Turk Neurosurg, 2021

Original Investigation

Received: 07.12.2019
Accepted: 04.02.2020

DOI: 10.5137/1019-5149.JTN.28775-19.2

Published Online: 23.08.2021

Anatomical Assessment of the Endoscopic Assisted Lateral Supraorbital Approach and Endoscopic Endonasal Transclival Approach to Basilar Apex Aneurysms

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ABSTRACT

AIM: To assess the feasibility of using an endoscopic-assisted lateral supraorbital (LSO) approach and an endoscopic endonasal transclival approach (EETA) for basilar apex (BAX) aneurysms.

MATERIAL and METHODS: Ten cases with LSO approaches, with or without posterior clinoidectomy and endoscopic assistance, and 10 cases with EETA, with or without drilling of the dorsum sellae, were performed on 20 cadaveric heads. Anatomical exposure and surgical freedom at the BAX were evaluated.

RESULTS: Anatomical exposure provided by the LSO approach was limited to the BAX and ipsilateral posterior cerebral artery (PCA) and increased with a mean value of 5.0 mm after posterior clinoidectomy; the basilar artery, contralateral PCA, and superior cerebellar arteries (SCAs) were visualized in all cases. Accordingly, surgical freedom was larger. Endoscopic assistance provided a significant increase in basilar artery exposure; however, surgical freedom did not increase markedly. The main advantage of EETA was the greatest exposure of the basilar artery. With drilling of the dorsum sellae, anatomical exposure increased by a mean value of 3.4 mm, and provided the greatest amount of surgical freedom and visualization of the basilar artery terminal bifurcation and of the SCAs in all cases.

CONCLUSION: The endoscopic-assisted LSO approach and the EETA may represent a feasible approach for treatment of BAX aneurysms lying within 5.0 mm below and within 3.4 mm above the dorsum sellae.

KEYWORDS: Anatomy, Basilar apex, Endoscopic assistance, Endoscopic approach, Lateral supraorbital approach

INTRODUCTION

Basilar apex (BAX) aneurysms are among the most challenging to treat, due to their deep location and intimate relationship with the brainstem, cranial nerves, and perforating branches (1,2). The high morbidity associated with surgical clipping has prompted a rapid transition to endovascular treatment, with the perception that microsurgery should be reserved only for those aneurysms not amenable to coiling or stenting (3-5). With the evolution of endovascular techniques, the demand for improved patients' outcomes after surgery has increased. For these reasons, the investigation of

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alternative surgical approaches for treating BAX aneurysms is warranted.

Classically, pterional and subtemporal approaches have been used to clip aneurysms of the upper basilar trunk, with the choice based first on the relative anatomical conformation of the BAX and dorsum sellae (6,7). Many variants of these approaches have been proposed to reduce the surgical exposure, but the increasing complexity of the approach corresponded to a greater risk of vascular and neural injury (8-10). In order to create the least amount of iatrogenic damage, recent literature has focused more on the lateral supraorbital (LSO) approach and the endoscopic endonasal transclival approach (EETA) (11-14). The impetus for the LSO approach, which is useful in most indications in which the pterional approach would have been used, has been its minimal interference with the temporalis muscle, reduced exposure and dissection of the Sylvian fissure, and less risk of oculomotor nerve palsy and temporal lobe injury due to retraction. The location of the basilar artery complex in the center of the surgical field, the lack of brain retraction, and the panoramic close-up view provided by the endoscope make EETA appealing for the treatment of BAX aneurysms.

The aim of this study was to assess the anatomical feasibility of using the LSO approach and the EETA for the treatment of BAX aneurysms. The advantage of endoscopic assistance during the LSO approach was also evaluated. This study was performed primarily to provide relevant anatomical details for planning of these surgical routes to the BAX, according to the patient's individual anatomy.

MATERIAL and METHODS

Twenty formalin-fixed cadaveric heads were used for anatomical dissections. Cerebral arteries were injected with a colored silicone rubber mix through the carotid and vertebral arteries. Dissections were performed at the Laboratory of Surgical NeuroAnatomy in the Human Anatomy and Embryology Unit, Faculty of Medicine (Universitat de Barcelona, Barcelona, Spain). During microsurgical dissection, an operative microscope (OPMI; Zeiss, Oberkochen, Germany) that allowed magnification ranging from 4× to 40× was used. Digital images were obtained during dissections. During endoscopic dissection, we used a 4-mm-diameter endoscope, measuring 18 cm in length, with 0-degree rod-lenses (Karl Storz GmbH and Co., Tuttlingen, Germany). The endoscope was connected to a light source through a fiberoptic cable as well as to a camera (Endovision Telecam SL; Karl Storz) fitted with three charge-coupled device sensors. Both video and digital images were obtained during dissection.

