transferred to a workstation (Ziostation 2.4; Ziosoft, Inc., Tokyo, Japan) to generate the 3D multifusion image. Various shapes and sizes of virtual supraorbital keyhole mini-craniotomy are simulated to optimize visualization of the target aneurysm.[17] At this point, if the target aneurysm cannot be adequately seen through the virtual keyhole because of the anterior clinoid process, shape and length of the parent ICA, or aneurysm dome point, keyhole clipping is not selected for the treatment. DSA is performed to confirm the relationship between the perforators and the aneurysm, especially in cases of ICA-AntChoA aneurysm. If the perforators are deeply involved in the aneurysm and detachment of the perforators from the aneurysm through the narrow operative field is considered to be difficult, keyhole clipping is not selected. Figure 1 shows the preoperative simulation of a representative case of ICA-PcomA aneurysm.

Table 1. Locations and Numbers of Unruptured ICA Aneurysms Treated by Keyhole Mini-Craniotomy and Standard Craniotomy

Location of Aneurysm	Keyhole Craniotomy (Rate of Keyhole, %)	Standard Craniotomy	Total
ICA-PcomA	32 (45.1)	39	71
ICA-AntChoA	15 (60.0)	10	25
ICA bifurcation	2 (40.0)	3	5
ICA paraclinoid	2 (3.7)	52	54
Total	51 (32.9)	104	155

ICA, internal carotid artery; PcomA, posterior communicating artery; AntChoA, anterior choroidal artery.

Surgical Procedures and Early Postoperative Imaging

The details of the supraorbital keyhole approach through eyebrow skin incision have been described previously.[1,10] Endoscopy was not routinely used and applied mainly to confirm the perforators and clip blade condition if necessary. Figure 2 shows the intraoperative photographs of a representative case of ICA-PcomA aneurysm clipping through the supraorbital keyhole approach.

On the day after the operation (postoperative day 1), CT, 3D CTA, and diffusion-weighted imaging (DWI) were performed to determine the completeness of the clipping and identify any ischemic and hemorrhagic complications. If no clinical or radiologic abnormalities were confirmed, the patient was discharged.

Clinical and Radiologic Examinations and Follow-up Protocol

Patient status was evaluated with the NIHSS, modified Rankin Scale (mRS), Barthel index, Mini-Mental State Examination (MMSE),[18] and Revised Hasegawa Dementia Scale (HDS-R)[19] a few days before the operation and at 3 months, 1 year, and then every few years after the operation. An mRS score of 2 or more or an MMSE score of less than 24 was defined as morbidity according to the International Study of Unruptured Intracranial Aneurysms (ISUIA).[20] The levels of depression were assessed using the Beck Depression Inventory (BDI)[21] and Hamilton Depression Scale (HAM-D)[22] a few days before and 3 months after the operation. The patients were asked about the cosmetic results, including the surgical scar, 1 year after the operation, and their replies were classified as satisfied, moderately satisfied, moderately dissatisfied, and dissatisfied. Follow-up imaging evaluation was basically based on 3D CTA performed 1 year after the operation and every few years thereafter.

The clinical and radiologic data were compared with those of unruptured AcomA or MCA aneurysms as studied and reported by us previously. All data were collected from the medical charts by

Figure 1. Preoperative and postoperative images of a representative case of internal carotid artery (ICA)-posterior communicating artery (PcomA) aneurysm. (**A**) Preoperative digital subtraction angiography image showing laterally projecting ICA-PcomA aneurysm. (**B**) Preoperative simulation using 3-dimensional (3D) computed tomography angiography (CTA) multifusion image. The keyhole generated by computer graphics is applied to the skull to determine the optimal supraorbital keyhole. (**C**) Postoperative 3D CTA multifusion image.

the treating physicians. The Kruskal–Wallis, χ^2, or Fisher exact test was used to compare outcomes between these 3 groups, and a P value of less than 0.05 was considered to be significant.

Statistical Analysis

Data are expressed as mean ± standard deviation. NIHSS, mRS, Barthel index, MMSE, HDS-R, BDI, and HAM-D scores for each follow-up period were compared with the preoperative scores by the Mann–Whitney U test using IBM SPSS Statistics, version 20 (IBM Corp., Armonk, New York, USA). A P value <0.05 was considered as statistically significant.

