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Endoscopic transorbital approach for clipping middle cerebral artery aneurysms: a cadaveric study with clinical application (SevEN-14)

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OBJECTIVE The authors examined the clipping of middle cerebral artery (MCA) aneurysms using the endoscopic transorbital approach (ETOA) with cadavers and in clinical cases to clarify which patients are good candidates based on preoperative imaging data.

METHODS To determine the indications for MCA clipping using an ETOA with superior-lateral orbital rim osteotomy, 10 sides of 5 cadavers were investigated. The clippable range, defined as the horizontal range, and exposure of the middle cranial fossa base, defined as the vertical extent area, were evaluated. To assess the ETOA trajectory in the MCA, the superior and inferior maximal angles based on the nasion-sella line were evaluated during cadaveric dissection. To test the surgical properties for actual use, 2 clinical cases were evaluated.

RESULTS The bases of the middle cerebral fossa, which were located below the sphenoid ridge, were accessible in all 5 cadavers. The suction tip and clip applier did not conflict with each other when access was made approximately 17.6 ± 3 mm (mean ± SD) laterally from the cranial midline and 6 ± 2 mm from the median temporal bone margin (clippable range). The superior angle was 16.7° ± 7.8°, and the inferior angle was 18.7° ± 9.6°. Two clinical cases underwent procedures using the ETOA. The aneurysms were at the MCA bifurcation in the anterior direction. The clippable ranges of the patients were 29 mm and 31 mm, respectively, and the distances from the midline to the median temporal bone margins were 32 mm and 36 mm. The M1 lengths were 14.5 mm and 17.2 mm, and the maximal diameters of the aneurysms were 3.58 and 3.67 mm.

CONCLUSIONS Clipping using an ETOA is appropriate for MCA aneurysms with anterior, superior, and inferior dome projections. Aneurysms with a horizontal boundary from the anterior clinoid process to the lateral bone margin of the orbital ball and a vertical boundary around and below the sphenoid ridge can be properly clipped using the ETOA.

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KEYWORDS aneurysm; clipping; endoscopic transorbital approach; middle cerebral artery

Endoscopic neurosurgical tools are gaining popularity owing to improvements in imaging and surgical instruments. Over the past few decades, the endoscopic endonasal approach has become a common technique in endoscopic surgery to access the midline skull base.[1] In the vascular field, minimally invasive surgery has the advantages of a small incision and less cosmetic problems.[2] In this regard, supraorbital, lateral supraorbital, and mini pterional keyhole approaches are gaining popularity in microscopic vascular surgery.[3,4] Recently, the transorbital approach (TOA) has become a mainstay treatment, especially for the anterior and middle fossa that usually require the traditional skull base approach.[5] In the neurovascular field, TOA using a microscope has been applied in some studies.[2,6–9] These studies investigated a wide range of surgical fields and showed feasible results for an-

ABBREVIATIONS ACP = anterior clinoid process; ETOA = endoscopic TOA; ICA = internal carotid artery; MCA = middle cerebral artery; TOA = transorbital approach.