For each specimen, before dissection, radiological images were obtained in a multislice helical computed tomography (CT) scanner Siemens® SOMATOM Sensation 64 with axial spiral sections of 0.6-mm thick, without an X-ray tube inclination factor. Cadaveric heads were positioned to simulate the surgical position in the operating room in a rigid three-pin Mayfield–Kees device to allow use of the neuronavigation system (Stealthstation®S7TM System, Medtronic, Dublin, Ireland). Neuronavigation data were processed by using specific software for visualization and manipulation of biomedical data (Amira® Visage Imaging Inc., San Diego, CA) to quantify anatomical exposure and surgical freedom around the basilar apex. Anatomical exposure corresponded to the maximum visualized length of the main arterial branches at the region of the basilar apex: i.e., the ipsilateral and contralateral posterior cerebral artery (PCA), the ipsilateral and contralateral superior cerebellar artery (SCA), and the basilar artery measured from its terminal bifurcation to the most proximal exposed point. Surgical freedom was defined as an area limited by selected key anatomical targets around which the maneuverability of a malleable laying-clip (SIAD Healthcare S.P.A., Assago, Italy) with straight and curved clips (L-Aneurysm Clip Titanium permanent, Peter Lazic GmbH, Tuttlingen, Germany) was not limited by any anatomical barrier. Key anatomical target points were the following: the most distal visible point on the ipsilateral PCA, the most distal visible point on the contralateral PCA, the most distal visible point on the ipsilateral SCA, the most distal visible point on the contralateral SCA, the most proximal visible point on the basilar trunk, and the most distal visible point on the basilar artery. For each point, we assessed surgical freedom by fixing the tip of the clip on the target point and moving the laying-clip in four directions: superior, inferior, medial, and lateral, until a deep or superficial obstacle hindered the movement. Each position reached was registered with the neuronavigation pointer placed on the distal end of the instrument handle. The Cartesian coordinates of each point were registered, and surgical freedom was calculated. For a more intuitive analytical comparison of the approaches, the volumetric measurements were transferred onto schematic anatomical drawings, which were used to produce digital artworks of exposure and surgical freedom (Figures 1, 2).

Paired Student's *t*-tests were used to calculate statistical significance of differences among approaches and between sides for the measured variables. A p value of <0.01 was considered to be statistically significant.

On 10 cadaveric heads, a right LSO approach was used, as previously described by Hernesniemi et al. (12,15). The head was rotated 15 degrees toward the left side and a short oblique frontotemporal incision was made. The skin, galea, and temporal muscle were dislocated anteriorly until the superior orbital rim and the anterior zygomatic arch were reached. A small frontal craniotomy was performed, and the Sylvian fissure was exposed at the temporal edge of the bony opening. The lateral sphenoid wing and the frontal bone were drilled off to the level of the skull base. The dura mater was opened, and the Sylvian fissure was split from the frontal side. The internal carotid artery (ICA) at the opto-carotid cistern was visualized, followed by microsurgical dissection until the posterior communicating artery (PcomA) was identified. The ICA was medially withdrawn together with PcomA to increase visibility through the oculomotor-carotid corridor. Opening of Liliequist's membrane between the posterior clinoid process and the third cranial nerve allowed for exposure of the BAX in the interpeduncular cistern. The LSO approach was completed with right posterior clinoidectomy. The endoscope was finally

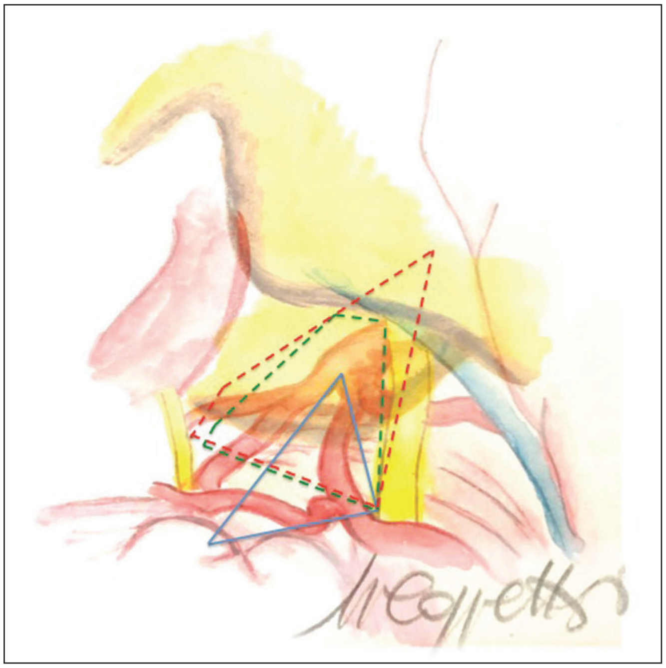

Figure 1: Anatomical drawing shows the perspective around the basilar apex through the lateral supraorbital approach, with schematic representation of surgical freedom provided before posterior clinoidectomy (blue lines), after posterior clinoidectomy (green dotted lines), and with endoscopic assistance (red dotted lines).