RESULTS

Surgical Results

Table 2 shows the surgical characteristics of the 51 cases of unruptured ICA aneurysms. 3D CTA performed immediately after surgery showed complete neck clipping in 45 (88.2%) of

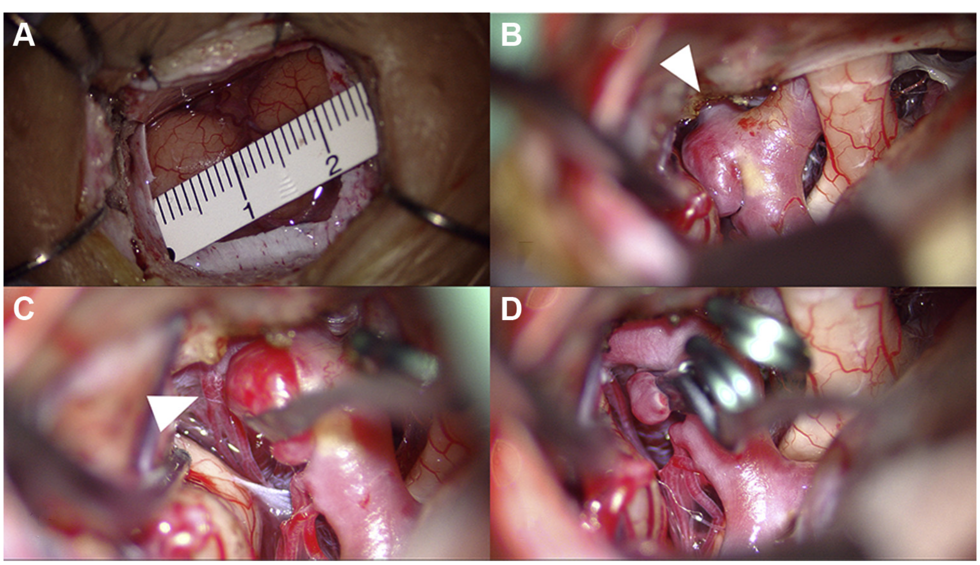

Figure 2. Intraoperative photographs of clipping of a representative case of internal carotid artery (ICA)-posterior communicating artery (PcomA) aneurysm through the supraorbital keyhole approach. (**A**) After dural opening. (**B**) After exposing the ICA-PcomA aneurysm complex. *Arrowhead* indicates the partially resected cerebellar tent. (**C**) Dissecting the perforators (*arrowhead*) from the PcomA behind the dome. (**D**) After neck clipping.

Table 2. Operative Data of the 51 Patients with Unruptured ICA Aneurysm Treated by the Supraorbital Keyhole Approach

Diameters of supraorbital mini-craniotomy	
Maximum diameter, mm, mean ± SD	28 ± 2
Minimum diameter, mm, mean ± SD	22 ± 2
State of clipping of ICA aneurysms	
Complete clipping	45 (88.2%)
Neck remnant (dog-ear)	4 (7.9%)
Wrapping	2 (3.9%)
State of clipping of other aneurysms	
Complete clipping	4
Intraoperative rupture	0
Other intraoperative problems	0
Operation time, minutes, mean ± SD (range)	171 ± 33 (122–273)
Complications	
Hemiparesis	1 (2.0%)
Oculomotor palsy (transient)	1 (2.0%)
Frontalis muscle weakness (transient)	1 (2.0%)
Seizure	0
Meningitis	0
Wound infection	0
CT/MRI abnormalities	
Lacunar infarction	1 (2.0%)
Brain contusion	0
Acute epidural/subdural hematoma	0
Chronic subdural hematoma	5 (9.8%)
Hospitalization time after the operation, days, mean ± SD (range)	3.4 ± 6.9 (1–51)

ICA, internal carotid artery; SD, standard deviation; CT, computed tomography; MRI, magnetic resonance imaging.

the 51 ICA aneurysms. Four aneurysms (7.9%) showed "dog-ear" neck remnant. Wrapping was performed for the 2 cases of ICA-AntChoA aneurysms, one of which had a small AntChoA branching from the dome and the other showed motor-evoked potential changes even after multiple clipping trials. The 4 other aneurysms were completely clipped.