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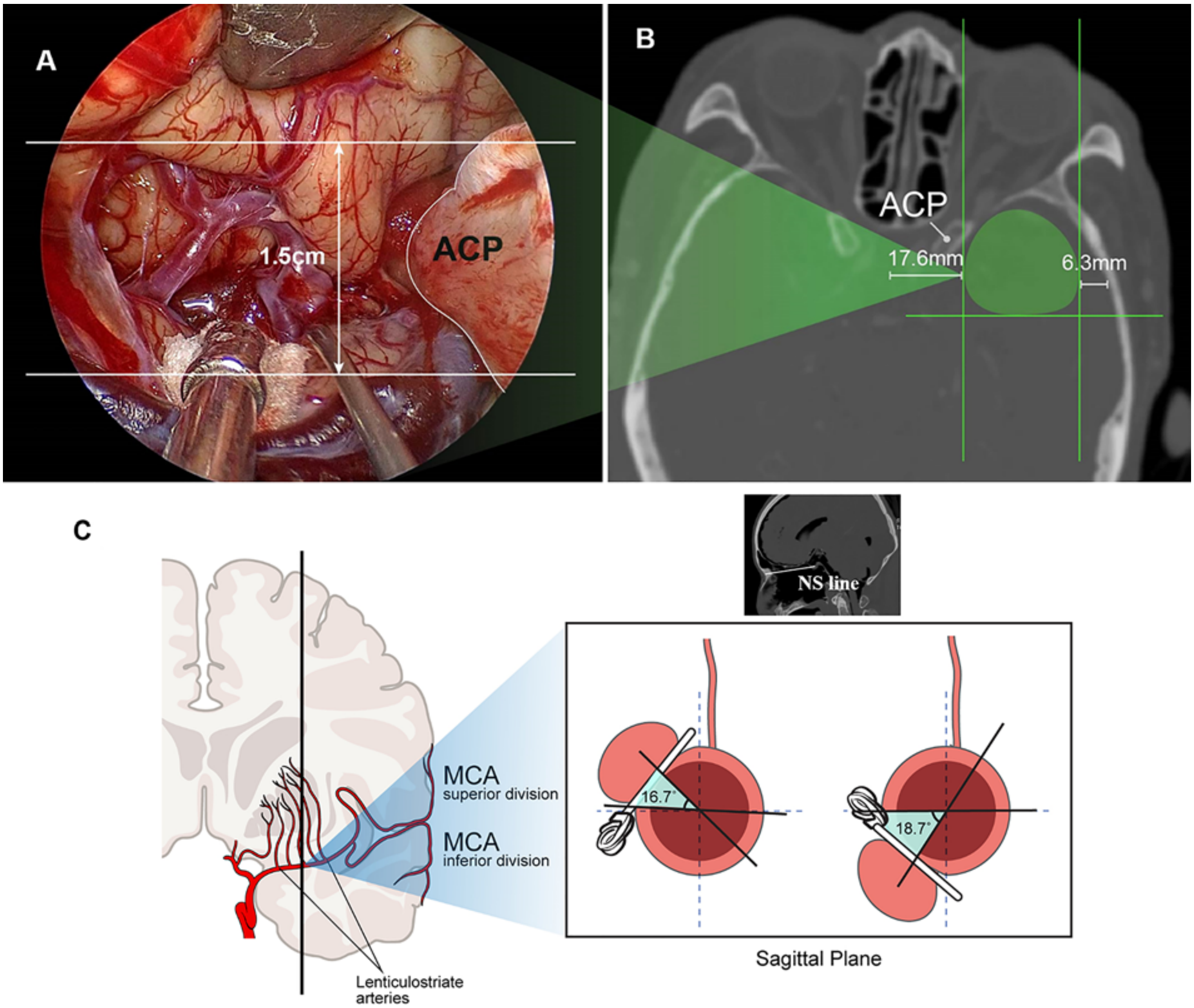

FIG. 1. Schematic illustration of the clippable range in the axial plane (**A and B**) and the clippable angle of the MCA in the sagittal plane (**C**). The axial range was investigated to achieve a vertical extent over 1.5 cm (i.e., the clippable range, shown in panel A as the *double-headed arrow*). The clippable range was estimated to be 17.6 ± 3 mm lateral from the cranial midline and 6 ± 2 mm from the median temporal bone margin (panel B). The clippable angle was assumed to be perpendicular to the clip or tip of the navigation trajectory in the sagittal view based on the nasion-sella line (NS line) (panel C). The superior angle was mean ± SD (range) 16.7° ± 7.8° (4.8°–28.2°). The inferior angle was 18.7° ± 9.6° (5.5°–33.7°). © Chang Ki Jang, published with permission (panels A and C).

eurysm clipping, usually in anterior circulation, but also in posterior circulation aneurysms.[8] Middle cerebral artery (MCA) aneurysms are readily accessible and do not require extensive tissue manipulation. Therefore, this study aimed to determine the type of MCA aneurysms suitable for the endoscopic TOA (ETOA) approach using an endoscope.

Methods

This study was conducted following the EQUATOR (Enhancing Quality and Transparency of Health Research) guidelines. Five cadaveric dissections were performed. This study was approved by and obtained permission for the publication of the images in the cadaveric study from the committee of Yonsei University of Medicine. Institutional review board approval was not required. Cadavers were prepared using Thiel embalming and ethanol-glycerin fixation and injected with silicone rubber compounds to fill the vessels. Cadaveric dissection was performed using a rigid endoscope (4 mm in diameter and 18 cm in length) equipped with a 0° optic lens (Stryker Neuroendoscopy).