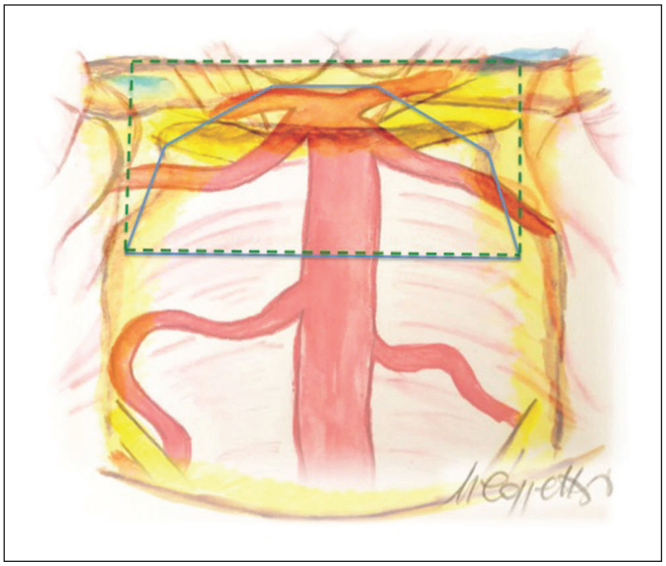

Figure 2: Anatomical drawing shows the perspective around the basilar apex through the endoscopic endonasal transclival approach, with schematic representation of the surgical freedom as provided before (blue lines) and after drilling of the dorsum sellae (green dotted lines).

introduced into the surgical field. Anatomical exposure and surgical freedom around the BAX were calculated before and after posterior clinoidectomy was performed and after the introduction of the endoscope in the operative field.

On 10 cadaveric heads, an EETA was used. The surgical nasal and sphenoidal steps of the extended endoscopic endonasal approaches were followed, as extensively described in previous publications (13,14). Following the identification of the vidian nerve, the clival bone was removed from the floor of the sella inferiorly, to the level of the paraclival internal carotid artery at the foramen lacerum. Next, the exposed dura was opened at the midline, avoiding injury to the abducent nerve laterally. The ventral brainstem and the posterior circulation vessels were exposed. The approach was completed by drilling of the dorsum sellae. The same anatomical variables described for the LSO approach were measured and recorded before and after drilling of the dorsum sellae.

The study was approved by the institutional review board of the University of Barcelona (1R800003099).

RESULTS

Lateral Supraorbital Approach

Exposure of the main arterial branches around the basilar artery by the LSO approach was limited to the basilar apex and ipsilateral PCA, in all specimens, for a mean length of 11.5 mm (± 2.,6 mm) (Figure 3A–C). Visualization of the PCA corresponded to the whole P1 segment, from the basilar terminal bifurcation to its union with the PComA. The basilar trunk, the ipsilateral SCA, and the contralateral arteries were never visible (100%). With this reduced anatomical exposure, the area of surgical freedom was 28.2 mm^2 (± 6.8 mm^2). Anatomical barriers to surgical instrument maneuverability corresponded to the posterior clinoid process, anteriorly; the mamillary bodies in the interpeduncular fossa, posteriorly; the oculomotor nerve running along the petroclinoid fold at the entrance to the cavernous sinus, laterally; and the posterior communicating artery, medially.

Lateral Supraorbital Approach with Posterior Clinoidectomy

Once the LSO approach was performed, the only anatomical barrier to the basilar apex region was the posterior clinoid process. Thus, anatomical exposure and surgical freedom as provided by this approach were further investigated after posterior clinoidectomy. Using this approach, anatomical exposure increased caudally and contralaterally in all specimens, for a mean length of 5.0 mm: the basilar artery was exposed for 4.6 mm (± 2.8 mm) from its apex, the contralateral (left) PCA was visible for 5.4 mm (± 3.1 mm), the right SCA was visible for 4.8 mm (± 2.4 mm), and the left SCA was visible for 3.7 mm (± 2.2 mm), on average (Figure 3D). The maximum visualized length of the ipsilateral (right) PCA did not change before or after posterior clinoidectomy. Exposure of the PCAs was significantly greater on the ipsilateral side (p=0.004). Removal of the posterior clinoid process allowed wider maneuverability of the laying-clip inside the enlarged area of anatomical exposure. Anatomical barriers to surgical maneuverability were the root of the posterior clinoid process, anteriorly; cranial nerve III running along the petroclinoid fold, laterally; the hippocampal gyrus in the medial surface of the temporal lobe, medially; and the cerebral crura in the midbrain,