Perioperative complications occurred in 3 cases (6%): hemiparesis caused by lacunar infarction in 1 patient with ICA-AntChoA aneurysm resulting in permanent deficit (mRS 3), transient oculomotor nerve palsy in 1 patient, and transient frontalis muscle weakness in 1 patient. Postoperative Computed tomography/magnetic resonance imaging (CT/MRI) showed no abnormality except for lacunar infarction in 1 patient. Chronic subdural hematoma was detected in 5 (9.8%) patients and surgically evacuated without sequelae. The mean duration of postoperative hospitalization was 3.4 ± 6.9 days. Six patients (11.8%) were discharged on the next day (overnight hospital stay), and 45 patients (88.2%) were discharged within 3 days of the operation.

Long-Term Clinical Follow-up

The mean clinical follow-up period was 6.6 ± 3.2 years (1–12 years). One patient died of leukemia during the follow-up period and 5 patients were lost to follow-up. No death related to the surgery occurred. Two patients had persistent neurologic deficits of mRS ≥2. One patient had lacunar infarction after keyhole clipping of ICA-AntChoA aneurysm resulting in mRS 3. The other patient suffered recurrence of ICA-PcomA aneurysm 8 years after the keyhole clipping and was treated at another institution resulting in mRS 5. No patient showed MMSE of less than 24 points. Therefore, the overall ISUIA morbidity (mRS ≥2 or MMSE <24) was 3.9%. No patient had subarachnoid hemorrhage. The follow-up findings at each time point are shown in **Table 3**. Both MMSE and HDS-R cognitive scores were significantly improved at 3 months and not significantly changed at 1 year and last examination after the operation compared with the preoperative values. Levels of depression estimated by both BDI and HAM-D were significantly improved at 3 months after the operation. Cosmetically, 47 patients (92.2%) were satisfied, 1 moderately satisfied, and 3 moderately dissatisfied.

Long-Term Radiologic Follow-up

The mean follow-up period was 6.3 ± 3.1 years (1–12 years). The follow-up findings at each time point are shown in **Table 4**. No aneurysm recurrence was noted in the 45 cases of completely clipped aneurysms including associated clipped aneurysms. However, 2 ICA-PcomA aneurysms among the 4 aneurysms with neck remnants showed regrowth. One case showed recurrence at 8 year and was reoperated at another institution, and the other showed recurrence at 10 years and continues to be followed up. Two patients with ICA-AntChoA aneurysms treated with wrapping showed no change. Two de novo aneurysms were found at the last examination. All de novo aneurysms were small (1–2 mm) and were followed up without intervention.

Clinical and Radiologic Results of Keyhole Clipping of ICA Aneurysms and Comparisons with Other Aneurysms

Table 5 summarizes the clinical and radiologic findings of unruptured aneurysms of the AcomA,[1] MCA,[2] and ICA (present study) clipped via keyhole mini-craniotomies by the same senior author (K.M.) in the same institutions during almost the same time period.

Rates of Surgical Indication for Keyhole Surgery

The rates of indication for keyhole clipping were 60% for AcomA and 57% for MCA aneurysms but was significantly lower at 33% for ICA aneurysms. These indications for keyhole clipping were carefully determined by the same senior author (K.M.) based on the limited surgical indications for unruptured ICA aneurysms at each location.

Table 3. Long-Term Clinical Follow-Up of 51 Patients with Unruptured ICA Aneurysm

		3-Month Postoperative		1-Year Postoperative		Last Examination (Mean 6.6 Years)	
	Preoperative		*P* Value		*P* Value		*P* Value
Neurologic state							
NIHSS (no. of patients)			<0.005		NS		NS
0	49	50		49		48	
1	2	0		0		0	
≥2	0	1		1		2	
mRS (no. of patients)			<0.005		NS		NS
0	49	50		49		48	
1	2	0		0		0	
≥2	0	1		1		2	
Barthel index 100 (no. of patients)	51	50	NS	49	NS	48	NS
Cognitive function							
MMSE score, mean ± SD	28.7 ± 2.1	29.3 ± 1.2	<0.05	29.0 ± 1.4	NS	28.9 ± 2.3	NS
HDS-R score, mean ± SD	28.1 ± 2.3	29.0 ± 1.3	<0.01	29.1 ± 1.0	NS	28.3 ± 1.8	NS
MMSE <24 (no. of patients)	0	0		0		0	
Depression state							
BDI score, mean ± SD	5.8 ± 5.9	2.5 ± 4.6	<0.001				
HAM-D score, mean ± SD	4.1 ± 4.0	1.5 ± 2.1	<0.001				

Data were analyzed by the Wilcoxon signed-rank test.
ICA, internal carotid artery; NIHSS, National Institute of Health Stroke Scale; NS, not significant; mRS, modified Rankin Scale; MMSE, Mini-Mental Status Examination; SD, standard deviation; HDS-R, Revised Hasegawa Dementia Scale; BDI, Beck Depressive Inventory; HAM-D, Hamilton Depression Scale.

