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Original Article

On clipping of anterior communicating artery aneurysm via eyebrow-lateral keyhole approach

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Abstract: Objective: To evaluate the application of eyebrow-lateral keyhole approach in clipping of anterior communicating artery aneurysm (ACAA) through observing the therapeutic effect of eyebrow-lateral keyhole approach on ACAA. Methods: In 37 patients with ACAA, cisterns were exposed via the eyebrow-lateral keyhole approach to reveal ACAA complex followed by clipping of ACAA. Of the 37 patients, external ventricular drainage was performed on 5 patients before microsurgery. All patients underwent head CT angiography on the second day after operation. Results: Clipping of ACAA was successful in all patients at the first time. In 3 patients, ruptured aneurysm occurred during operation. Three patients underwent ventriculoperitoneal shunt because of postoperative hydrocephalus. Two patients had one-sided anterior cerebral artery infarction after operation. No patient died during operation. Follow-up after the operation indicated that 26 patients returned to normal life and work, 6 patients were able to look after themselves, 4 patients required care in their daily life and one patient died. Conclusion: The eyebrow-lateral keyhole approach is a preferred choice for surgical treatment of ACAA because it can cope with brain swelling and intraoperative ruptured aneurysm. However, it has a certain range of application, so we must strictly follow its indications.

Keywords: Keyhole, anterior communicating artery aneurysm, microsurgery

Introduction

Anterior communicating artery aneurysm (ACAA), one of the most common intracranial aneurysms, accounts for 30%~35% of all intracranial aneurysms [1]. There is usually no symptom before ruptured ACAA but after ruptured ACAA, iconography commonly shows subarachnoid hemorrhage (SAH), which mostly accumulates in suprasellar cistern, cerebral longitudinal fissure or cisterna lamina terminalis, and sometimes forms hematoma under frontal lobe or in lateral ventricles [2].

The anatomic structure in the region around anterior communicating artery (ACA) is complex, and aneurysm is closely related to some important structures, such as peripheral perforating vessels, hypothalamus and optic chiasm; so the exposure of aneurysmal neck segment is difficult [3]. ACA complex is quite variable, with lots of branch and perforating arteries, supplying some important regions, such as hypothalamus, optic chiasm, lamina terminalis and corpus callosum [4]. These features make clipping of ACAA become the most difficult surgery among anterior circulation aneurysms, and clipping of ACAA is still a challenge for neurosurgeons [5].

Pterion approach as a standard method for clipping of ACAA has been widely accepted, yet there are still some problems, such as temporalis atrophy and facial nerve injury of frontal branch. With improvement of anatomical knowledge, and progresses of microscopic instruments and surgical techniques, keyhole approach for clipping of ACAA is winning approval of neurosurgeons. Supraorbital keyhole and related improved approaches can treat most suprasellar and parasellar lesions including ACAA [6]. The cases which are treated by keyhole approach and well recover become more and more, but there is still debate about keyhole approach for clipping of ACAA. Some doctors believe that keyhole approach for clipping of ACAA brings a certain degree of difficulty for

Table 1. Case information

Items	Case (n)
Sex	
Male	24
Female	13
Symptoms ad signs	
Headache	35
Vomiting	33
Consciousness disorders	12
Meningeal irritation sign	33
Hunt-Hess grading	
Grade 0	2
Grade I	5
Grade II	18
Grade III	9
Grade IV	2
Grade V	1
Fisher grading	
Grade 1	2
Grade 2	22
Grade 3	2
Grade 4	11
Aneurysmal directionality	
Aneurysm pointing upwards	8
Aneurysm pointing downwards	12
Aneurysm pointing forwards s	8
Aneurysm pointing backwards	6
Aneurysm pointing toward multiple directions	3
ACA complex variation	
Right dominant blood supply	13
Left dominant blood supply	17
No marked variation	7

Note: ACA: anterior communicating artery.

coping with posthemorrhagic swollen brain tissues and intraoperative ruptured aneurysm [7]. Since 2011, we have treated ACAA via eyebrow-lateral keyhole approach and have obtained better therapeutic effects. Now we report and summarize our experience to resolve the debate about clipping of ACAA via eyebrow-lateral keyhole approach.

Materials and methods

All study methods were approved by Institutional Review Board and Ethics Committee of the Third Affiliated Hospital, Sun Yat-sen University. All the subjects or their guardians enrolled into the study gave written formal consent to participate.

Subjects

Between January 2011 and November 2014, microsurgical clipping of ACAA via eyebrow-lateral keyhole approach was performed on 37 patients in our department. Of the 37 patients, 24 were men and 13 women, with a mean age of 46.3 years (range 5-76) (**Table 1**).