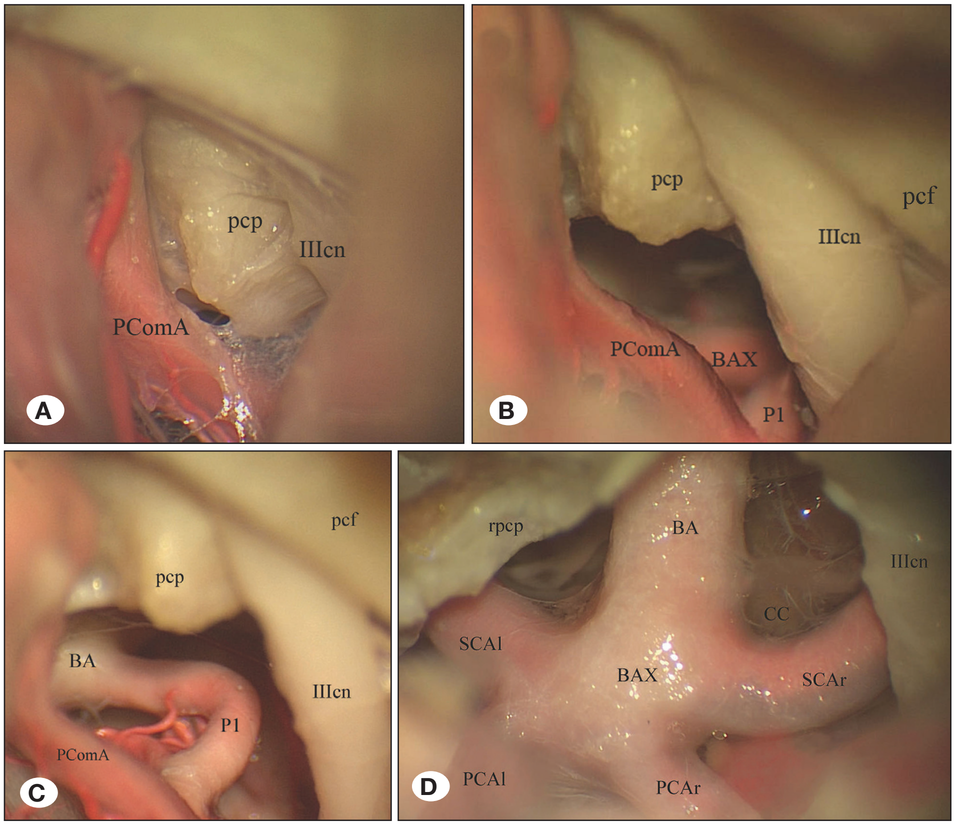

Figure 3: Through a lateral supraorbital approach, the internal carotid artery and the posterior communicating artery were identified and followed along the oculomotor-carotid corridor **(A)**. Opening of Liliequist's membrane between the posterior clinoid process and the third cranial nerve allowed for exposure of the basilar apex in the interpeduncular cistern **(B)**. Visualization of the main arterial branches around the basilar artery as provided by the lateral supraorbital approach was limited to the basilar apex and ipsilateral posterior cerebral artery **(C)**. After posterior clinoidectomy, anatomical exposure was increased, allowing for visualization of the contralateral posterior cerebral artery, basilar trunk, and superior cerebellar arteries **(D)**. **BA:** basilar artery; **BAX:** basilar apex; **CC:** crus cerebri; **P1:** posterior cerebral artery pre-communicating segment; **pcf:** petroclinoid fold; **PCAl:** left posterior cerebral artery; **PCAr:** right posterior cerebral artery; **PComA:** posterior communicating artery; **pcp:** posterior clinoid process; **rpcp:** root of the posterior clinoid process; **IIIcn:** oculomotor nerve; **SCAl:** left superior cerebellar artery; **SCAr:** right superior cerebellar artery.

posteriorly. Surgical freedom measured 34.3 mm^2 (± 7.5 mm^2), on average, which was a significant increase compared to the LSO approach without posterior clinoidectomy (p=0.005).

Endoscopically Assisted Lateral Supraorbital Approach

The advantages of endoscopic assistance in the LSO approach were assessed after removal of the posterior clinoid process. Once the endoscope was introduced into the surgical field along the carotid-oculomotor corridor and parallel to the posterior clinoid root, deeper anatomical structures were visualized with an increment of caudal anatomical exposure in all cases (Figure 4A, B). The mean measured value for the basilar artery from its terminal bifurcation to the most proximal visible point was 10.7 mm (± 1.7 mm), yielding a significant increase over the exposure provided under microscopic view (p=0.003). Both SCAs were visualized in all specimens: the ipsilateral SCA for 6.6 mm (± 3.2 mm) and the contralateral SCA for 4.0 mm (± 2.8 mm) on average, with no statistically significance differences between sides (p=0.072), or in comparison to the LSO approach without endoscopic assistance (p=0.067). Surgical freedom around the BAX region measured 36.8 mm^2 (±7.5 mm^2), with values significantly greater than those obtained with the LSO approach without posterior clinoidectomy (p=0.0007), but not those of LSO with posterior clinoidectomy (p=0,154). The limits of surgical freedom were represented by the root of the posterior clinoid process, anteriorly; the cisternal segment of cranial nerve III running from the midbrain to the petroclinoid fold, laterally; the petrous apex, medially, and the pons–medulla passage, posteriorly. Given these anatomical barriers, the anatomical structures that were exposed could not all be safely reached under the endoscopic view (Figure 3C).