DISCUSSION

Previous studies of the supraorbital keyhole approach to clip anterior circulation aneurysms have shown that this approach is safe, effective, and less invasive (less soft-tissue damage), so provides an alternative method comparable to standard craniotomy,[5,11,23] but both the advantages and disadvantages of the keyhole concept must be carefully considered from the viewpoint of safety. Keyhole surgery provides a straight-axis trajectory, so the limited operative angle hinders multidirectional observation and manipulation of the target aneurysm. Use of endoscopy

Table 4. Long-Term Radiologic Follow-Up of 51 Cases with Unruptured ICA Aneurysm

	Day After Operation ($n = 51$)	1 Year After Operation ($n = 50$)	Last Check (Mean 6.3 Years) ($n = 50$)
Modality (3D CTA/MR angiography)	51/0	46/4	41/9
MCA aneurysm ($n = 154$)			
Complete clipping	45	45 (all complete)	45 (all complete)
Neck remnant	4	4 (no change)	2 (no change), 2 (regrowth)
Wrapping	2	2 (no change)	2 (no change)
Other treated aneurysms ($n = 4$)	4 (all complete)	4 (all complete)	4 (all complete)
Other untreated aneurysms ($n = 7$)	7 (all no change)	7 (all no change)	7 (all no change)
De novo aneurysm ($n = 2$)	0	0	2

ICA, internal carotid artery; 3D CTA/MR, 3-dimensional computed tomography angiography/magnetic resonance; MCA, middle cerebral artery.

Table 5. Comparisons of Clinical and Radiologic Results of Keyhole Clipping in Different Aneurysm Locations Treated by the Same Operator

Target Aneurysm (Number)	AcomA (63) Ref. 1	MCA (160) Ref. 2	ICA (51) Present Study	*P* Value*
Mean age, years, mean ± SD	64 ± 8	62 ± 9	62 ± 10	NS
Sex, female/male	41:22	109:40	27:24	NS
Mean size of aneurysm, minutes, mean ± SD	6.4 ± 1.7	6.4 ± 1.8	5.8 ± 1.8	NS
Type of mini-craniotomy	Lateral supraorbital	Pterional	Supraorbital	
Maximum diameter, mm, mean ± SD	30 ± 3	25 ± 2	28 ± 2	0.001
Rate of keyhole surgery	63/105 (60.0%)	160/280 (57.1%)	51/155 (32.9%)	0.001
State of clipping				0.01
Complete clipping	62 (98.4%)	157 (98.1%)	45/51 (88.2%)	
Dome remnant	0	1	0	
Neck remnant	1	1	4	
Wrapping	0	1	2	
Operation time, minutes, mean ± SD	198 ± 37	171 ± 39	171 ± 33	0.001
Perioperative complication	5/63 (7.9%)	10/160 (6.3%)	3/51 (5.9%)	NS
CT/MR abnormalities				NS
Lacunar infarction	0 (0%)	8/160 (5.0%)	1/51 (2.0%)	
Symptomatic/non-symptomatic	0:0	2:6	1:0	
Brain contusion	0	0	0	
Acute epidural/subdural hematoma	0	0	0	
Hospitalization after operation, days, mean ± SD	2.4 ± 2.2 days	2.3 ± 3.4	3.4 ± 6.9	0.01
Chronic subdural hematoma	2/63 (3.2%)	6/160 (3.8%)	5/51 (9.8%)	NS
Mean clinical follow up, years, mean ± SD	5.2 ± 2.1	5.4 ± 2.7	6.6 ± 3.2	0.001
Overall mortality	0	0	0	
Overall morbidity	1/63 (1.6%)	0/160 (0%)	2/51 (3.9%)	NS
mRS ≥2	0	0	2	0.05
MMSE <24	1	0	0	NS
Mean radiologic follow-up, years, mean ± SD	4.9 ± 2.1	5.0 ± 2.7	6.3 ± 3.1	0.05
Recurrence	0/63 (0%)	0/160 (0%)	2/51 (3.9%)	0.05
Cosmetic results				NS
Satisfied	56 (88.9%)	137 (85.6%)	47 (92.2%)	
Moderately satisfied	7	17	1	
Moderately dissatisfied	0	6	3	
Dissatisfied	0	0	0	

