Lateral Transorbital Neuroendoscopic Approach to the Lateral Cavernous Sinus

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Abstract

Objective To design and assess the quality of a novel lateral retrocanthal endoscopic approach to the lateral cavernous sinus.

Design Computer modeling software was used to optimize the geometry of the surgical pathway, which was confirmed on cadaver specimens. We calculated trajectories and surgically accessible areas to the middle fossa while applying a constraint on the amount of soft tissue retraction.

Setting Virtual computer model to simulate the surgical approach and cadaver laboratory.

Participants The authors.

Main Outcome Measures Adequate surgical access to the lateral cavernous sinus and adjacent regions as determined by operations on the cadaver specimens. Additionally, geometric limitations were imposed as determined by the model so that retraction on soft tissue structures was maintained at a clinically safe distance.

Results Our calculations revealed adequate access to the lateral cavernous sinus, Meckel cave, orbital apex, and middle fossa floor. Cadaveric testing revealed sufficient access to these areas using <10 mm of orbital retraction.

Conclusions Our study validates not only the use of computer simulation to plan operative approaches but the feasibility of the lateral retrocanthal approach to the lateral cavernous sinus.

Keywords

- ▶ cavernous sinus
- ▶ endoscopic
- ▶ pituitary
- ▶ transnasal
- ▶ transsphenoidal
- ▶ transorbital

Introduction

Traditional open craniotomy approaches to the cavernous sinus have been extensively described with wide-ranging outcomes in terms of morbidity and mortality.^{1–15} However, the potential neurovascular morbidity from these approaches in addition to patient dissatisfaction from these traditional open operations have made open techniques for cavernous sinus surgery wane in popularity.

The advent of stereotactic radiosurgery has made open approaches for many lesions of the cavernous sinus

e.g., meningiomas) unnecessary.^{16–18} There are, however, lesions of the cavernous sinus for which radiosurgery has limited benefit including secreting pituitary tumors and hemangiopericytomas.^{19,20} For these neoplasms, completeness of resection is the most important determinant of long-term outcome.^{21–23} New surgical approaches to the cavernous sinus are thus needed that achieve acceptable oncologic outcome with reduced morbidity.

Transnasal transsphenoidal endoscopic approaches provide an operative pathway to the medial cavernous sinus, and surgery of this portion of the cavernous sinus is well

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described.^{24–26} Similarly, expanded endonasal approaches—including transmaxillary and trans-ethmoid/pterygopalatine—further improve visualization of the cavernous sinus but are limited in their ability to access its lateral portions.^{24,27} Recent reports have studied endoscopic approaches to the lateral cavernous sinus facilitated via supraorbital craniotomy or via open transorbital approaches that provide surgical access to the orbital apex and adjacent skull base.^{28–31} These approaches, however, still require craniotomy, temporary removal of the orbital rim, or expanded canthotomy incisions, all of which create unnecessary tissue damage. Surgical approaches that minimize collateral tissue damage are needed.

We sought to design a new transorbital surgical approach corridor to the lateral cavernous by performing a rigorous geometric analysis with recently developed computer-aided surgical planning techniques.³² Orbital retraction is one of the major factors that might limit adequate transorbital access to the lateral cavernous sinus. Experience in transorbital skull base surgery suggests that ≤ 10 mm of orbital retraction at the lateral orbital rim is safe and not associated with negative ophthalmologic outcomes.^{31,33,34} Using this as a constraint in the computer analysis, the surgical corridor can be designed and tested for adequate access.

Further, the size requirement for a surgical pathway is decreasing with modern endoscopes and the introduction of multifunctional instruments such as ultrasonic bone aspiration that irrigates, suctions, and preferentially ablates bone. By reducing the number of instruments traversing the surgical corridor, yet maintaining the surgical capability at the target site, smaller, less disruptive surgical corridors may be used.

We previously reported on a system of endoscopic transorbital approaches to lesions of the anterior cranial fossa, middle cranial fossa, and orbital apex.^{33–35} Here we describe a minimally disruptive endoscopic transorbital approach to the lateral cavernous sinus via the lateral retrocanthal approach that does not require a skin incision or orbital rim resection. We hypothesized that the use of computer modeling would determine the geometric limits and the amount of orbital retraction needed to adequately access the lateral cavernous sinus using the endoscopic lateral retrocanthal approach. The efficacy of this approach was then tested in a cadaver study.