A neuronavigation system was used to measure the following parameters: axial extent defined by the clippable range and vertical extent area defined by the exposure of the middle cerebral fossa base were designated as the two target areas. The clippable range was defined as the axial extent that could secure a space of over 1.5 cm vertically for the suction tip, clip, and its applier (Fig. 1A). The clippable range was measured from the cranial midline as the middle point to the medial temporal bone as the lateral point (Fig. 1B). To evaluate the angle of freedom of the MCA at the M1 segment, the angle was measured using

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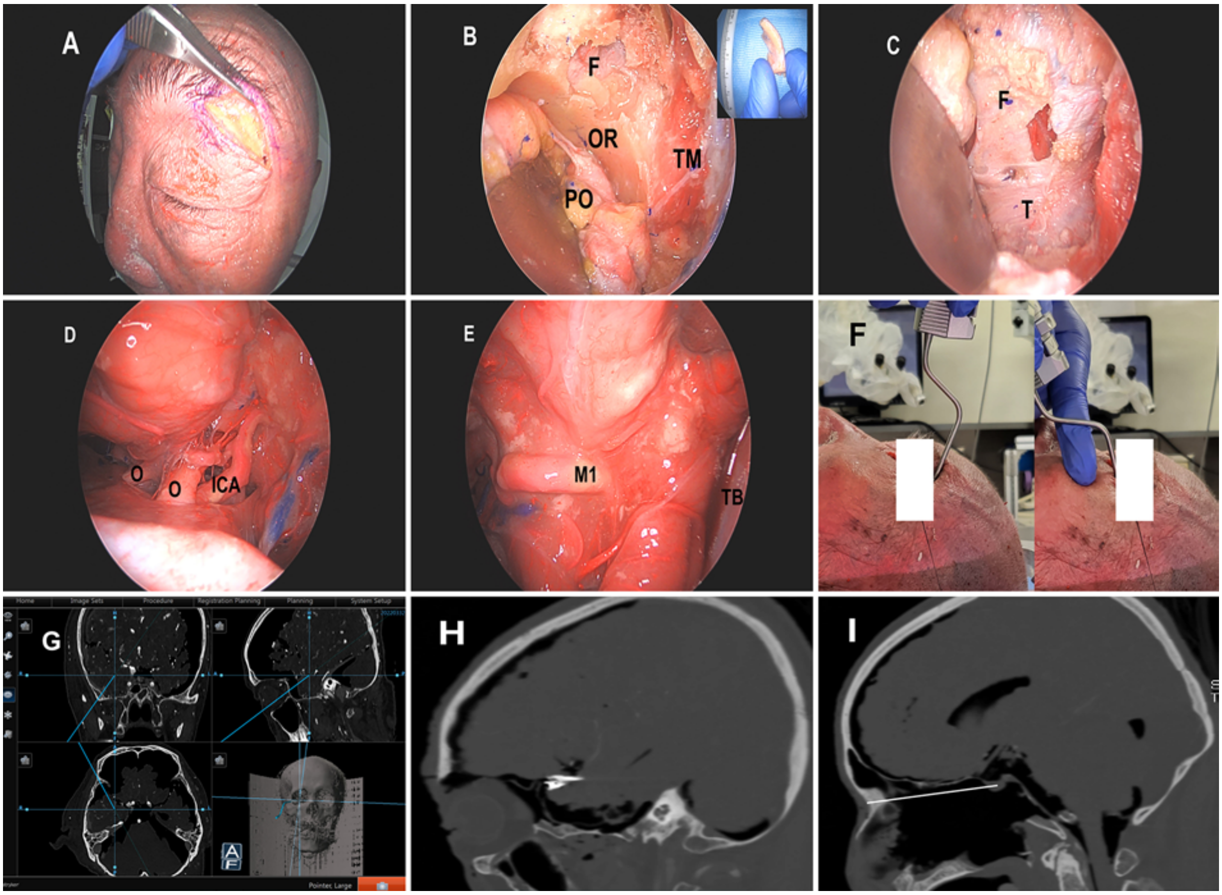

FIG. 2. Stepwise dissection of a cadaver using the ETOA and measurement of the angle of freedom. **A:** A left eyebrow incision was made from the midpupillary line to 1 cm over the eyebrow line. About 2.5 cm of superior and lateral orbit rim was removed (shown in the **inset** of panel B). **B:** After orbitotomy and retraction of the periorbit (PO), a part of the frontal dura (F) was exposed and remnant orbital rim (OR) and temporalis muscle (TM) were also noted. The orbital rim and sphenoid ridge were drilled until the greater and lesser wings of the sphenoid bone were completely removed. **C:** After bone manipulation, the frontal dura and temporal dura (T) were exposed. **D:** Following the opening of the dura and the sylvian fissure, the bilateral optic nerves (O) and ICA were identified, mostly at the median border. **E:** At the most lateral margin, we found the MCA branches (M1) and the temporal bone margin (TB). **F and G:** Using the navigation tool, we calculated the extreme upper and lower angles based on the MCA. **H:** Without navigation, a clip was used to measure the angle. **I:** The nasion-sella line was used as the reference line to measure the angle. © Chang Ki Jang, published with permission (panels A–F).

a line perpendicular to the clip or navigation tip and the nasion-sella line (Fig. 1C). We utilized a neuronavigation system with a snap shot to measure the angle (Fig. 2G). When the clip was available, we used a straight clip (Fig. 2H). After dissection, cadaver CT was performed to check the status of the craniotomy and the angle of freedom using a clip.