AcomA, anterior communicating artery; MCA, middle cerebral artery; ICA, internal carotid artery; SD, standard deviation; NS, not significant; CT/MR, computed tomography/magnetic resonance; mRS, modified Rankin Scale; MMSE, Mini-Mental Status Examination.
*Kruskal—Wallis, χ^2, or Fisher exact test was used.

during the keyhole approach can increase light intensity, broaden the operative viewing angles, allow close observation of the aneurysm complex including the perforators, and confirm complete neck clipping,[8] but endoscopy cannot enhance microsurgical manipulations such as detaching a perforator behind the aneurysm. Therefore, our institution limits the indications for keyhole surgery for safety. The ICA aneurysm complex is highly individualized and careful preoperative simulation using 3D CTA helps us to make the optimum decision whether or not to select keyhole clipping in each patient.

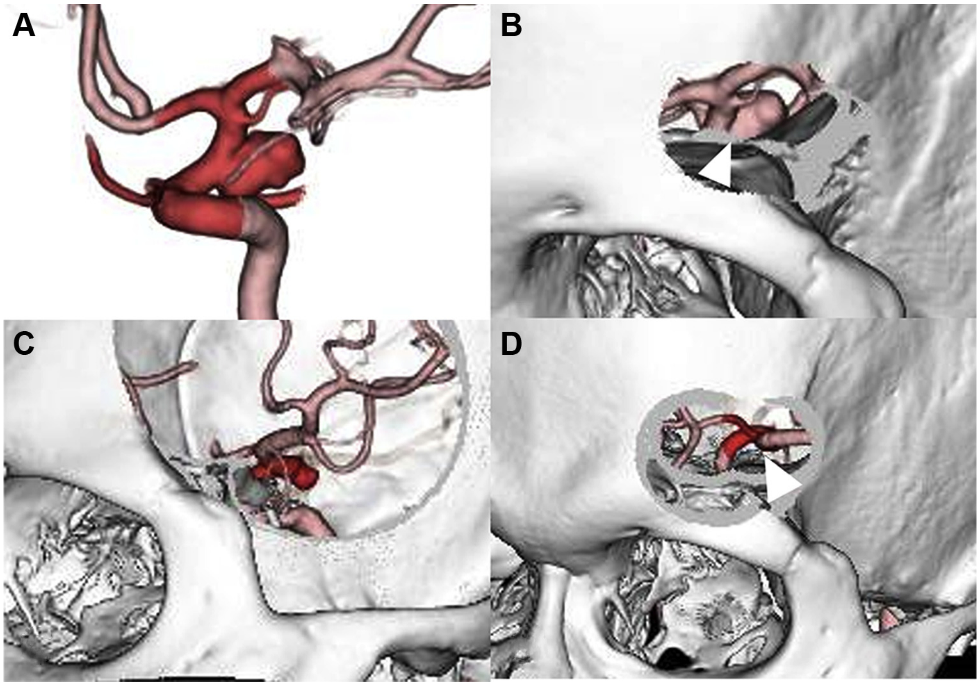

Figure 3. Two cases of internal carotid artery (ICA)-posterior communicating artery (PcomA) aneurysms considered not suitable for supraorbital keyhole clipping. (**A**–**B**) ICA-PcomA aneurysm with short and low-lying ICA. Computer graphic image showing the proximal neck and the PcomA hidden by the anterior clinoid process (*arrowhead*). (**C**–**D**) Posteriorly projecting ICA-PcomA aneurysm. The aneurysm cannot be observed through the supraorbital keyhole (*arrowhead*) generated by computer graphics.

Surgical Indications and Limitations of Supraorbital Keyhole Clipping for ICA Aneurysms

ICA-PcomA Aneurysms. The ICA-PcomA is the most frequently encountered location for unruptured ICA aneurysms.[24] Laterally projecting ICA-PcomA aneurysm is generally considered as a good indication for keyhole clipping.[10,12,13] The morphologic variations of the supraclinoid carotid siphon of the ICA are very important. ICA-PcomA aneurysm of the low-lying and short ICA carries potential risks, such as no clipping space for proximal control and hidden aneurysm complex under the tent.[25-28] As many as 11.1%–15.5% of ICA-PcomA aneurysms require either anterior clinoidectomy or resection of the tent for clipping via standard craniotomy.[25,29] Moreover, posteriorly projecting ICA-PcomA aneurysms require the anterior temporal approach to observe and manipulate the aneurysms.[30,31] In our institution, we carefully examine the anatomical variations of the parent ICA and ICA-PcomA aneurysms, and aneurysms that apparently require complicated procedures such as anterior clinoidectomy and tentorial incision are basically not indicated for keyhole clipping for safety (Figure 3).