Endoscopic Endonasal Transclival Approach

Upon opening of the clival dura, the basilar trunk was visualized in every specimen. The mean length of exposure of the basilar artery was 12 mm (± 2.6 mm), including its terminal bifurcation in three specimens (30%). The EETA provided greater exposure of the basilar trunk than did the LSO approach with posterior clinoidectomy, both before (p=0.0008) and after endoscopic assistance (p=0.058). Along with the exposure of the BAX, the PCAs were visible in three specimens (30%) for a mean length of 8.7 mm (± 2.7 mm) on the right side, and 7.4 mm (± 4.3 mm) on the left side, with statistically significant differences among approaches (p=0.008 for the right PCA, which was greater for LSO approaches; p=0.006 for left PCA, which was greater for the EETA approach), but not between sides (p=0.23) (Figure 5A). The SCAs were visualized in six specimens (60%) for a mean length of 8.7 mm (± 4 mm) on the right side and 7.2 mm (± 3.6 mm) on the left side (Figure 4A), with no statistically significant differences between sides (p=0.09). Comparison of the measured values for SCA exposure through the LSO approach, both before and after endoscopic assistance, and the EETA revealed significant differences (mean p=0.009). The surgical freedom provided by the EETA was measured as 32.8 mm^2 (± 0.7 mm^2), which was greater than that provided by the LSO approach (p=0.007), but was less than that provided by the LSO approach extended with posterior clinoidectomy (p=0.19) and with endoscopic assistance (p=0.02). The anatomical barriers limiting surgical instrument maneuverability inside the area of anatomical exposure corresponded to the dorsum sellae, anteriorly; clival bone removal to the level of the internal carotid arteries at the foramen lacerum, posteriorly; and the paraclival internal carotid arteries, laterally.

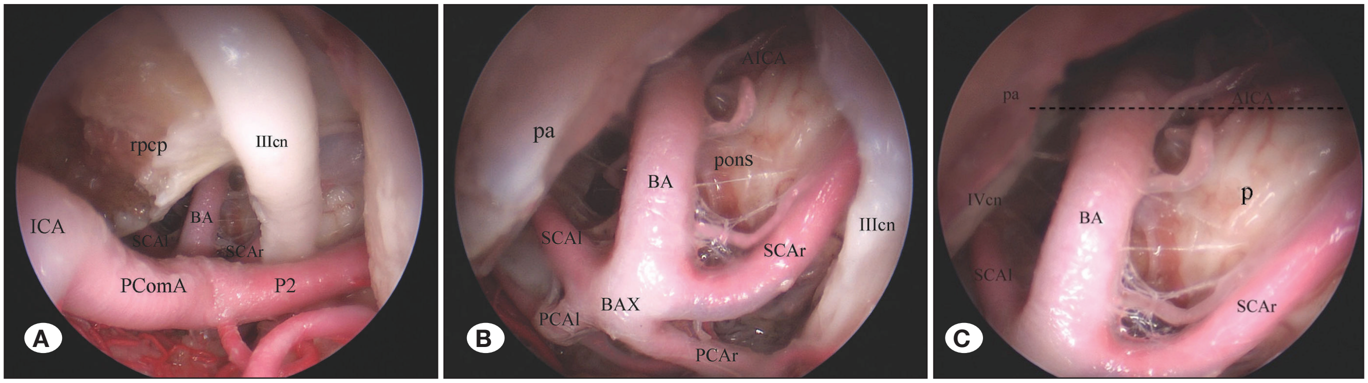

Figure 4: After posterior clinoidectomy was performed trough a lateral supraorbital approach, the endoscope was introduced into the surgical field along the carotid-oculomotor corridor and parallel to the posterior clinoid root **(A)**. Endoscopic assistance provided an increment of the caudal anatomical exposure: visualization of the basilar artery was significantly greater than under the microscopic view and longer sections of both superior cerebellar arteries were exposed **(B)**. The dotted line indicates the inferior limit for surgical freedom, which corresponds to the pons–medulla passage, where the natural curvature of the brainstem hindered safe maneuvering of surgical instruments **(C)**. **AICA:** anterior inferior cerebellar artery; **BA:** basilar artery; **pa:** petrous apex; **ICA:** internal carotid artery; **p:** pons; **P2:** right post-communicating segment of the posterior cerebral artery; **PCAl:** left posterior cerebral artery; **PCAr:** right posterior cerebral artery; **PComA:** posterior communicating artery; **rpcp:** posterior clinoid process root; **SCAl:** left superior cerebellar artery; **SCAr:** right superior cerebellar artery; **IIIcn:** oculomotor nerve; **IVcn:** trochlear nerve.