On 10 sides (5 cadavers), an eyebrow incision from the midpupillary line to 1 cm over the eyebrow line was made (Fig. 2A). The periosteal layer was dissected as one flap from the superior orbital rim into the orbital wall. During slight orbital retraction, the frontal bone, greater wing of the sphenoidal bone, and zygomatic bone were exposed. The superior and lateral orbital rims were disconnected using a saw drill. A small keyhole was made on the frontosphenoidal suture, and the frontal bone above the orbital rim was drilled off. The remaining orbital roof was disconnected using a chisel and hammer. A one-piece bone flap composed of the superior-lateral orbital rim was created (Fig. 2B, inset). The frontal, zygomatic, and greater wing of the sphenoidal bone were drilled off without cutting the meningo-orbital band and removing the anterior clinoid process (ACP). Thereafter, the frontal and temporal dura were exposed (Fig. 2C). The sylvian vein and cistern were identified after opening the dura vertically. Arachnoid dissection is widely used to expose the internal carotid artery (ICA) and the MCA. Endoscopic exploration was performed to determine the clippable range. The middle cranial fossa was also identified to confirm access to the temporal base region. Angle measurements using clips or navigation were taken, and the identified clippable ranges were measured.

Results

Approach to Target Areas

In 5 cadavers, we reached the anterior temporal pole located below the sphenoid ridge. Compared with the su-

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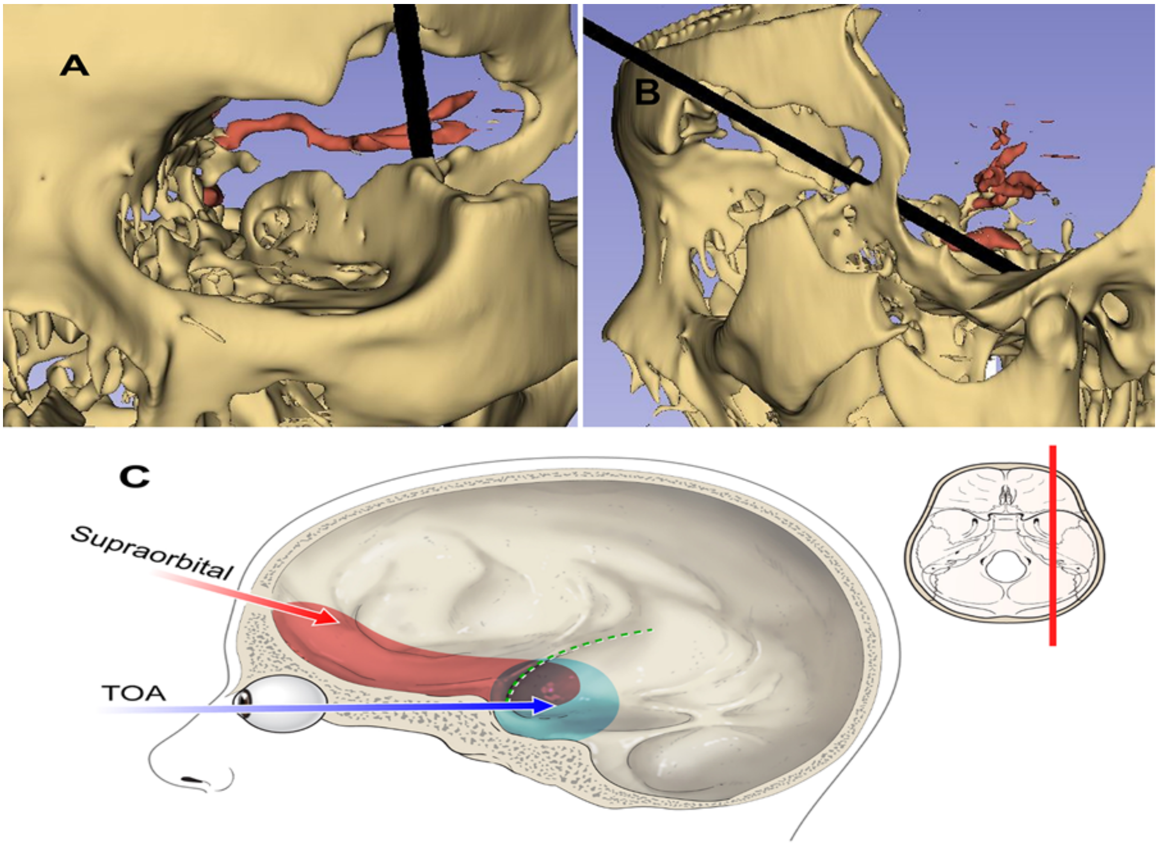