ICA-AntChoA Aneurysms. ICA-AntChoA aneurysms are generally small and sometimes associated with larger ICA-PcomA aneurysm as kissing aneurysms.[32,33] Most ICA-AntChoA aneurysms project laterally, and the AntChoA is generally divided from the posterolateral wall and the proximal part runs lateral to the ICA. Consequently, the AntChoA is frequently incorporated in the base of the aneurysm and may be hidden by the dome, so that AntChoA occlusion during clipping surgery carries the risk of various serious neurologic deficits.[32,34,35] For that reason, DSA is still required for ICA-AntChoA aneurysm among the various ICA aneurysms (Figure 4). Among our 51 ICA aneurysms, the one case of ICA-AntChoA aneurysm resulted in persistent hemiparesis due to lacunar infarction.

ICA Bifurcation Aneurysms. The direction of the fundus of ICA bifurcation aneurysms is varied but can be classified into 3 types, anterior, superior, and posterior projection.[15,36-38] The direction of the aneurysm dome and the height are major determinants of surgical difficulties.[36,37] Observation and manipulation of perforators behind the neck and dome require more lateral microscopic view, which is hard to obtain by the supraorbital keyhole approach. However, anterior projection ICA bifurcation aneurysm is a good indication for supraorbital keyhole clipping (Figure 5).

ICA Paraclinoid Aneurysms. Surgical clipping of ICA paraclinoid aneurysms via standard craniotomy is still challenging because of the vicinity to vital neurovascular structures. We performed keyhole clipping in only 3.7% of cases of ICA paraclinoid aneurysms, which were very small but required partial anterior clinoidectomy (Figure 6). We suggest that the supraorbital keyhole approach is not generally indicated to clip ICA paraclinoid aneurysm.

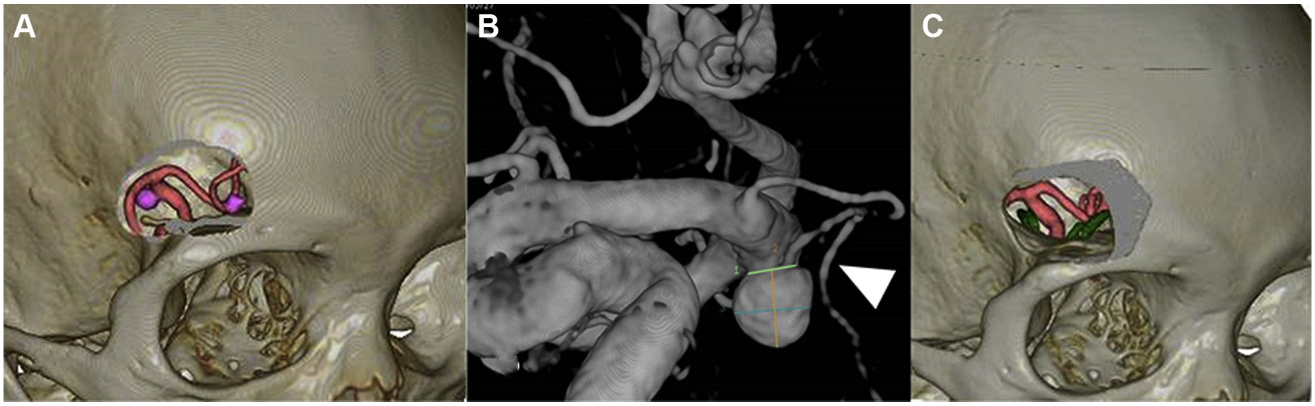

Figure 4. Preoperative and postoperative images of a representative case of internal carotid artery (ICA)-anterior choroidal artery (AntChoA) aneurysm. (**A**) Preoperative simulation using 3-dimesnional (3D) computed tomography angiography (CTA) multifusion image. The image shows the IC-AntChoA and anterior communicating artery; aneurysms. (**B**) Preoperative Digital subtraction angiography image showing the AntChoA running apart from the aneurysm neck (*arrowhead*). (**C**) Postoperative 3D CTA multifusion image.

