Three-Dimensional and 2-Dimensional Endoscopic Exposure of Midline Cranial Base Targets Using Expanded Endonasal and Transcranial Approaches

Objective: Endoscopic endonasal approaches provide an access method to the midline cranial base. To integrate these approaches into neurosurgical practice, the extent of their anatomic exposure must be compared with that provided by more traditional transcranial approaches.

Methods: Ten fresh cadaver heads were studied. Both endonasal and transcranial approaches to the midline cranial base were performed. The midline cranial base was divided into several areas, and the relative exposure provided by each approach was described and presented in both 2-dimensional and 3-dimensional images. Limitations and advantages of each approach are discussed.

Results: The endonasal approaches achieved a direct and wide exposure of the midline extracranial and intracranial cranial base anatomy. The main lateral limitations of the endonasal approaches were the optic nerves, lateral cavernous sinus, vidian nerve, internal carotid artery, abducens nerve in Dorello’s canal, jugular tubercle, and hypoglossal canals. Limitations of the transcranial approaches were the neurovascular structures which lie in the operative corridor and create narrow working spaces.

Conclusion: The endonasal approaches achieve a direct and wide exposure of the midline cranial base bilaterally. Lateral exposure, beyond the cranial nerves and carotid artery, are challenging. Transcranial approaches are limited by the narrow corridors provided by the cranial nerves, and they do not visualize the contralateral paramedian cranial base very well. Three-dimensional endoscopes augment the spatial orientation and may improve patient safety and the learning curve for endoscopic approaches to the midline cranial base.

Key Words: Cranial base, Endonasal, Endoscopic, Minimal access, Minimally invasive, Skull base, Stereoscopic, 3-dimensional, Transcranial

Extended endoscopic endonasal approaches are becoming increasingly applied in the management of various intracranial pathologies along the midline cranial base. On one end of the complexity spectrum lie lesions such as pituitary adenomas and encroaching sections of the cribriform plate, which can be more easily approached through the endonasal corridor (5, 13, 16, 39, 43). On the other end, increasingly challenging lesions such as chordomas, meningiomas, esthesioneuroblastomas, and suprasellar craniopharyngiomas are more demanding to the endoscopic approaches, as they often require extensive drilling of the cranial base and can surround or invade neurovascular structures (12, 14, 15, 17, 22, 25–28, 30, 31, 33, 42, 47). However, these same challenges face the surgeon using open transcranial approaches to similar lesions. Despite the availability of both endonasal and transcranial corridors, little work has been performed to directly compare their applicability and limitations in reaching cranial base targets (6–8).
At present, standard state-of-the-art endoscopes provide high-resolution 2-dimensional (2D) images. When the surgeon is working in extremely delicate intracranial spaces, where neural and vascular structures are often separated by millimeters, depth perception is crucial to reduce the risk of injury to these structures (21). With 2D scopes, depth perception is based on the surgeon’s knowledge of the spatial orientation and distances between various anatomic structures, size discrepancies between these structures, light and dark shadows, as well as visual and tactile feedback during the various surgical maneuvers. However, despite these visual and tactile senses, these cues can be misleading (21, 49). Most neurosurgeons perform surgical approaches transcranially using a microscope, which enables 3-dimensional (3D) visualization. Even experienced surgeons face a steep learning curve using the 2D endoscope (21). In such a setting, use of 3D endoscopy could help facilitate the transition from a stereoscopic microscopic view to endoscopic visualization (48). In this study, we performed a range of well-described transcranial cranial base approaches and compared the view with the corresponding extended endonasal endoscopic approaches. We then compared the transcranial and endonasal approaches using both a 2D endoscope and a novel 3D endoscope.