FIG. 3. Three-dimensional (3D) reconstruction using 3D slicer software showed total removal of the sphenoid ridge and direct visualization of the middle cranial fossa. The anteroposterior view (**A**) and lateral view (**B**) are shown. Illustration of an accessible surgical route for the MCA in the sagittal view compared with the supraorbital keyhole approach representing the area of vertical extent. When the aneurysm is located below the sphenoid ridge (*dotted line*) in the sagittal plane, a more direct and proper visualization can be achieved using the ETOA rather than supraorbital craniotomy (**C**). © Chang Ki Jang, published with permission (panel C).

praorbital keyhole approach using the same incision line, a more inferior area could be acquired below the sphenoid ridge. The middle cranial fossa bone, which is limited by the traditional supraorbital approach, can be visualized and reached (Fig. 3A and B). Thus, if the aneurysm is located below the sphenoid ridge in the sagittal plane, more direct and proper visualization can be achieved using the ETOA rather than supraorbital craniotomy (Fig. 3C). Arachnoid dissection followed the middle and lateral directions, and the ICA, anterior cerebral artery, MCA bifurcation, distal MCA, and frontotemporal bone were identified (Fig. 2D and E). After sufficient arachnoid dissection, the clippable range using an endoscope was measured as 17.6 ± 3 mm lateral from the cranial midline and 6 ± 2 mm from the median temporal bone margin. On postoperative CT scan, these lengths were approximated as the lateral ACP border on the median margin and the lateral orbital rim on the lateral margin (Fig. 1B).

The upper and lower restrictions on the trajectory to the MCA through the ETOA were made by the frontal bone and temporalis muscles, respectively, in the sagittal plane (Fig. 2F). The upper movement to the target MCA was increased due to superior orbital rim osteotomy. The angle was calculated using a straight clip in 2 cases and a navigation trajectory line in 3 cases. The clippable angle in the aneurysm direction was assumed to be perpendicular to the clip or line of the navigation trajectory. The superior angle was mean ± SD (range) 16.7° ± 7.8° (4.8°–28.2°). The mean inferior angle was 18.7° ± 9.6° (5.5°–33.7°). The suitable aneurysm dome directions in the sagittal view were anterior, superior, and inferior based on the calculated clippable angle (Fig. 1C). If the aneurysm dome direction is in the anterior, superior, or inferior directions, the aneurysm neck can be more easily identified and clipped than that in the posterior dome direction (Table 1).

Illustrative Cases

Case 1

A 45-year-old patient was admitted with an incidental finding of a right MCA bifurcation aneurysm (Fig. 4, Video 1).

VIDEO 1. Clipping of MCA aneurysm using the ETOA. MCBIF = middle cerebral artery bifurcation. © Chang Ki Jang, published with permission. Click here to view.

The maximum aneurysm diameter was 3.58 mm. The clippable range of the patient was 29 mm, and the distance was 32 mm from the midline to the median temporal bone

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TABLE 1. Surgical angle, vertical extent, and axial extension of ETOA for MCA aneurysms

	Clippable Angle		Middle Cranial Fossa Base	Clippable Range	
	Superior Angle (°)	Inferior Angle (°)		Cranial Midline (cm)	Median Temporal Bone (cm)
Cadaver 1*					
Rt	22.3	5.5	Accessible	1.7	0.3
Lt	13.8	7.3	Accessible	1.9	0.6
Cadaver 2*					
Rt	4.8	15.2	Accessible	2.1	0.5
Lt	28.2	9.8	Accessible	1.5	0.7
Cadaver 3†					
Rt	10.8	17.9	Accessible	1.8	0.5
Lt	5.8	24.3	Accessible	2.3	1
Cadaver 4†					
Rt	22.1	33.7	Accessible	1.6	0.7
Lt	21.2	27.1	Accessible	1.3	0.5
Cadaver 5†					
Rt	15.3	29.3	Accessible	2.2	0.8
Lt	23.4	17.4	Accessible	1.2	0.4

