Quantitative Anterior and Posterior Clinoidectomy Analysis and Mobilization of the Oculomotor Nerve during Surgical Exposure of the Basilar Apex Using Frameless Stereotaxis

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Abstract

Background Anterior and posterior clinoidectomies have been proposed to augment exposure of the basilar apex. A sequential quantitative benefit analysis offered by these maneuvers has not been reported.

Methods Fourteen datasets from eight cadaveric specimens were analyzed. A modified orbitozygomatic frontotemporal craniotomy was performed. The extent of proximal control of the basilar artery was determined through the exposed opticocarotid and carotidoculomotor triangles before and after clinoidectomies and mobilization of the third nerve at the porous oculomotarius.

Results Removal of the anterior and posterior clinoids significantly improved proximal basilar artery access ($p < 0.012$) and increased the opticocarotid triangle and carotidoculomotor triangle areas ($p < 0.017$). Surgical freedom increased inferosuperiorally in the opticocarotid triangle following anterior clinoidectomy ($p < 0.047$) and in carotidoculomotor triangle following posterior clinoidectomy ($p < 0.047$). Mobilization of the third nerve increased surgical freedom in the mediolateral projection of the carotidoculomotor triangle ($p < 0.047$).

Conclusion Anterior and posterior clinoidectomies significantly improved the area of exposure of the opticocarotid triangle, carotidoculomotor triangle, and the exposed length of the basilar artery available for proximal control. This improvement is extremely important for large or giant aneurysms of the upper basilar artery or aneurysms hidden by the posterior clinoid.

Keywords
- anterior clinoidectomy
- posterior clinoidectomy
- third nerve mobilization
- basilar apex
- opticocarotid triangle
- carotidoculomotor triangle

Aneurysms of the upper basilar artery (BA), which arise from the basilar bifurcation, posterior cerebral artery (PCA), superior cerebellar artery (SCA) junction, and proximal P1 segment, represent some of the most difficult and technically challenging to clip directly. These aneurysms constitute 5 to 15% of all intracranial aneurysms and approximately 50% of all vertebrobasilar aneurysms.[1] Both the pterional (transsylvian) approach of Yasargil[2] and subtemporal approach of Drake[3] have traditionally been used with great success to treat these lesions. The pterional approach has the advantages of bilateral visualization of the basilar tip perforators, PCA and SCA, less temporal lobe retraction, less oculomotor nerve injury and is more familiar to most surgeons compared with the subtemporal approach. With the pterional approach,

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dissection of upper BA aneurysms is usually performed through a space on either the medial (opticocarotid triangle) or lateral (carotidoculomotor triangle) side of the internal carotid artery (ICA). In an early article, Yasargil noted that dissection through the opticocarotid triangle is sometimes limited when the ICA and optic nerve (ON) are closely opposed, and as such dissection lateral to the ICA is preferable.[1] In some circumstances, however, this corridor can also be limited and can be overcome by incising and laterally retracting the tentorial edge. In addition, aneurysms located below the level of the posterior clinoid process may be inaccessible with this approach. These limitations have prompted others to supplement the standard pterional craniotomy with removal of the zygoma,[4,5] and anterior[6,7] and/or posterior clinoidectomy,[1] in addition to mobilization of the carotid artery from the distal dural ring.[8]

The decision to use each or any of these surgical maneuvers is often determined preoperatively, and alterations in the surgical plan may become necessary intraoperatively if exposure is not optimal. Variables that are commonly thought to impact this decision include the positional relationship between the basilar apex and the posterior clinoids,[9] as well as the length of the carotid artery.[10] Youssef et al have recently published the effect of anterior and posterior clinoidectomies and ICA mobilization on the dimension of the carotidoculomotor window and rostracaudal exposure of the BA.[11] In this study, we employed a frameless stereotactic system to quantitatively measure the surgical area of the opticocarotid and carotidoculomotor triangle and the upper BA together with the surgical freedom before and after anterior and posterior clinoidectomies and finally after mobilization of the third cranial nerve from its tentorial insertion.