**MATERIALS AND METHODS**

Ten fresh cadaver heads, injected with blue and red latex to the venous and arterial systems, respectively, were used for anatomic dissection. The endonasal approaches were performed using 2D 0-degree and 30-degree endoscopes (4-mm diameter, 18-cm length; Telecam ccu 2023103, Telecam camera head 20212134 (single-chip charge-coupled device); Karl Storz, Tuttingen, Germany) and 3D 0-degree and 30-degree endoscopes (4.9-mm diameter, 30-cm length; VisionSense, Petach Tikva, Israel). The 3D endoscope uses a proprietary technology, incorporating a pair of pupils, a single lens, and a single chip mimicking a compound eye. Similar to an insect eye, the 3D image is fractionated by a matrix of microlenses to right and left images on a pixel level. The electronic data composing the multiplexed right and left channels are separated by the video processor and displayed using a standard 3D display. The camera (including lens and chip) is about 3 mm in diameter and about 15 mm long and is fixed at the tip of the endoscope shaft (3, 21, 48). The image is projected as a fusion of left and right images on a screen placed directly in front of the surgical team, who are required to wear stereoscopic glasses to view the 3D image. Images were recorded and stored by the Karl Storz Aida system and by the VisionSense software (version 1.6.03.01).

Transcranial approaches were performed using standard neurosurgical techniques with microscopic visualization. A Zeiss NC4 microscope (Carl Zeiss, Inc., Oberkochen, Germany) was used for dissections. Images were recorded and stored by the same endoscopes and recording systems mentioned above.

**RESULTS**

The anatomic regions of the cranial base and the corresponding endonasal and transcranial approaches are detailed in Table 1.

**Endonasal Dissections**

The endonasal approaches all began similarly as described in previous publications (10, 41–43). In the cadaver, it is often useful to remove the turbinates to provide more exposure, since the fixed tissues are firm and not easily compressed or manipulated. However, we attempt to avoid resecting the turbinates whenever possible during our surgical approaches in patients. In brief, using a unilateral approach, the natural ostia of the sphenoid sinus is enlarged in a medial and inferior direction with curettes, sphenoid punches, and Kerrison rongeurs (Codman/Johnson & Johnson, Raynham, MA). Approximately 2 cm of the posterior nasal septum is removed to create a large cavity and to facilitate binostril access to the sphenoid sinus. The entire anterior face of the sphenoid sinus is removed. This provides exposure to the sella, tuberculum sellae (TS), planum sphenoidale (PS), and intrasphenoidal clivus in the midline. Often, the posterior ethmoids must be removed to fully expose the anterior extent of the PS.

**Areas A and B**

**Endoscopic Approach to Area A**

The sellar floor is immediately identified in the center of the field of view. Visualization of the lateral and medial optico-

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<td>A</td>
<td>Sella, prechiasmatic cistern, suprasellar cistern, lamina terminalis</td>
<td>Transsphenoidal, transplanum, transstuberculum</td>
<td>1. Pterional &lt;br&gt; 2. Supracyllicary</td>
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<td>B</td>
<td>Postchiasmatic cistern</td>
<td>Transplanum, transtuberculum with pituitary transposition</td>
<td>1. Pterional &lt;br&gt; 2. Supracyllicary</td>
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<td>C</td>
<td>Basilar tip, interpeduncular cistern</td>
<td>Transsphenoidal, transsellar, removal of posterior clinoids</td>
<td>1. Subtemporal &lt;br&gt; 2. Orbitozygomatic</td>
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<tr>
<td>D</td>
<td>Preoptic cistern, basilar artery</td>
<td>Transsphenoidal, transclival</td>
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<td>E</td>
<td>Cavernous sinus, trigeminal nerve</td>
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<td>Lower two-thirds of clivus and cervicomедullary junction</td>
<td>Transnasal, transclival</td>
<td>1. Presigmoid retrolabyrinthine, transpetrosal &lt;br&gt; 2. Far lateral</td>
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The carotid recesses (OCR) bilaterally aids in the identification of the course of the optic nerves (ONs), as well as the parasellar and paracaval course of the internal carotid arteries (ICAs). The TS and PS are also identified (Fig. 1A). The sellar floor is drilled off, and the dura is thereby exposed. The TS connecting the medial OCRs is removed, and the PS is also removed between the lamina papyracea. Lateral exposure is defined by the lamina papyracea forming the lateral borders of the PS, the medial OCR forming the lateral borders of the TS, and the cavernous sinuses forming the lateral borders of the sella. The su-
rior intercavernous sinus is identified, and the dura is opened both above and below the intercavernous sinus (Fig. 1B). Anatomic structures exposed in this region include the anterior aspect of the optic chiasm and the medial aspect of the ONs, the proximal supraclinoid ICA as well as the several of its branches, such as the ophthalmic, superior hypophyseal, and proximal posterior communicating arteries (Fig. 1C and D). Beneath the chiasm, the pituitary stalk is exposed. Above the chiasm, the anterior communicating artery complex, including A1, the anterior communicating artery, and A2 are visualized, as is the lamina terminalis, enabling a suprachiasmatic approach to the third ventricle (Fig. 1E). The exposure is symmetrical; thus, bilateral structures are easily approached. The caudal extent of the olfactory nerves is visualized, as are the gyri rectus. This approach exposes and enables treatment of pathologies involving the gyrus rectus, prechiasmatic cistern, suprasellar cistern, medial aspect of both ONs, medial supraclinoid ICA, stalk, and sella.