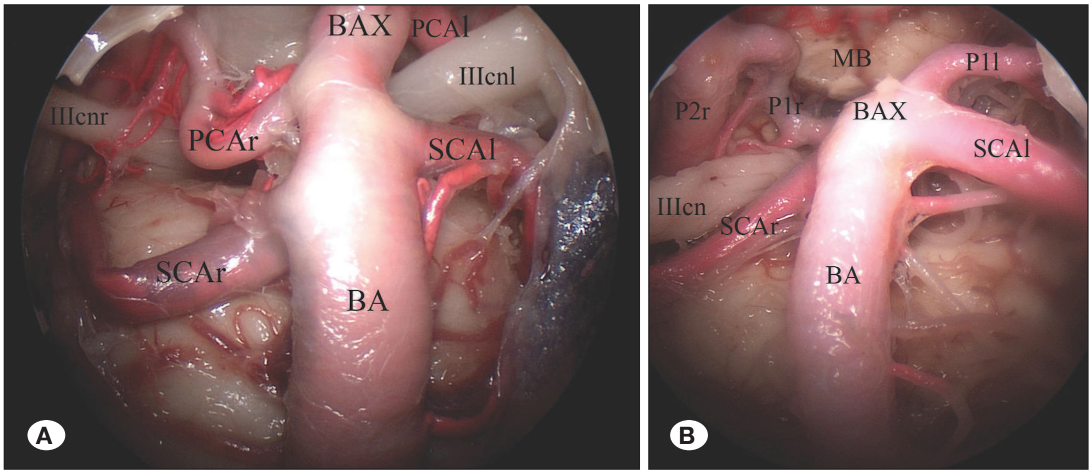

Figure 5: Using an endoscopic endonasal transclival approach, upon opening of the clival dura, the basilar trunk was always observed in the center of the surgical field. In cases with a low-lying basilar apex, the approach provided exposure of the basilar apex, posterior cerebral artery and superior cerebellar arteries. However, the limited visualization did not ensure safe distal vascular control **(A)**. Drilling of the dorsum sellae allowed for constant exposure of the terminal bifurcation of the basilar artery and the superior cerebellar arteries, with adequate vascular control **(B)**. **BA:** basilar artery; **BAX:** basilar apex; **MB:** mamillary bodies; **P1l:** left pre-communicating posterior cerebral artery; **P1r:** pre-communicating posterior cerebral artery; **right PCAl:** left posterior cerebral artery; **PCAr:** right posterior cerebral artery; **P2r:** right post-communicating posterior cerebral artery; **SCAl:** left superior cerebellar artery; **SCAr:** right superior cerebellar artery; **IIIcn:** oculomotor nerve; **IIIcnl:** oculomotor nerve; **left IIIcnr:** right oculomotor nerve.

Endoscopic Endonasal Transclival Approach with Drilling of the Dorsum Sellae

Anatomical exposure and surgical freedom as provided by the EETA were further evaluated after drilling of the dorsum sellae. Anatomical exposure increased anteriorly for a mean extension of 3.4 mm, allowing for visualization of the BAX, both PCAs, and both SCAs in all specimens (Figure 5B). The mean length of BA exposure of the basilar artery from its terminal bifurcation to the most proximal visible point measured 15.4 mm (± 3.2 mm), resulting in statistically significant differences as compared to the LSO approach with posterior clinoidectomy, LSO with endoscopic assistance, and the EETA (mean $p<0.0001$). The maximum visualized length of the right PCAs was 12.1 mm (± 1.5 mm) and 9.6 mm (± 4.2 mm) for the left PCA, with no statistically significant differences between sides ($p=0.23$). If SCAs were visible before drilling of the dorsum sellae, their exposure did not change after drilling. No significant difference was found for PCA exposure, if PCAs were visible, as compared to the EETA ($p=0.07$). Anatomical barriers limiting surgical instrument maneuverability inside the area of anatomical exposure were presented by the dura covering the pituitary gland, anteriorly; clival bone removal to the level of the internal carotid arteries at the foramen lacerum, posteriorly; and the paraclival internal carotid arteries, laterally. The mean measured value for surgical freedom as provided by the EETA with drilling of the dorsum sellae was 37.3 mm^2 (± 4.7 mm^2), which was greater than that provided by the EETA alone ($p=0.0008$), endoscopically assisted LSO ($p=0.39$), the LSO approach with posterior clinoidectomy ($p=0.07$), and the LSO approach alone ($p=0.00004$).

Measured values for anatomical exposure provided by each approach are summarized in Table I. Anatomical barriers to surgical freedom are reported in Table II.