Methods

Cadaveric Preparation

This study was performed on six cadaveric head specimens bilaterally and two unilaterally, yielding a total of 14 datasets.

The cadaver preparation technique used was based on that described in the University of Southern California Skull Base Dissection Manual.[12] The cerebral arterial and venous systems were flushed with normal saline, followed by one bottle of an arterial conditioner (Metaflow, Dodge Chemicals, Cambridge, Massachusetts). Cadaveric head specimens were then soaked in a diluted Metaflow solution overnight followed by soaking in methanol for 24 hours. Carotid arteries were next flushed with 5% buffered formalin and heads left to soak in this solution for 1 to 2 weeks until brain consistency mimicked that of living tissue.

Dissection Technique

Specimens were rigidly fixed in place and a bicoronal scalp flap elevated. An orbitozygomatic craniotomy was then performed and included mobilization of the temporal process of the zygomatic bone. Extradural dissection was conducted to maximize removal of the orbital roof. At completion of this portion of the dissection and under the operative microscope, the dura was opened and an extensive dissection of the sylvian fissure and basal cisterns was performed. Frontal and temporal lobe retractors were then placed. At this point in the dissection, a base set of measurements was obtained (►**Table 1**). These measurements were repeated after intradural anterior and posterior clinoidectomies and finally after mobilization of the third cranial nerve from its tentorial insertion.

Stereotactic Measurements

Cadaveric head specimens were rigidly fixed to the bench top and remained in the same position during all dissection steps and data gathering. Stereotactic data was gathered by use of a frameless navigational device (StealthStation, Medtronic Inc., Broomfield, Colorado). The StealthStation reference arc was positioned in a vice close to the cadaveric head and measurements obtained with the frameless stereotactic pointer probe. Measurements consisted of simple three-dimensional coordinates for each data point and were extracted from the

Table 1 Changes in exposure and surgical freedom following resection of the anterior and posterior clinoids during a modified orbitozygomatic approach to the basilar tip

Resection	"Triangle" exposure (mm^2)		Proximal control (mm)	Surgical freedom at basilar tip (degrees)		
	Nerve III	Optic nerve		Nerve III access (inferior–superior)	Nerve III access (medial–lateral)	Optic nerve access (inferior–superior)
Baseline	93.7 ± 38.5^a	57.1 ± 19.3^a	8.3 ± 3.1^a	22.6 ± 6.8^a	–	18.7 ± 9.3^a
Anterior clinoid	91.4 ± 35.2^a	89.7 ± 31.9^b	9.0 ± 3.1^a	24.4 ± 9.2^a	29.7 ± 6.3^a	23.6 ± 10.6^b
Posterior clinoid	120.4 ± 25.1^b	$74.0 \pm 19.0^{a,b}$	11.4 ± 5.1^b	30.3 ± 5.5^b	31.7 ± 4.6^a	26.5 ± 11.1^c
Mobilization of the third nerve	140.1 ± 25.4^b	82.1 ± 31.1^b	12.2 ± 5.1^b	30.8 ± 5.5^b	36.1 ± 6.1^b	–

Note: Mean ± standard deviation. Values with unlike superscripts are different at: $p < 0.017$ ("triangle" exposures); $p < 0.012$ (proximal control); $p < 0.047$ (surgical freedom). Hyphen indicates data not collected.

working files of the StealthStation recording system software. Cadaveric head specimens were not imaged.