Clinical and Radiologic Results of Keyhole Clipping of ICA Aneurysms and Comparisons with Other Aneurysms

Completeness of Clipping. Several studies have reported radiologic outcomes after clipping surgery with complete occlusion rates in excess of 90%.[39-41] In the present study, the rate of complete clipping of ICA aneurysms was 88% and significantly lower than those of AcomA and MCA aneurysms. This low rate of complete clipping was caused by either dog-ear residue behind the clip blade or unclippable aneurysm.

Perioperative Complications, CT/MRI Abnormalities, and Hospitalization. The rates of perioperative complications and CT/MRI (DWI) abnormalities after ICA aneurysm keyhole clipping were 5.9% and 2.0%, respectively, and not significantly different compared with those of AcomA and MCA aneurysms. The keyhole approach is less invasive than conventional craniotomy, so the risk of perioperative problems including DWI abnormality is less.[42,43]

Mean hospitalization after ICA clipping was 3.4 ± 6.9 days. We suggest that keyhole clipping for unruptured ICA aneurysm is superior to conventional craniotomy with respect to hospitalization.[44] In addition, no patient had ischemic complication due to vasospasm despite the very short hospitalization period, although 1 patient with ICA-AntChoA aneurysm developed lacunar infarction without vasospasm. The rate of chronic subdural hematoma after keyhole clipping for ICA aneurysms was as high as 9.8% but not significantly different compared with those for AcomA and MCA aneurysms. Our high rate of occurrence might have been caused by the relatively high age of the patients, relatively high proportion of male patients (47%), and excessive cerebrospinal fluid removal during keyhole clipping.[45-47] We may introduce some modifications such as arachnoid plasty to reduce the risk of chronic subdural hematoma.[45]

Long-Term Neurologic State and Overall Mortality and Morbidity. The ISUIA showed asymptomatic patients aged younger than 50 years

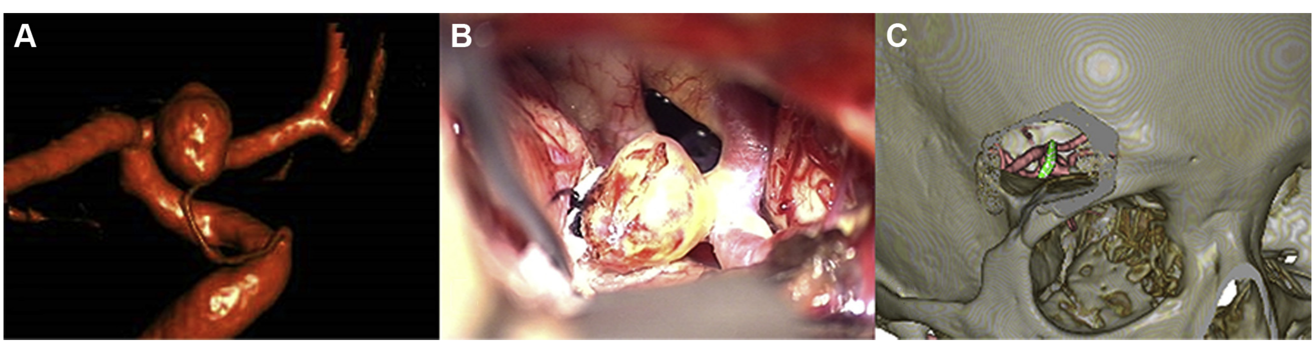

Figure 5. Pre-, intra-, and postoperative images of a representative case of internal carotid artery (ICA) bifurcation aneurysm. (**A**) Preoperative digital subtraction angiography image showing anteriorly projecting ICA bifurcation aneurysm. (**B**) Intraoperative photograph showing anteriorly projecting ICA bifurcation aneurysm. (**C**) Postoperative 3-dimensional computed tomography angiography multifusion image.