Subarachnoid hemorrhage (SAH) occurred in 35 patients. Of the 35 patients, SAH occurred twice in 2, and SAH was found during physical examination in 2. All patients were hospitalized within 24-48 h after symptom onset. Of the 37 patients, 35 had sudden headache, 33 vomiting, 12 consciousness disorders, 33 positive meningeal irritation sign, 5 hydrocephalus, 7 intracerebral hematoma, and 11 intraventricular hemorrhage (**Table 1**).

Hunt-Hess grading and fisher grading

Preoperative Hunt-Hess grading was grade 0 in 2 patients, grade I in 5 patients, grade II in 18 patients, grade III in 9 patients, grade IV in 2 patients and grade V in one patient (**Table 1**).

Preoperative Fisher grade 1 in 2 patients, grade 2 in 22 patients, grade 3 in 2 patients and grade 4 in 11 patients are shown in **Table 1**.

Imaging

Aneurysmal number and size: The 37 patients were diagnosed with ACAA by head CT angiography (CTA) using 320-slice CT (Aquillion One, Toshiba, Tokyo, Japan). For the 37 patients, there were a total of 37 aneurysms with a mean diameter of 4.8 mm (range: 1.4-16 mm).

Aneurysmal directionality: According to Yasargil typing method [8], aneurysm pointing upwards in 8 patients, pointing downwards in 12 patients, pointing forwards in 8 patients, pointing backwards in 6 patients, and pointing toward multiple directions in 3 patients (**Table 1**).

Aneurysm was arranged into two groups according to aneurismal directionality, and then their correlations with blood loss (little blood loss including Fisher grade 1 and 2, and severe

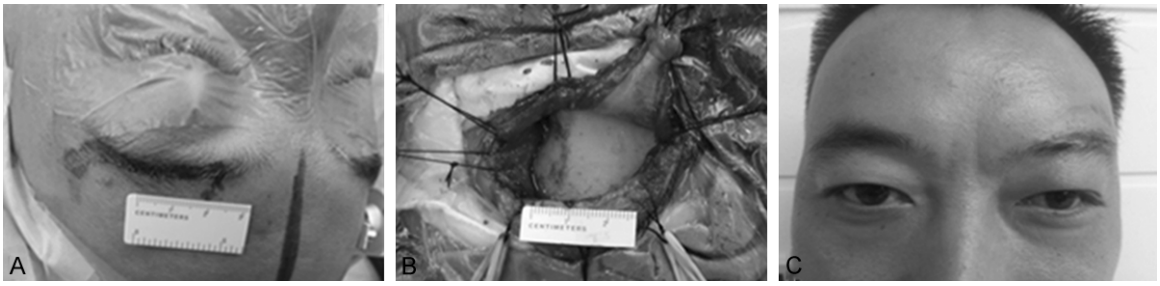

Figure 1. A. Surgical incision; B. Size of bone flap; C. The surgical incision one month after operation.

Table 2. Correlation between aneurismal directionality and blood loss

Aneurysmal directionality	A little blood loss (Fisher 1 and 2)	Severe blood loss (Fisher 3 and 4)	Total
Upwards	2	6	8
Other directions	22	7	29

X^2=7.117; P=0.013.

blood loss including Fisher grade 3 and 4) were analyzed.

ACA complex variation: Thirteen patients had congenital absence or hypoplasia of the left A1, and the right dominant blood supply. Seventeen patients had congenital absence or hypoplasia of the right A1, and the left dominant blood supply. Seven patients had no marked variation (**Table 1**).

Microsurgery

Surgical timing and side: Microsurgery was performed on all patients within 24~48 h after the last SAH. Of the 37 patients, external ventricular drainage was performed on 5 patients before microsurgery. Generally, the side with the dominant blood supply was used for surgical approach because of easily controlling tumor-bearing artery. If at the frontal bottom opposite the dominant blood supply, there was hematoma which needed to be removed; the contralateral side was used for surgical approach. For the patients without marked ACA complex variation, the right side was generally used for surgical approach.