The exposure through the opticocarotid and carotidoculomotor triangles was estimated by calculation of the area defined by a small number of discrete points at the periphery of each respective "triangle." These discrete points were designated as follows: (1) lateral edge of the ON as it enters the optic canal, (2) lateral edge of the ON at the optic chiasm, at the inflection point, (3) medial edge of the ICA, at its bifurcation, (4) medial edge of cranial nerve III at the proximal-most point visible, (5) medial edge of cranial nerve III, midway between points 4 and 6, (6) medial edge of cranial nerve III as it enters the cavernous sinus, (7) lateral, proximal-most point visible on the ICA, (8) medial proximal-most point visible on the ICA, and (9) lateral edge of the ICA, midway between points 3 and 8. The area for the opticocarotid triangle was estimated as the sum of the areas of geometric triangles formed by points 2-3-9, 2-9-8, and 2-8-1. The carotidoculomotor triangle was likewise estimated as the sum of the areas of geometric triangles 3-4-5, 3-5-9, 5-9-6, and 9-6-7 (►**Fig. 1A, B**).

Surgical freedom available for the surgeon's instruments was estimated as an angle measured from the basilar apex as the vertex. The stereotactic probe was placed first at the basilar apex, through either the third nerve or the ON "triangle," and the coordinates of this point were recorded. Then a micro-dissector was placed at the basilar apex, and the dissector rotated sequentially to the medial- and lateral-most extent possible, and then the inferior- and superior-most extent possible and the coordinates of the dissector handle recorded with the stereotactic probe at each point. In this way, three points in space were recorded in turn, defining either a mediolateral or inferosuperior angle centered at the basilar apex. The measurements were repeated sequentially, as appropriate, after each stage of the dissection..

Proximal control was measured by recording the coordinates of the stereotactic probe first at the basilar apex and then at the proximal-most point visible along the artery after each stage of the dissection.

Statistical Analysis

Statistical analysis was performed using repeated analysis of variance measurements using the Bonferroni inequality to detect posthoc pairwise differences. For surgical freedom measurements through the ON "triangle," only six specimens allowed sufficient access to place the stereotactic probe, thus reducing the sample size from 14.

Results

The initial area of the carotidoculomotor triangle, the opticocarotid triangle, and the exposed length of the BA was 93.7 ± 38.5 mm^2, 57.1 ± 19.3 mm^2, and 8.3 ± 3.1 mm, respectively. Anterior clinoidectomy increased the exposed area of opticocarotid triangle significantly from 57.1 ± 19.3 mm^2 to 89.7 ± 31.9 mm^2 ($p < 0.017$). Surgical freedom for the surgeon's hands and instruments was also increased significantly from 18.7 ± 9.3 degrees to 23.6 ± 10.6 degrees in inferosuperior projection of the opticocarotid triangle ($p < 0.047$). Resection of the anterior clinoid process (ACP)