* Angle calculated with a straight clip.
† Angle calculated with the navigation trajectory line.

margin. The M1 length (the length between the ICA and MCA bifurcation) was 14.5 mm. The dome was placed in the anteroinferior direction. The aneurysm was located around the sphenoid ridge. The periorbita was slightly protected from the surgical instruments and endoscope using a retractor. The arachnoid membrane between the frontal and temporal lobes was easily identified. The aneurysm dome was isolated immediately after the arachnoid layer was dissected. The M1 and M2 arteries were observed, and 2 permanent clips were used with the counter-clipping technique. Indocyanine green fluorescence was used to determine clipping status. Prior to suturing the dura mater, a dura substitute was placed within the dura. Multilayered TachoComb patches were then applied over it.

Case 2

A 59-year-old patient was admitted with an incidental finding of left MCA bifurcation aneurysm. The maximum aneurysm diameter was 3.67 mm. The clippable range of the patient was 31 mm, and the distance was 36 mm from the midline to the median temporal bone margins. The M1 length was 17.2 mm. The dome was placed in the anteroinferior direction. The aneurysm was located superior to the sphenoid ridge, and a straight clip was used.

Discussion

This study delineates the appropriate surgical indications for ETOA for MCA aneurysms on the basis of cadaver dissections and 2 clinical cases. According to this study, an MCA aneurysm presenting anteriorly superior and with inferior dome projection, located around and below the sphenoid ridge in the vertical plane and between the lateral border of the ACP and the lateral border of the orbital wall in the horizontal plane, is suitable for clipping using the ETOA (Fig. 1A–C).

Keyhole approaches, such as the supraorbital approach, are now popular in the neurovascular field for cerebral aneurysm clipping. However, the surgical trajectory of MCA aneurysms using the keyhole approach has certain limitations. In 2020, Park reported that an aneurysm distal to the MCA genu is an unfavorable indication for the supraorbital keyhole approach.[10] Further, Esposito et al. reported that a lateral supraorbital approach was proper when the M1 length was less than 15 mm from the M1 origin.[11] Rathore et al. revealed that a posteriorly projecting MCA aneurysm was a relative contraindication for the keyhole approach.[12] In a study comparing the transpalpebral versus transciliary incision for the supraorbital keyhole approach, Rychen et al. reported that it was difficult to reach a low-riding M1 segment aneurysm using the transpalpebral supraorbital approach.[13]

The introduction of endoscopes in neurosurgery helped to obtain wide surgical angles and greater illumination in deep planes, which have limited access under the microscope alone. There are also some studies on endoscopic aneurysm clipping using the endonasal approach.[14–16] In a review of endoscopic endonasal clip ligation, we discussed some limitations of this approach. First, a narrow working angle makes clip repositioning technically challenging. Second, endonasal routes can result in cerebrospinal fluid leakage and meningitis, and appropriate skull base restoration is difficult to minimize because of the presence of a protruding clip. Third, because of the limited space, we preferred to perform surgery in a hybrid endovascular operating room because treatment of an intraoperative rupture can be challenging.[14] Transorbital aneurysm clipping under a microscope has been reported in some cases.[2,6–9] These studies mostly focused on surgical accessibility through this approach and acceptable results for clipping of aneurysms. From their experience, they commonly described the advantages of this approach as early proximal control using a short working distance and exposure of the base of the cerebrum without retraction. In these previous studies, TOA was performed not only in the MCA, ICA, and anterior and posterior communicating arteries, which are usually in the anterior circulation, but even in the posterior circulation.[8,17] To achieve such a broad surgical range, they involved extensive manipulation through deep and wide resections of inner structures such as ACP removal.[18–21] In contrast, our study focused on the quantification of proper surgical ranges with minimal manipulation of the normal anatomy (ACP and meningo-orbital band). Di Somma et al. reported that MCA aneurysm is a potential indication for ETOA in an anatomical study.[5] Thus, our study aimed to clarify adequate and suitable indications for ETOA.