Surgical procedures: The patient's head was lifted up for 15°, rotated to opposite side for 20°~30°, and then tilted back for 20°; so frontal lobe could naturally droop due to gravity, reducing traction towards brain tissues. The incision started from the lateral side of supraorbital foramen, went along supraorbital margin and outwards within eyebrow, then slightly extended outwards at eyebrow-lateral edge, and stopped at 0.5 cm after zygomatic process of frontal bone (**Figure 1A**). During this procedure, supraorbital nerves and blood vessels should be paid more attention to and protected. An incision parallel to orbital margin was made outwards. The upper frontal muscles were pulled upwards with rubber bands, and temporalis was pulled outwards to expose the zygomatic process of frontal bone, low frontal muscles and musculus orbicularis oculi were pushed down to orbital margin and were fixed with sutures. Drilling was performed after the zygomatic process of frontal bone, and then frontal bone was opened along supraorbital margin from outside to inside. After that, a half-moon bone flap with a size of about 2.5 × 2 cm was shaped (**Figure 1B**). The bony protrusions on supraorbital margin and in anterior skull base were removed. Dura mater was cut along a half-moon shape, with its bottom facing towards skull base. After releasing cerebrospinal fluid, internal carotid artery cistern, optic chiasm cistern, basal cistern and lamina terminalis cistern were then cut open to fully expose tumor-bearing artery and aneurysm in the order of internal carotid artery-A1 segment of anterior cerebral artery-aneurysm. The aneurysmal neck was accurately clipped using an appropriate clamp. Before and after clipping the aneurysmal neck, neuroendoscopy or fluorescein angiography were used to observe statuses of aneurysm, tumor-bearing artery and perforating artery. Before closing the skull, papaverine saline was used to fill the subdural space, cerebral dura mater was tightly sutured, bone flap was placed to original position using Ti strips,

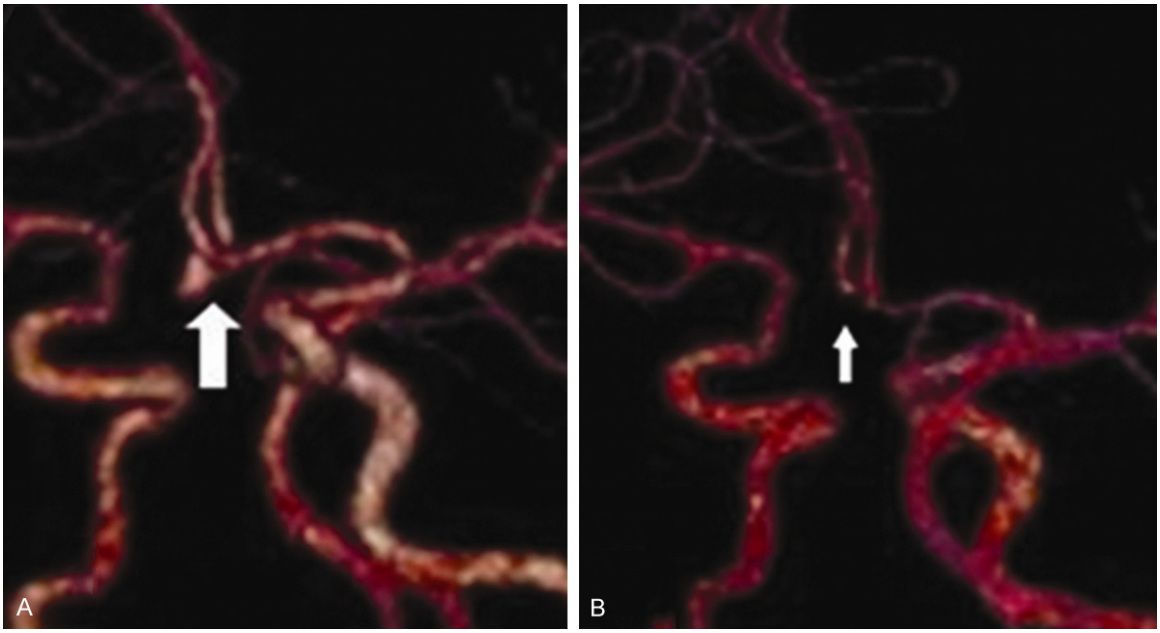

Figure 2. A. Preoperative CT angiography shows that the ACAA points downwards, with hypoplasia of the right A1; B. Postoperative CT angiography shows that the ACAA is occluded, but the tumor-bearing artery is unobstructed.

Table 3. Advantages and disadvantages of pterional and anterior longitudinal fissure approaches for microsurgery of anterior communicating artery aneurysm

Approaches	Advantages	Disadvantages
Pterional approach	A standard approach can sufficiently expose Willis ring and more cisterns, so it is conducive to cisternal douching	It easily damages facial nerve, only can control one-sided A1 in advance and unnecessarily exposes temporal lobe
Anterior longitudinal fissure approach	It can sufficiently expose bilateral A1	It easily opens frontal sinus, and makes the distance from aneurysm be longer. If there is adhesions involving frontal lobe, when the frontal lobe is pulled aside, ruptured aneurysm readily occurs

muscles were sutured layer by layer without drainage catheter and intradermal suture was finally performed using 4-0 suture (**Figure 1C**). All patients underwent CTA on the second day after operation.