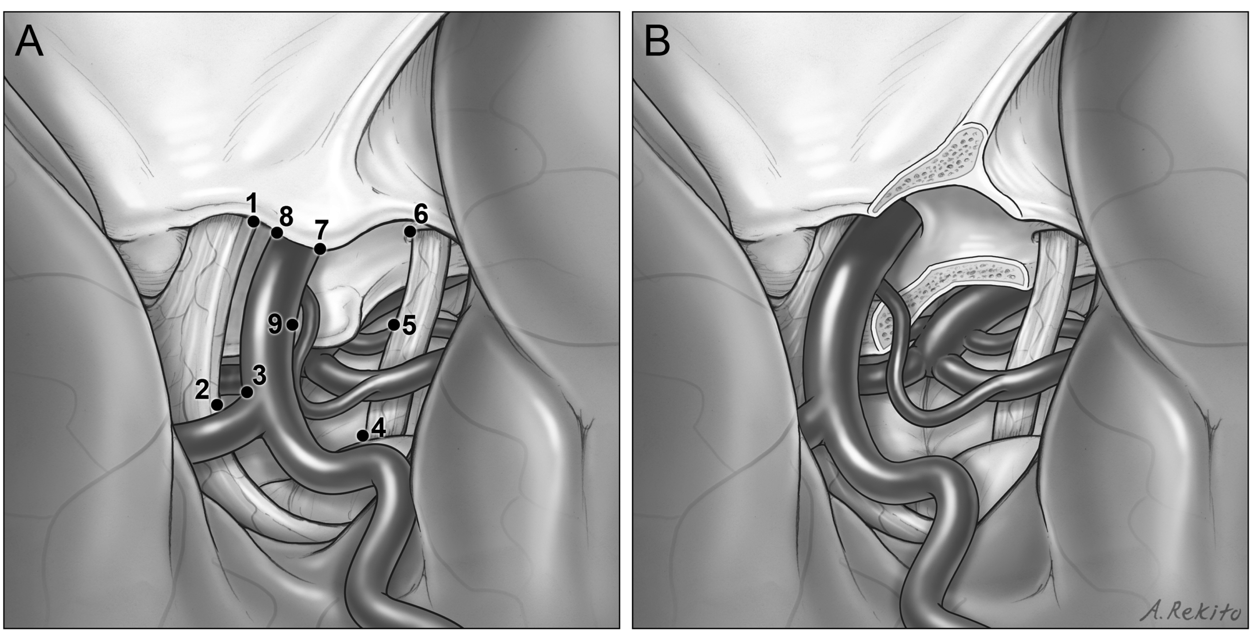

Fig. 1 Surgical positioning, skin incision, and bony exposure of the orbitozygomatic approach (left and right). Left landmarks: **1** lateral edge of the optic nerve as it enters the optic canal; **2** lateral edge of the optic nerve at the optic chiasm, at the inflection point; **3** medial edge of the internal carotid artery, at its bifurcation; **4** medial edge of cranial nerve III at the proximal-most point visible; **5** medial edge of cranial nerve III, midway between points 4 and 6; **6** medial edge of cranial nerve III as it enters the cavernous sinus; **7** lateral, proximal-most point visible on the internal carotid artery; **8** medial proximal-most point visible on the internal carotid artery; **9** lateral edge of the internal carotid artery, midway between points 3 and 8.

did not improve the exposed area of the carotidoculomotor triangle and proximal control of the BA.

Posterior clinoidectomy significantly increased the carotidoculomotor triangle from 93.7 ± 38.5 mm^2 to 120.4 ± 25.1 mm^2 ($p < 0.017$) together with the exposed length of the upper BA from 8.3 ± 3.1 mm to 11.4 ± 5.1 mm ($p < 0.012$). Surgical freedom is also increased in the inferosuperior projection of the carotidoculomotor triangle after posterior clinoidectomy ($p < 0.047$). Mobilization of the third nerve did not increase the exposure of the carotidoculomotor triangle and the proximal control of the BA significantly. The mobilization of the third nerve resulted in an increased in surgical freedom in the mediolateral projection of the carotidoculomotor triangle only ($p < 0.047$). Results are summarized in ►**Table 1**.