DISCUSSION

Under specific anatomical conditions, the LSO approach and the EETA may both be considered as minimally invasive alternatives to the classical surgical routes for treating BAX aneurysms, with different but complementary indications: the LSO is used for high-lying and the EETA for low-lying BAX aneurysms. Characteristics and application of these approaches and their extensions to BAX aneurysms are discussed together, below. The LSO approach has been established and developed as a faster and simpler alternative to the standard pterional approach. With the advantage of reduced craniotomy-related complications, the LSO approach is useful for reaching the whole anterior part of the Circle of Willis, the sellar and suprasellar regions, as well as the anterior part of the basilar artery, if it is located superiorly to the posterior clinoid process (16,17). However, the subfrontal trajectory provides a limited angle of view in the interpeduncular cistern, making the approach unsuitable for lower-positioned basilar tip aneurysms (12,15,17). Posterior clinoidectomy has been advocated as a surgical maneuver for overcoming this limitation (9,18,19). Here, we aimed to

Table I: Anatomical Exposure of the Main Arterial Branches at the Region of the Basilar Apex as Provided by the LSO Approach Before and After Posterior Clinoidectomy, Endoscopic Assisted LSO Approach After Posterior Clinoidectomy, and EETA with and without Drilling of Dorsum Sellae. Measurements are Presented as the Mean ± Standard Deviation

	Right LSO	Right LSO with posterior clinoidectomy	Right Endoscopic assisted LSO with posterior clinoidectomy	EETA	EETA with drilling of dorsum sellae
Right PCA	11,5 mm (±2,6 mm)	11.5 mm (±2.6 mm)	11.5 mm (±2.6 mm)	8.7 mm (±2.7 mm); not visible in 70% of specimens	12.1 mm (±1.5 mm)
Left PCA	Not visible	5.4 mm (±3.1 mm)	5.4 mm (±3.1 mm)	7,4 mm (±4.3 mm); not visible in 70% of specimens	9.6 mm (±4.2 mm)
Right SCA	Not visible	4.8 mm (±2.4 mm)	6.6 mm (±3.2 mm)	8.7 mm (±4 mm); not visible in 40% of specimens	8.7 mm (±4 mm)
Left SCA	Not visible	3.7 mm (±2.2 mm)	4 mm (±2.8 mm)	7.2 mm (±3.6 mm); not visible in 40% of specimens	7.2 mm (±3.6 mm)
BA (from the apex to the most proximal point)	Only apex; basilar trunk not visible	4.6 mm (±2.8 mm)	10.7 mm (±1.7 mm)	12 mm (±2.6 mm); apex not visible in 70% of specimens	15.4 mm (±3.4 mm)

BA: *Basilar artery;* ***EETA:*** *Endoscopic endonasal transclival approach;* ***LSO:*** *Lateral supraorbital approach;* ***PCA:*** *Posterior cerebral artery;* ***SCA:*** *Superior cerebellar artery.*

Table II: Anatomic Barriers to Surgical Freedom as Noted During Each Approach

	LSO	LSO with posterior clinoidectomy	Endoscopic assisted LSO with posterior clinoidectomy	EETA	EETA with drilling of dorsum sellae
Surgical freedom	28.2 mm^2 (±6.8 mm^2)	34.3 mm^2 (±7.5 mm^2)	36.8 mm^2 (±7.5 mm^2)	32.8 mm^2 (± 0.7 mm^2)	37.3 mm^2 (± 4.7 mm^2)
Anatomic Barrier					
Anterior	Posterior clinoid process	Root of posterior clinoid process	Root of posterior clinoid process	Dorsum sellae	Dura covering the pituitary gland
Posterior	Mamillary bodies	Cerebral crura	Pons-medulla passage	Clival bone at the level of foramen lacerum ICAs	Clival bone at the level of foramen lacerum ICAs
Lateral	Oculomotor nerve	Oculomotor nerve	Oculomotor nerve	Paraclival ICA	Paraclival ICA
Medial	PComA	Hippocampal gyrus	Petrous apex	Paraclival ICA	Paraclival ICA

***EETA:** Endoscopic endonasal transclival approach, **ICA:** Internal carotid artery, **PcomA:** Posterior communicating artery, **LSO:** Lateral supraorbital approach*

evaluate the advantage of endoscopic assistance during the LSO approach after posterior clinoidectomy for the treatment of BAX aneurysms, quantitatively; this has not been reported previously. Although the use of endoscopic assistance during microsurgical skull-base approaches is widely accepted, little quantitative data are available for describing the amount of increased exposure and the surgical freedom that it can provide (20-23). Recently, the endoscopic endonasal technique has been advocated as a feasible option to complement the role of traditional microsurgical and endovascular techniques in the care of patients with carefully selected intracranial vascular pathologies, such as paraclinoid and ventral posterior fossa aneurysms (11,24,25). The main components of the vertebrobasilar system may be easily exposed through an EETA, with a direct route to these vessels that avoids extensive skull-base approaches and brain retraction (13). Our results add to those of the few available anatomical studies that sought to provide objective and quantitative evidence of the relative advantages and limitations of the EETA for treating BAX aneurysms (11,24).

The choice of the surgical approach used to treat BAX aneurysms generally depends on the size, shape, exact location of the aneurysm, its direction of projection, its relationship with perforators, the degree of brain swelling, other patient comorbidities, and the surgeon's experience. Relevant pre-operative radiological characteristics include the basilar bifurcation angle, PCA symmetry, presence of a fetal posterior cerebral artery, location of the SCAs, and the vertical distance from the aneurysm neck to the dorsum sellae and posterior clinoid process (1,17,26).