Statistical analysis

Statistical treatment was performed with SPSS 19.0. Data were analyzed by chi-square test. Statistical significance was established at $P<0.05$.

Results

Correlation between aneurismal directionality and blood loss

Blood loss was more in the aneurysm pointing upwards than in other aneurysms ($P<0.05$) (**Table 2**).

Surgical results and postoperative imaging

Clipping of ACAA was successful in all the 37 patients at the first time. Surgical duration lasted 2.5 h (range 1.5-3.5 h). Postoperative CTA confirmed that clipping of ACAA was complete and reliable (**Figure 2A**, **2B**), and the tumor-bearing artery and perforating artery were unobstructed. In 3 patients, ruptured aneurysm occurred during operation. We temporarily blocked the tumor-bearing artery, and then separated the aneurysm followed by accurately clipping the aneurysmal neck.

Postoperative complications

Postoperative incisions exhibited various degrees of swelling in the 37 patients, and 2 patients had subcutaneous hydrops. In this study, 2 patients had one-sided anterior cere-

bral artery infarction after operation, and 3 patients had postoperative hydrocephalus which was cured by ventriculoperitoneal shunt.

Follow-up

Follow-up lasted 24 months (range: 2-50). Of the 37 patients, 26 returned to normal life and work, 6 patients were able to look after themselves, 4 patients required care in their daily life and one patient with preoperative Hunt-Hess grade V died. No patients were in vegetative state in this study.

Discussion

Because ACA complex has complicated anatomic structure and severe variation, microsurgical clipping of ACAA is the most difficult surgery among anterior circulation aneurysms, and the therapeutic effect of microsurgical clipping on ACAA is relatively poor [5]. Pterion approach has been widely used as a standard approach for the treatment of ACAA, but such problems as temporalis atrophy and facial nerve injury of frontal branch are still difficult to be completely avoided. Reisch and Perneczky [6] treated most suprasellar and parasellar lesions via supraorbital keyhole and related improved approaches, and achieved good therapeutic outcomes. However, there is still debate about application of keyhole approach in clipping of ACAA, because some doctors believe that keyhole approach for clipping of ACAA can bring a certain degree of difficulty for coping with posthemorrhagic swollen brain tissues and intraoperative ruptured aneurysm [7]. We used the eyebrow-lateral keyhole approach in microsurgical clipping of ACAA, and achieved satisfactory therapeutic outcomes.

In this study, we found that blood loss was more sever in aneurysm pointing upwards. This may be due to narrow space.

Advantages of the eyebrow-lateral keyhole approach

A new or controversial technique can be accepted, it must have more advantages than traditional techniques. The most common approaches for clipping of ACAA currently include pterional and anterior longitudinal fissure approaches. The advantages and disadvantages of the two approaches are listed in **Table 3** [9-11].

Compared with the above two traditional approaches, the eyebrow-lateral keyhole approach has the following advantages [12]: ① It can directly reach the region of ACA complex through the natural gap in frontal base, reducing or even avoiding pulling the brain; ② The brain tissues exposed to air are greatly reduced because the bone flap is 2.5 cm × 2 cm; ③ Because the incision extends towards eyebrow-lateral side, it possesses the advantage of pterional approach, more exposed cisterns conducive to cisternal douching, and avoids the disadvantage of pterional approach, unnecessarily exposes temporal lobe; ④ Surgical duration is short and postoperative recovery is rapid. In this study, the mean surgical duration was 2.5 h among which cranial cut-open and closure generally took about 40-60 min, shortening surgical duration; ⑤ It can avoid facial nerve injury of frontal branch without occurrence of facial paralysis; ⑥ It does not require shaving of hair and eyebrows, which can retain patients' appearance and can greatly relieve the fear of surgery from patients and their families. In this study, among the 37 patients, except one patient with preoperative Hunt-Hess grade V who died, 32 patients (86.5%) were able to look after themselves, no patients were in persistent coma, with satisfactory therapeutic effects.

Solutions to the problems in eyebrow-lateral keyhole approach

The eyebrow-lateral keyhole approach has many advantages, but some neurosurgeons still do not accept it, because they believe that there is a certain degree of difficulty for coping with posthemorrhagic swollen brain tissues and intraoperative aneurysmal rupture in eyebrow-lateral keyhole approach [13-15].