Discussion

The pterional transsylvian approach is a standard procedure for upper BA aneurysms.[2] Combining it with resection of the orbital roof or rim or with resection of the zygomatic arch may result in more gentle brain retraction with a shorter trajectory to the lesion. Despite this extensive removal of extradural bony structures, the size of the operative field continues to be limited since dissection for upper BA aneurysms is performed mainly through deeper spaces, either the opticocarotid or carotidoculomotor triangle. The opticocarotid triangle is limited by the ON, ICA, A1, and anterior clinoid, whereas the carotidoculomotor triangle is limited by the oculomotor nerve, ICA, and anterior clinoid and posterior clinoid process (PCP) (►**Fig. 2**). As reported by Yasargil, dissection through the opticocarotid triangle is sometimes limited when the ICA and ON are closely opposed.[1] If this triangle is wide enough for aneurysm dissection, temporary clipping makes the space narrower and neck clipping becomes more difficult. Under these circumstances, both the opticocarotid and carotidoculomotor triangles should be used for major dissection of aneurysms and/or temporary clipping. Several techniques have been suggested to expand these triangles, including anterior clinoidectomy, mobilization of the ICA and oculomotor nerve, and posterior clinoidectomy.[7,8,13,14] The removal of the ACP has been an important step in the management of aneurysms involving the paraclinoid region and upper BA.[6,15–17] It allows early decompression and mobilization of the ON and improved surgical exposure as reported by Evans et al[18] in a cadaveric study. This group of investigators documented a twofold increase in the exposed length of the ON and the opticocarotid triangle and an almost fourfold increase in the maximal width of the opticocarotid triangle by removing the ACP. Exposure and incision of the distal dural ring after anterior clinoidectomy allows more effective ICA mobilization laterally or medially by increasing the movable portion of the ICA from a mean of 6 to 13 mm.[14] Our results showed that anterior clinoidectomy increased the exposed area of opticocarotid triangle significantly from 57.1 ± 19.3 mm^2 to 89.7 ± 31.9 mm^2. Surgical freedom for the surgeon's hands and instruments was also increased significantly from 18.7 ± 9.3 degrees to 23.6 ± 10.6 degrees in inferosuperior projection of the opticocarotid triangle. Resection of the ACP did not improve the exposed area of the carotidoculomotor triangle and proximal control of the BA.

Although ACP can be removed extradurally[1,19] or intradurally,[8,20] extradural clinoidectomy has several advantages over an intradural technique, such as easier anatomical orientation that may result in more extensive and faster removal and better protection of the intradural structures by the overlying dura. We recently reported a modified technique of performing an extradural anterior clinoidectomy that results in technical simplicity, decreased incidence of neurovascular damage, postoperative cerebrospinal fluid leaks, and tension pneumocephalus.[1,16,21,22] When surgery is performed following subarachnoid hemorrhage of an aneurysm in close anatomical association with the ACP, removal of the extradurally hollowed ACP should be performed intradurally to avoid inadvertent rupture from

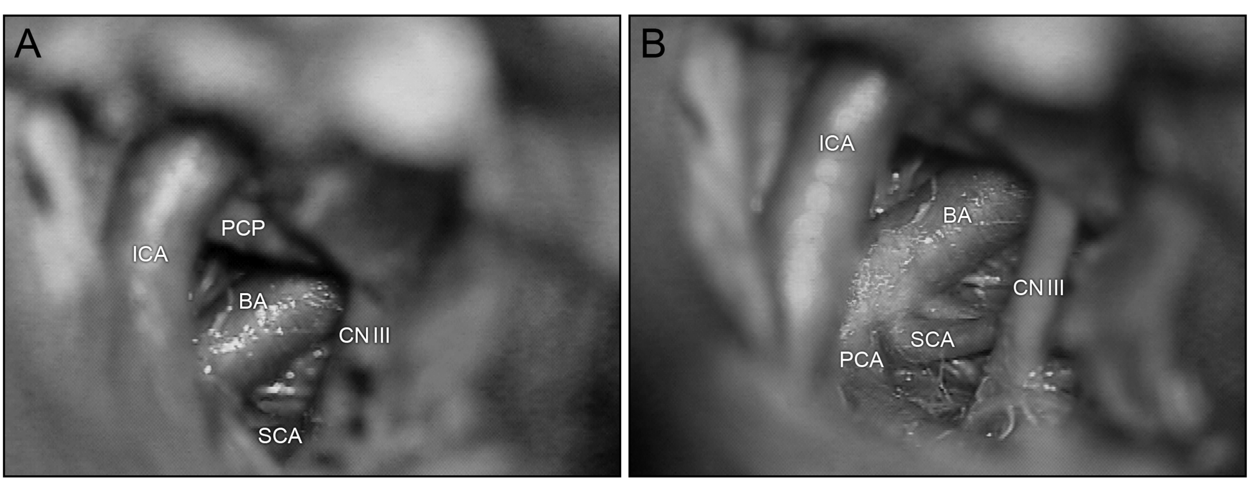

Fig. 2 Cadaveric surgical exposure of the opticocarotid and carotidoculomotor triangles before (left) and after (right) drilling of the anterior and posterior clinoids. BA, Basilar artery; CN III, oculomotor nerve, the third cranial nerve; ICA, internal carotid artery; PCP, posterior clinoid process; SCA, superior cerebellar artery.