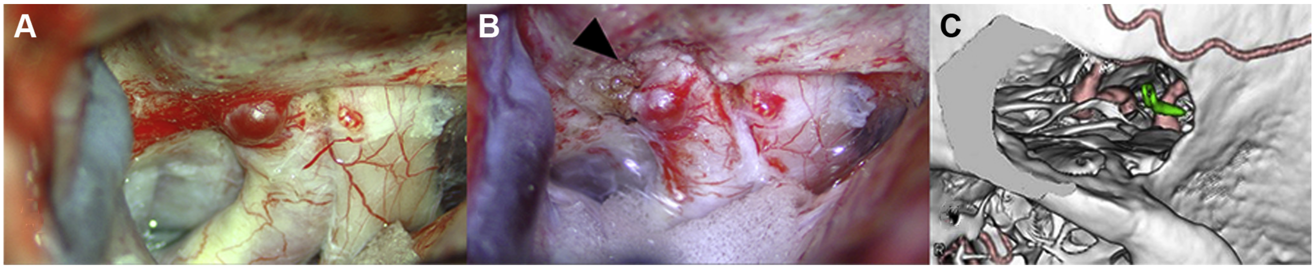

Figure 6. Intraoperative and postoperative images of a representative case of internal carotid artery (ICA) paraclinoid aneurysm. (**A**) Intraoperative photograph showing small ICA paraclinoid aneurysm. (**B**) Intraoperative photograph showing the partially resected anterior clinoid process (arrowhead). (**C**) Postoperative dimensional computed tomography angiography multifusion image.

with UCAs excluding giant aneurysms in the anterior circulation suffer surgical mortality and morbidity of 5%–6% at 1 year.[20] Mortality and morbidity after clipping surgery for UCAs of less than 10-mm diameter is generally as low as 0.6%–0.9%.[48,49] However, this rate increased to 9.6% in patients older than 70 years.[50] The recent pragmatic randomized trial showed the mortality and morbidity of patients with UCAs treated by surgical clipping (mostly less than 10-mm diameter and anterior circulation aneurysms) was 4.2% at 1 year.[51] In the present study, the mean age of the patients with unruptured ICA aneurysms was 62 years, including 13 patients (25%) older than 70 years. Long-term overall mortality and morbidity of keyhole clipping was 3.9% at mean 6.6 $\pm$ 3.2 years, which is comparable with that of clipping through standard craniotomy.[52] The present overall mortality and morbidity were not significantly different compared with those of keyhole clipping of AcomA and MCA aneurysms, but the rate of mRS $\geq$2 was significantly greater than those of AcomA and MCA aneurysms despite the strict surgical indications. We assume that checking the state of perforators and residual neck after keyhole clipping was more limited in the cases of ICA aneurysm.

According to the ISUIA, the rate of impaired cognitive function (MMSE $<$24) was 8.5% for surgical clipping and 5.4% for endovascular coiling.[20] In this study, no patient showed impaired cognitive function. The quality of life of patients with UCAs is also reduced by anxiety and depression, resulting from fear of aneurysm rupture and treatment complications.[53] In the present study, the depressive mood significantly improved after treatment. We can conclude that keyhole clipping for ICA aneurysms has less effect on the quality of life of patients.

Aneurysm Recurrence. The incidence of recurrence after complete clipping of aneurysms is low (0.02%–1.5%/year), but the total annual angiographic recurrence rate in clipped aneurysms including residual aneurysms has been estimated as 0.5%–2.9%.[39,54-56] Angiographic regrowth rate of aneurysms including dog-ear remnant after clipping surgery ranges as high as 3.7%–25% after mean angiographic follow-up period of 4.4–8 years.[39,54,57] In the present study, 2 (3.9%) of 51 cases of unruptured ICA aneurysms showed recurrence, both of which were ICA-PcomA aneurysm with dog-ear remnant. The findings that residual aneurysm including dog-ear remnant is a strong predictive factor of late regrowth suggests that the ICA aneurysms, especially ICA-PcomA aneurysms, require careful checking for neck remnant after clipping.[39,54,58] Observation of the clip condition after clipping of ICA-PcomA aneurysm might be limited in keyhole surgery because the dog-ear remnant is located in the posterior wall of the ICA behind the clip blade. This may be one of the drawbacks in keyhole clipping of ICA-PcomA aneurysms and will require more careful checking for dog-ear remnant.

Cosmetic Results. Cosmetic results were considered satisfactory by 92.2% of the patients after keyhole clipping via eyebrow skin incision, greater than those of AcomA and MCA keyhole clipping surgeries, but without statistical significance.

CONCLUSIONS

Our long-term results were comparable with clipping by standard craniotomy and less invasive in some aspects. Long-term durability was good after complete clipping, but the rate of dog-ear neck remnants was not negligible. We conclude that supraorbital keyhole clipping for ICA aneurysms requires strict surgical indications based on preoperative simulation and careful checking of the post clipping state.

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