As for brain swelling, we adopted the following principles: ① For slight brain swelling, the bones in frontal base should be fully removed, and the projected iliac crest in anterior skull base should be grinded and polished. Dehydration should be performed before microsurgery; and after brain tissues are exposed, an appropriate hyperventilation should be done. Brain spatula should be rationally used with appropriate traction. Chiasmatic cistern, carotid artery cistern and lateral cleft cistern are opened in order to release cerebrospinal fluid,

waiting for the collapse of brain tissue. ② For severe brain swelling, especially for CT-showed enlarged ventricle, the external ventricular drainage should be first performed. If the aneurysm still can not be sufficiently exposed after releasing cerebrospinal fluid in some patients, partial gyrus rectus may be cut to obtain space. In general, brain swelling is not severe in most patients with ACAA. When brain swelling is marked, the swelled brain tissues which do not require to be exposed may be squeezed and damaged by the edge of bone window. However, the keyhole approach is able to protect this part of brain tissues under the skull. In this study, there were good exposures in all the 37 patients, external ventricular drainage was performed on 5 patients before microsurgery, and partial gyrus recti were intraoperatively cut in 4 patients.

Intraoperative ruptured aneurysm is the most dangerous situation, which is also the important reason why many neurosurgeons do not accept the keyhole approach [16]. The top of aneurysm is a common ruptured site because in the eyebrow-lateral keyhole approach, the tops of the aneurysms pointing downwards and forwards, first enter operative field with blocking the exposure of aneurysmal neck, and inappropriately pulling the frontal lobe readily leads to ruptured aneurysm when there is adhesions between the top of aneurysm and skull base caused by bleeding [10, 17]. To avoid intraoperative ruptured aneurysm, we should pay special attention to the following points: ① Carefully read imaging data preoperatively to determine tumor-pointing direction, and analyze the possibility of intraoperative ruptured aneurysm to perfect surgical schema [18]; ② Use the side with dominant blood supply as surgical approach, which is conducive to controlling tumor-bearing artery [19]; ③ The aneurysm is exposed from subarachnoid space rather than from brain parenchyma. Sharp dissection is conducive to avoiding ruptured aneurysm, and dissociation sequence is from proximal and distal ends of tumor-bearing artery to aneurysm, which provides a possibility to block the tumor-bearing artery when it is necessary to prevent or treat intraoperative ruptured aneurysm [20]; ④ When the exposure of aneurismal neck is difficult, cerebrospinal fluid should be released to obtain a space, or a cross-hemangioma clamp is used for clipping of ACAA under neuroendoscopic observation. If intraoperative ruptured aneurysm occurred, the surgical field is first cleaned with a double suction instrument, a pressure is applied to the broken point with small pieces of cotton, A1 segment is temporarily blocked, and the aneurysmal neck is rapidly separated followed by clipping the aneurysm with an appropriate clamp. In this study, 3 patients had intraoperative ruptured aneurysm, and clipping of ACAA were all successful, respectively, 5 min, 6 min and 9 min after emergency treatment. The 3 patients all obtained good therapeutic effects. Therefore, we believed that the eyebrow-lateral keyhole approach is enough to cope with intraoperative ruptured aneurysm.

Indications of the eyebrow-lateral keyhole approach for treatment of ACAA

Although the eyebrow-lateral keyhole approach has many advantages, it has higher requirements for surgeons and surgical instruments. Besides carefully reading comprehensive imaging data, expertly microsurgical skills, rich experience and specific surgical instruments, the eyebrow-lateral keyhole approach also require certain indications. It is generally applicable to the patients who have Hunt-Hess grade I~III, better conscious state and no severe intracranial hypertension. As to it is suitable for the patients with Hunt-Hess grade IV depends on the statuses of brain cistern, sulci and ventricle showed by CT. It is not suitable for the patients who have Hunt-Hess grade V and severe conditions, such as intracranial hypertension, brain hernia and requiring enlargement of bone window for decompression.

In the eyebrow-lateral keyhole approach, after cranial basal bone is fully removed and cerebrospinal fluid is released from cisterns, the exposed space is able to satisfy clipping of ACAA; if necessary, preoperative external ventricular drainage, or (and) intraoperative removal of partial gyrus recti are performed. The eyebrow-lateral keyhole approach is an effective and ideal approach for clipping of ACAA because it has many advantages, such as slight trauma, better therapeutic effect, fewer complications, more decorative appearance and less cost, but there may be considerable difficulties occurring during operation. Therefore, we propose that individual therapeutic regimens for the patients

with ACAA should be adopted, neither increasing redundant exposure, nor ignoring reasonable exposure because of overemphasis on small incision.

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Disclosure of conflict of interest

None.

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