Yaşargil classified MCA aneurysm into three subgroups according to its dome direction: anterosuperior, posterior, and inferior.[22–24] Our results show that anterior, superior, and inferior MCA aneurysms, following the classification of Chung et al.,[22] are suitable for clipping with the ETOA. We defined the clippable angle based on the perpendicular

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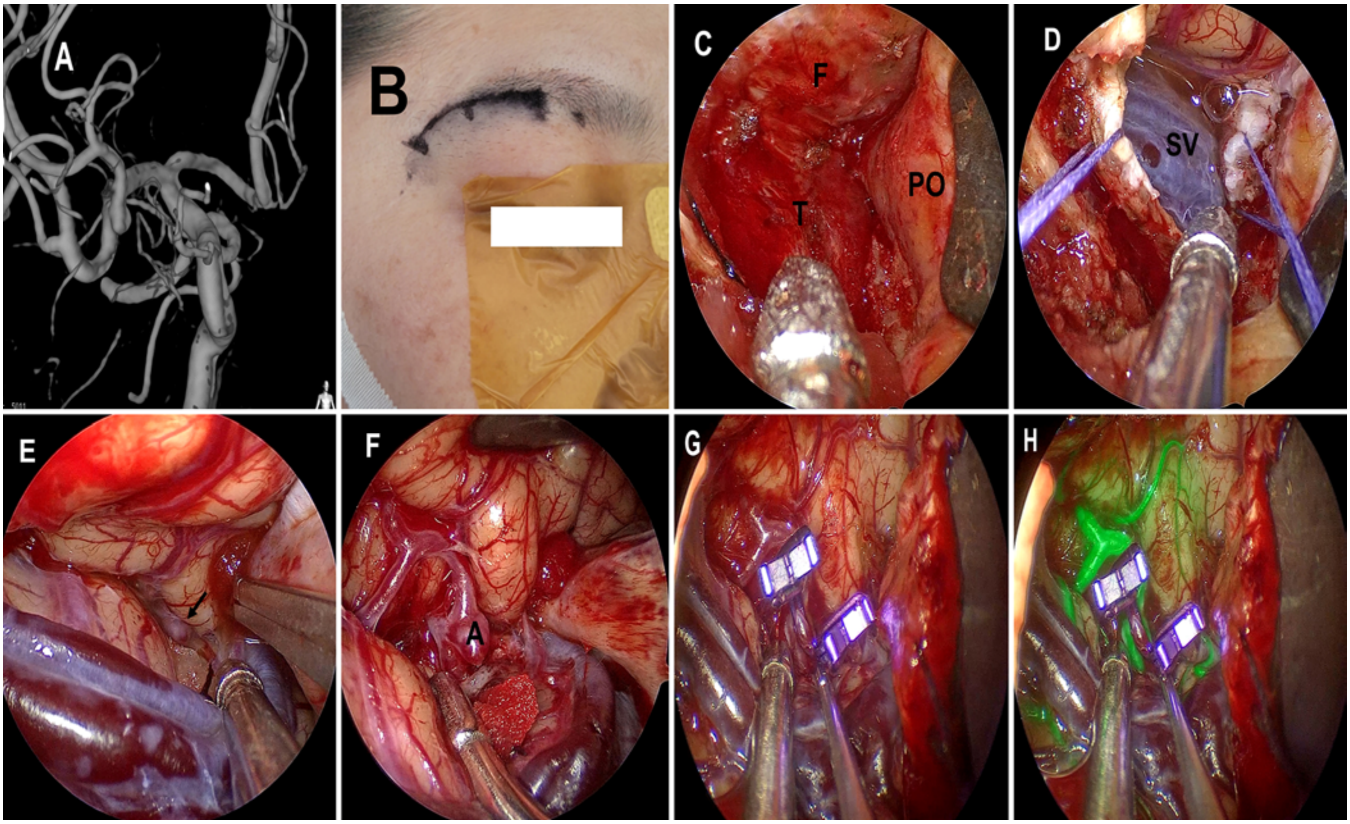

FIG. 4. Illustrative case. **A:** On the 3D distal subtraction angiographic image, the right MCA bifurcation aneurysm is shown projected in the anteroinferior direction. **B:** A skin incision was made from the lateral supraorbital notch to the end of the eyebrow line. **C:** After superior-lateral orbital rim osteotomy, the frontal dura (F), temporal dura (T), and periorbit (PO) were identified with mild retraction of the periorbital region. **D:** A horizontal dural incision was made, and the sylvian vein (SV) and frontal lobe were exposed. **E and F:** The arachnoid membrane was dissected, and the tip (*black arrow*) of an aneurysm dome (A) was found. The aneurysm dome and neck were isolated. **G:** Two curved clips were applied in a neck using the counter-clipping technique. **H:** Complete exclusion of the aneurysm was confirmed using endoscope-integrated indocyanine green fluorescence (*green*).

line of the straight clip because we could safely apply a clip during sufficient exploration of the aneurysm boundary. Considering that these angles are measured using a straight clip blade, it is not an absolute indication for this surgical approach. The range of angles in the sagittal plane can be widened using the proper devices such as curved, angled, and ring clips under limited visualization. However, MCA aneurysms oriented posteriorly and superiorly have a higher risk of postoperative ischemic lesions because of a perforating artery.[25] Considering the relatively limited accessible angles and the risk of complications related to surgery, a posterior direction of the aneurysm dome is not an appropriate indication for clipping using an ETOA.