Methods

Computer Pathway Planning and Analysis

iNtellect Cranial Navigation (Stryker Corporation, Kalamazoo, MI) was used to evaluate approach trajectories as described earlier.⁷ ▶ **Fig. 1** is a schematic of the approach entry window. Six Cartesian (x, y, z) coordinates were selected to define the entrance to the surgical corridor and the target polygon at the lateral cavernous sinus. A polygon with six vertices was chosen because it is a relatively simple shape, yet accurately approximates the surgical corridor with three points to account for the curvature of the orbital rim and three points to represent a malleable retractor for the orbital contents. The target area was a polygon placed on the lateral cavernous

Fig. 1 Schematic showing the entry portal to the surgical pathway. The white line represents the entrance to the surgical corridor, bounded laterally by the orbital rim and medially by a malleable retractor retracting the orbital contents. The ipsilateral cavernous sinus, internal carotid artery, and segments of the optic nerve and chiasm are shown in blue, red, and yellow.

sinus in the sagittal plane, bounded superiorly by the superior orbital fissure and posterior clinoid process, and its inferior extent was set to 5 mm inferior to the sella turcica's most inferior extent. ▶ **Fig. 2A** shows the surgical corridor with lines connecting the entrance and target polygons at the vertices. Connecting these two polygons created a surgical corridor volume and revealed an additional polygon of six vertices where the volume intersected the greater wing of the sphenoid (▶ **Fig. 2B**); this represented the area of bone that required removal. The surgical corridor, defined by Cartesian coordinates, was imported into MATLAB for visualization and analysis of cross-sectional area, distance calculations, and volumetric analysis.

Standard linear algebraic formulas were used to compute distances between two coordinates. Polygon area calculations were performed by rotating the polygon in three-dimensional (3D) space to find the maximum area, thus finding a best fit onto a two-dimensional (2D) plane. Each polygon was not entirely in one 2D plane, but by the nature of the coordinates selected, it was within ~ 3 mm of being in the same plane at any one vertex, resulting in an accurate area estimation. Volume was computed by numerically integrating the equations of the six lines defined by the entry, intersection at the greater wing of the sphenoid, and target vertices over the length of the volume, summing the polygon areas for each integration.

Cadaver Operations

The procedure was performed on three preserved latex-injected cadaver heads (six orbits) with surgical navigation. Based on the morphometric analysis, retraction of orbital contents was limited to < 9 mm (see Results). For visualization purposes, an orbital exenteration was performed on one orbit; the surgical approach as described below was performed on the remaining five orbits. The amount of bone removed between the superior and inferior orbital fissures was measured, and endoscopic images were obtained to show the limits of the approach. In all cadavers, an endoscopic

Fig. 2 Defining the volume and dimensions of the surgical corridor. (A) Superior view showing the six vertices selected as boundaries to reach the target location, which is a polygon at the lateral cavernous sinus oriented in the sagittal plane. (B) Three-dimensional rendering of surgical corridor by vertices in MATLAB from the same viewing angle. The red lines represent the entrance window bounded by the orbital rim and the retracted orbital contents. The yellow rectangle is the target location at the lateral cavernous sinus. The blue triangles indicate the intersection of the surgical volume with the greater wing of the sphenoid.

transsphenoidal approach was performed with skeletonization of the medial cavernous sinus. In addition, the Dolenc approach to the cavernous sinus was performed with skeletonization of the cranial nerves (a temporal lobectomy was performed to assist in visualization following completion of the endoscopic approaches).

Surgical Technique

The lateral retrocanthal approach as previously described involves an incision posterior to the lateral canthal tendon in the conjunctiva (a skin incision is not required).³⁴ The head was retroflexed 15 degrees to allow gravity to displace the brain from the skull base. The periorbital was dissected free from the lateral orbital wall under endoscopic guidance. If present, a zygomatic arterial branch was coagulated with bipolar cautery. Dissection continued until the inferior and superior orbital fissures were exposed back to the orbital apex (►Fig. 3A). Using a ultrasonic bone aspirator (Sonopet Stryker Corp.), initially with the Payner 360 Tip, followed by the Long Spetzler Micro Claw Tip, the bone in the greater wing of the sphenoid was removed to expose the dura (►Fig. 3B).

Medially, the optic strut was thinned to ~2 mm. Inferiorly, enough bone was removed to visualize the trajectory of the infraorbital nerve as it coursed posteriorly and inferiorly toward the foramen rotundum. Once the bony window had been created, the dura overlying the temporal lobe between the ophthalmic and maxillary branches of the trigeminal nerve was dissected laterally to approach the cavernous sinus.

Results

Morphometric Analysis

The analysis was performed on four computed tomography (CT) scans of normal skull base anatomy (2 men, 2 women; age range: 23 to 59 years). ►Table 1 summarizes the results. The average length of the approach corridor (from midpoint of entrance polygon to midpoint of target polygon) was 61.5 mm (standard deviation [SD]: 1.93). From entry vertex to target vertex, the average minimum distance was 55.6 mm (SD: 4.4), and the maximum was 67.1 mm (SD: 0.7).