A major limitation of the present study was the impossibility of reproducing so many variables in an anatomical laboratory environment. Assessment of the endoscopically assisted LSO approach and the EETA for BAX aneurysms focused on the relationship between the basilar artery and the dorsum sellae. Clearly, whether this information can be transferred from a cadaveric environment to live surgery needs to be clinically validated. The lack of surgical demonstrative cases for each approach to facilitate better understanding of the surgical technique is a major limitation and further clinical studies are needed to translate the anatomical information obtained into surgical practice.

Anatomical Feasibility of the Approaches

A sound neurosurgical approach should achieve a careful balance between minimizing iatrogenic damage and maximizing safe anatomical exposure and operability. In aneurysm clipping, the core principles of ensuring adequate proximal and distal control and careful dissection of the aneurysm should be respected. In BAX aneurysm surgery, control of the basilar trunk is the most important parameter, because the aneurysm is usually less vigorously filled through backflow from the PCAs and even less through inflow from the SCAs (1,27,28). Surgical freedom is particularly important in aneurysm surgery, because a larger area of exposure inside which maneuverability of surgical instruments remains safe may allow for easier stepwise clip application and intraoperative aneurysm rupture control.

Regarding the LSO approach, our results are in keeping with previous recommendations that consider this approach useful for BAX aneurysms only if the basilar artery is located superior to the posterior clinoid process (12,16). In the present anatomical study, no cadaver specimens harboring a high-lying BAX was observed and the anatomical exposure provided by the LSO approach was not viable for appropriate vascular control. To achieve basilar artery control, posterior clinoidectomy was always required. The endoscopically assisted LSO and the EETA with drilling of the dorsum sellae provided exposure of the whole basilar artery complex, ensuring adequate visualization of the basilar trunk, BAX, PCAs, and SCAs. The main advantage offered by endoscopic assistance was greater anatomical exposure than obtained with the LSO with posterior clinoidectomy, without additional surgical exercise. Although it provided greater surgical freedom, based on our results, endoscopic assistance may still not fully address the challenge of providing better vascular control in a larger area of exposure. The basilar trunk could not be reached over the whole exposed length because the natural curvature of the brainstem at the pons–medulla passage hindered the illumination provided by the endoscope, and surgical instruments remained out of direct visualization in the depth of the field. The posterior clinoid root and the petrous apex prevented positioning of the tip of the endoscope tangential to the basilar apex and contralateral vessels, which could not be reached safely under endoscopic view. We recommend that endoscopic assistance is used as an added measure of safety in the assessment of clip placement and patency of the surrounding vessels, without adding iatrogenic morbidity to the LSO approach with posterior clinoidectomy. The only significant advantage offered by the EETA was better proximal exposure of the basilar artery. However, the limited surgical freedom and anatomical exposure of the basilar artery terminal bifurcation would prevent safe surgical maneuvers around the aneurysm sac, which reduces the clinical relevance of robust proximal control. Our results showed that the EETA with drilling of the dorsum sellae may be a feasible option for treating BAX aneurysms; the advantages of this approach are particularly evident with low-lying BAX. This ensures adequate proximal and distal vascular control and increased surgical freedom around the BAX as compared to the EETA alone. Pituitary transposition could be an option for overcoming the limitation of the EETA to the BAX region; however, in such cases, less complex surgical approaches should be considered (29, 30).

Relevant Anatomical Details for Planning of the Surgical Approach

With refinements of diagnostic methods, it has become increasingly feasible to ensure visibility of the anatomical details in the examined region for the neurosurgeon. This presents the possibility of planning the approach according to the patient's individual anatomy. The measured value of increased anatomical exposure of the basilar artery provided by posterior clinoidectomy during the LSO approach makes it possible to identify the lowest position of the BAX below the dorsum sellae at which BAX aneurysms can be safely addressed using this approach. It is not feasible to use this approach for a BAX lying lower than 5.0 mm from the dorsum sellae, as the basilar artery is then outside of the exposed field. On the other hand, by quantifying the increased anatomical exposure achieved with the EETA after drilling of the dorsum sellae, we determined that 3.4 mm is the highest position of the BAX below the dorsum sellae for safely addressing BAX aneurysms through the EETA; if the BAX is located higher, this approach is also not feasible, as the BAX would be outside of the exposed field.

CONCLUSION

In carefully selected cases, the endoscopically assisted LSO approach and the EETA may represent feasible options for treatment of BAX aneurysms lying within 5.0 mm below the dorsum sellae and no higher than 3.4 mm above the dorsum sellae. The correct indication for these approaches can be predicted based on pre-operative imaging studies, as determined by the relationship between the BAX and the dorsum sellae. Further clinical studies are needed to translate this cadaver-based anatomic information into surgical practice.

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