In order to safely explore and clip a short M1 aneurysm, the frontal lobe frequently needs to be retracted. Retraction of the frontal lobe is typically thought to be risk free because the branches of the M1 trunk rarely supply the frontal lobe.[26] However, the early frontal branches arising from the prebifurcation region of the M1 segment were found in more than 30% of the hemispheres.[27] Thus, retraction of the frontal lobe rather than the temporal lobe should be considered. In a previous cadaveric study, the median (range) length of the prebifurcation part of the M1 segment was 17.82 (10.14–29.32) mm.[27] MCA aneurysms, mostly with short M1 segments, have been reported to cause neurological deficits from lenticulostriate artery injury related to excessive retraction of the brain during surgery.[28,29] In this study, we found that aneurysms in the axial plane between the ACP and the lateral bone margin of the orbital ball could be safely accessed with minimal brain retraction using an ETOA. By definition, this range offers a vertical area of 15 mm for clipping operations. Niknejad et al. reported that the extent of the supraorbital approach cutoff point is an 18.2-mm distance between the MCA aneurysm and the clinoid process.[30] An ETOA offers a more panoramic view with a smaller entry site compared with a microscope. It can provide greater visualization of MCA aneurysms in positions that are difficult to observe under a microscope. Therefore, it can reduce the morbidity caused by retraction injuries with cosmetic benefits. In addition, patient positioning of the vertex down using gravity-assisted frontal lobe retraction made this possible, with little retraction of the lenticulostriate artery during surgery. In our 2 clinical cases, M1 lengths of 14.5 mm and 17.2 mm were observed, and the operations proceeded with minimal retraction of the frontal lobe.

Another advantage of the TOA is that the craniotomy range, which involves drilling off the sphenoid ridge, al-

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lows for better visualization of the MCA aneurysm beneath the sphenoid ridge. We visualized the trajectory using 3D slicer software (Fig. 4B and C). Kliś et al. reported that MCA tortuosity is strongly associated with MCA aneurysm formation.[31] The surgeon sometimes encountered an MCA aneurysm that was elongated and situated below the sphenoid ridge. In this situation, the pterional route was not problematic; however, the surgeon experienced some visual limitations when using the supraorbital keyhole approach. We reported that the ETOA provides a logical line for temporal lobe lesions located below the sphenoid ridge.

Limitations

This study had some limitations. First, we included the small number of cadaveric studies with 2 clinical cases. Secondly, the concept of clippable range was applied using a threshold of 1.5 mm, which was arbitrarily established to ensure a surgical margin of 5 mm above and below the average aneurysm size of 5 mm. This space allows for the application of a temporary clip in the event of intraoperative rupture and maintaining an area of freedom for devices in the surgical field. While this threshold point is arbitrary, it is important to note that, as previously mentioned, the focus of studies about the ETOA for clipping have primarily shown the overall operable range. Our study focused on proper indication rather than revealing the wide surgical field range using minimal manipulation. Finally, some selection biases can interfere with safety issues during case selection as we only studied a small number of cadaveric specimens and clinical cases.

Conclusions

Clipping using an ETOA is an appropriate route for MCA aneurysms with anterior, superior, and inferior dome projections. The aneurysm, located between the ACP and the lateral bony margin of the orbital ball as the horizontal boundary and extending around and below the sphenoid ridge as the vertical boundary, could be properly clipped using the ETOA.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Jang, Oh, Han, Moon, KY Park, SW Park. Acquisition of data: Yoon, Oh, Han, Kim. Analysis and interpretation of data: Yoon, Oh. Drafting the article: Yoon, Oh. Critically revising the article: Jang, Oh, Moon, SW Park. Reviewed submitted version of manuscript: Jang, Moon, Kim, KY Park, SW Park. Approved the final version of the manuscript on behalf of all authors: Jang. Administrative/technical/material support: Yoon, Kim, KY Park, SW Park. Study supervision: Yoon, Oh, SW Park.

Supplemental Information

Videos

Video 1. https://vimeo.com/1126782205.

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