Fig. 3 (A) Anatomy of the right orbit, exenterated. SOF, superior optic fissure; IOF, inferior optic fissure; ION, infraorbital nerve; Z, zygomatic arterial branch; OR, orbital rim; LP, lamina papyracea. The area in green approximates the region of bone to be removed in the greater wing of the sphenoid. (B) Creating the craniotomy and exposing the dura in a right orbit.

Table 1 Morphometric analysis results

	Average	SD
Distance from entry polygon to target polygon	61.5 mm	1.9
Retraction distance of orbital contents at entry polygon	8.2 mm	0.1
Entry polygon area	127.2 mm ²	19.2
Target polygon area	120.2 mm ²	37.2
Greater wing of sphenoid polygon area	210.3 mm ²	14.0
Volume of surgical corridor	6817.0 mm ³	736.0
Volume of orbital component surgical corridor	2750.7 mm ³	523.6

Abbreviation: SD, standard deviation.

The average retraction distance of the orbital contents away from the orbital rim was 8.2 mm (SD: 0.1) with a minimum vertex to vertex distance of 7.7 mm (SD: 0.4) and a maximum of 8.7 mm (SD: 0.4).

The average entrance polygon area was 127.2 mm² (SD: 19.2), and the target polygon area was 120.2 mm² (SD: 73.2). The average area of the polygon formed by the lines connecting the vertices of the entrance and target polygons and their intersection with the greater wing of the sphenoid was 210.3 mm² (SD: 14.0).

The average volume of the surgical corridor was 6817 mm³ ($\pm$ 736), and the volume component within the orbit was 2751 mm³ ($\pm$ 524).

Anatomical Observations

In the cadaver, minimal orbital retraction was necessary to achieve an adequate working corridor for the introduction of

an endoscope as well as instrumentation (suction and dissector). In fact, medial orbital retraction <9 mm achieved adequate visualization, consistent with previous reports from our group and others.^{31,34} The amount of orbital retraction can be visualized by examining the axial image (►Fig. 4) from the surgical navigation data during the procedure. Because of the bony removal of the greater sphenoid and lateral orbit and the fact that the surgical target is medially angulated, orbital retraction is virtually nonexistent in the posterior orbit and minimal anteriorly. The average volume of the orbital component of the surgical corridor was 2.75 cm³ on computer analysis, or 40% of the total surgical corridor volume.

The lateral retrocanthal corridor permits access to the orbital apex in addition to the cavernous sinus, middle fossa floor, Meckel cave region, and their associated neurovascular structures (►Figs. 5 and 6). An anatomical landmark to follow on the orbital floor is the infraorbital nerve (►Fig. 3A), which

Fig. 4 Surgical navigation demonstrating an instrument accessing the lateral cavernous sinus through the lateral retrocanthal corridor approach. Note that with this approach there is minimal compression of the orbital contents. Only the anterior half of the orbit is subject to compression forces due to the location of the craniotomy greater wing of the sphenoid.

Fig. 5 Right-sided transorbital (lateral retrocanthal corridor [LRC]) endoscopic photograph through craniotomy in greater wing of sphenoid to visualize lateral cavernous sinus. TO, instrument through LRC approach portal; V1 and V2, branches of trigeminal nerve; C, cavernous sinus; TN arrow points to instrument inserted transnasally (marked by asterisk), placed lateral to the internal carotid artery into the cavernous sinus; D, dura.

Fig. 6 Transcranial photograph of the lateral cavernous sinus and cranial nerves III, IV, V1, V2, V3, and VI. The internal carotid artery (ICA) and the dura (D) of the middle cranial fossa are labeled.

if traced posteriorly leads to the maxillary division of the trigeminal nerve (after drilling of the posterior orbital wall and middle fossa floor). To access the middle fossa floor adequately, particularly in the region of mandibular division of the trigeminal nerve, requires more lateral temporal bone drilling. Additionally, this approach requires a device like the ultrasonic bone aspirator because a rotating drill through the lateral retrocanthal approach would likely tear periorbita and disrupt the working field.

Because this approach is retrocanthal and endoscopic, no lateral orbital rim needs removal. Moreover, unlike other open approaches, this endoscopic approach starts by placing the surgeon at the medial floor of the middle fossa, thereby

making temporalis muscle dissection and an extended temporal craniectomy unnecessary.³¹

Because the superior extent of the exposure is the superior orbital fissure, access to the anterior clinoid is not provided with this approach (which would require passing the superior orbital fissure, as described elsewhere³¹). Additionally, access to more posterior structures such as the posterior limit of Meckel cave is somewhat cumbersome, due to current limitations in the size and length of endoscopic instruments. The working corridor also becomes more narrow posteriorly unless the medial temporal lobe is retracted.