extradural manipulation. Major complications of anterior clinoidectomy include rhinorrhea, visual defect, optic and oculomotor nerve injury, injury to the ICA, and rupture of the aneurysm.[1,16,22]

According to their location relative to the posterior clinoid, upper BA aneurysms can be divided into three types[23]: those located more than 5 mm above the PCP are called supraclinoid, those located within 5 mm of PCP are called clinoid, and infraclinoid aneurysms are located more than 5 mm inferior to the PCP. It has been reported that 14 to 19% of upper BA aneurysms are below the level of PCP.[24,25] Yasargil described removal of PCP to successfully expose aneurysms hidden by the PCP.[1] Dolenc described a transcavernous approach by mobilizing the ICA and oculomotor nerve after anterior and posterior clinoidectomies to increase in the carotidoculomotor triangle and the length of BA exposed.[7] The mean increase in the exposure of the upper BA in transcavernous approach was 13.4 and 12.8 mm in the cadaver studies performed by Chanda and Nanda[26] and Seoane et al,[27] respectively. Exposing the cavernous sinus and unroofing the oculomotor nerve in the transcavernous approach carries the risk of significant bleeding from the cavernous sinus and injury to the oculomotor nerve and cavernous ICA. Since additional procedures in this anatomically complex region of the skull base are associated with increased morbidity and risk, each step of bony removal and surgical procedure should be evaluated quantitatively and the resultant advantage and risks should be carefully analyzed. In this study, we document that posterior clinoidectomy significantly increase the carotidoculomotor triangle from 93.7 ± 38.5 mm^2 to 120.4 ± 25.1 mm^2 together with the exposed length of the upper BA from 8.3 ± 3.1 mm to 11.4 ± 5.1 mm. The angle available to use surgical equipment was also increased in the inferosuperior projection of the carotidoculomotor triangle. Altogether, this will result in an easier and safer application of temporary clipping for proximal control and a better angle without obstruction of the surgeon's view. Youssef et al[11] showed that anterior clinoidectomy and ICA mobilization increased the carotidoculomotor triangle 44% anteriorly and 28% posteriorly, and exposed length of the BA increased by 69% after posterior clinoidectomy. We, however, believe that the removal of the posterior clinoid is the major step in increasing the exposed area of the carotidoculomotor triangle mainly for two reasons. First, in our study, the removal of ACP did not affect the exposed area of the carotidoculomotor triangle, and, second, Youssef et al did not examine the successive exposure afforded by each step of this multistep approach.

The benefits from mobilizing the third nerve for exposure of the carotidoculomotor triangle and the proximal control of the BA were not significant enough compared with those after posterior clinoidectomy. Although it resulted in a significant increase in surgical freedom in the mediolateral projection of the carotidoculomotor triangle, we think that the mobilization of the third nerve should not be performed routinely in patients with the low lying basilar apex aneurysms since this approach is associated with oculomotor dysfunction in more than two-thirds of patients.[7,16]

Conclusion

Together, the anterior and posterior clinoidectomies significantly improved the area of exposure for the opticocarotid and carotidoculomotor triangle and exposed length of the BA available for proximal control. This improvement on both triangles is extremely important for large or giant aneurysms of the upper BA or aneurysms hidden by the posterior clinoid, since the main dissection and clipping of the aneurysms can be performed through one of these spaces without difficulty, while the other space is being used for proximal control by temporary clipping. The only benefit gained by mobilization of the third nerve was increased surgical freedom in the mediolateral projection of the carotidoculomotor triangle.

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

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