Finally, exposure of the cavernous sinus dura begins with lateral retraction of the medial temporal dura. Consequently, in our cadaveric specimens, the dura separated away from the cavernous sinus dura simply by this lateral retraction of temporal dura after a small incision at the junction of the temporal and cavernous sinus dura.

Discussion

Recent reports involving noncraniotomy approaches to the parasellar area have focused on either extended endoscopic maneuvers such as the transthemoid-pterygoid-sphenoidal approach or mini-open procedures such as the lateral orbital wall approach.^{27,31,36–40} However, transorbital endoscopic approaches to the cavernous sinus, middle fossa, and Meckel cave region are in their infancy, and the current literature is limited to orbital trauma, repair of meningoencephaloceles, and repair of cerebrospinal fluid leaks.^{33–35,41–43} This is the first report that systematically analyzes the feasibility of a transorbital endoscopic route to the parasellar area, middle fossa, and Meckel cave region.

A transorbital endoscopic route to address lateral cavernous sinus lesions has many inherent advantages. Visualization is superb with direct en face view of the lesion and critical surrounding structures as demonstrated in **Fig. 6**. The average distance to the target locations was 6 cm compared with >9.5 cm transnasally.³² Removal of the bone of the lateral orbital rim is not required or beneficial; the only bone removed is that between the superior and inferior orbital fissures. Skeletonization of the carotid via drilling is not required as it would be in the transthemoid-pterygoid-sphenoidal endoscopic endonasal approach to the cavernous sinus. Instead, posterior medial and lateral orbit is drilled, and then access to the medial portion of the middle fossa floor and parasellar area is achieved. This likely would increase the safety of and lessen the potential nasal morbidity of accessing lesions of the lateral cavernous sinus. Because the lateral cavernous sinus is in the center of visualization, surgical maneuverability is not compromised as is often the case with transsphenoidal approaches where the lateral cavernous sinus lies at the periphery of the exposure. Moreover, brain retraction is not required for visualization and manipulation. Cosmesis is excellent because the lateral retrocanthal approach requires no skin incision or any temporalis muscle detachment. The craniectomy performed in the greater wing of the sphenoid is easily reconstructed by insertion of a fat graft or onlay of a thin resorbable material such as PDS foil.

Potential disadvantages of this technique include unfamiliarity with the orbital anatomy, risk of globe injury from retraction, and the current paucity of multifunction endoscopic instrumentation that might minimize the crowding through the surgical access portal. However, recent reports suggest that permanent ocular morbidity from this approach is minimal.³³

The greatest utility of this approach may be for biopsy of lesions within Meckel cave and the lateral cavernous sinus. There are few indications for surgical excision of benign tumors within the lateral cavernous sinus due to the associated cranial nerve morbidity. Most pituitary adenomas that extend laterally into the cavernous sinus are most easily accessed by following the course of the tumor from medial to lateral. In the instances of significant lateral extension, a multiportal approach permitting both medial and lateral access may improve the rate of complete resection, which is paramount for the successful treatment of hormone-secreting adenomas.^{44,45} Another indication is in the cases of recurrent tumor where there is scarring lateral to the internal carotid artery (ICA). The approach is limited medially at the trigeminal nerve and ICA. Additionally, this technique could easily be adapted to treat lesions of the middle fossa or Meckel cave such as meningiomas, schwannomas, and so on. Moreover, intradural lesions of the temporal pole could readily be treated with this approach, but next generation multifunction endoscopic instrumentation will be required to make such approaches less cumbersome given the relatively narrow surgical corridor of the transorbital approach.

Conclusions

This study systematically addresses the feasibility of approaching the lateral cavernous sinus through a transorbital endoscopic approach. We hypothesized that the use of computer modeling would determine geometric limitations on orbital retraction and surgical access, and aid in the development of a surgical corridor that causes less collateral tissue damage. Indeed, the morphometric analysis calculated cross-sectional areas, quantified orbital volume retraction at 2.7 cm³, and demonstrated that <9 mm of retraction on the orbital contents can provide surgical access to the target location without removal of the orbital rim or a skin incision. The lateral retrocanthal approach offers minimal tissue disruption, adequate path volume, a short distance to the pathology, and does not necessitate manipulation of critical neurovascular structures. This was confirmed in cadaver specimens, and the surgical technique was described. Future studies will need to address the actual surgical ease of its use and the attendant clinical outcomes regarding extent of resection and morbidity. Our clinical experience with this approach will be reported subsequently.

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