Endoscopic Approach to Area B

Full exposure of the postchiasmatic cistern requires addition of the pituitary transposition. The diaphragma sellae is transected, and the pituitary gland is dissected free from the lateral dura of the sella (medial wall of the cavernous sinus). The inferior hypophyseal arteries are transected (Fig. 2A). This enables transposition of the pituitary gland superiorly, providing access to the postchiasmatic cistern (29). The superior hypophyseal arteries are preserved with this technique, and the gland is redirected anterosuperiorly. This provides exposure to the suprasellar area behind the pituitary stalk. The posterior boundary of this region is defined by the dorsum sellae (Fig. 2B).

FIGURE 2. A and B, 2D endoscopic images. A, 1, pituitary gland; 2, right inferior hypophyseal artery; 3, diaphragma sellae orifice. B, anterosuperior transposition of the pituitary gland. 1, pituitary gland; 2, pituitary stalk; 3, dorsum sellae; 4, supraclinoid ICA; 5, superior hypophyseal artery. C and D, 3D endoscopic images. C, view via a left pterional approach. 1, ONs; 2, optic chiasm; 3, supraclinoid ICA; 4, A1; 5, lamina terminalis; 6, CN3; 7, proximal M1. D, left opticocarotid triangle. 1, ON; 2, ICA; 3, superior hypophyseal artery; 4, pituitary stalk.
Transcranial Approach to Areas A and B

To reach both areas, a pterional and supraciliary (eyebrow incision) approach are performed (37). Generally, both approaches yield similar exposures and working space, producing a wide exposure of the PS, TS, both ONs, prechiasmatic and suprasellar cisterns, both ICAs, including supraclinoid segments (the medial ipsilateral supraclinoid segment is obstructed by the ipsilateral ON, and the contralateral ICA is obstructed by the contralateral ON from above the supraclinoid segment to just proximal to the bifurcation), both A1s, lamina terminalis, and anterior communicating arteries (Fig. 2C). The suprasellar area is typically approached anteriorly between both ONs. Thus, a more frontal approach is needed, such as in the supraciliary approach, or when the pterional approach includes a more medial subfrontal component. A postfixed chiasm enables a larger exposure of the suprasellar area, whereas a pre-fixed chiasm limits this approach, and a more lateral corridor, such as through the optocarotid or carotico-oculomotor triangle, is needed. Additionally, lesions immediately posterior and inferior to the TS may not be visualized well if there is a steep angle between the TS and the sella, necessitating endoscopic assistance or drilling of the TS.

The interpeduncular cistern and the stalk may be approached through the optocarotid triangle or the carotico-oculomotor

**FIGURE 3. A–D.** 3D endoscopic images. **A**, 1, basilar tip and interpeduncular cistern area; 2, incidental right superior cerebellar artery (SCA) aneurysm; 3, SCA; 4, P1 segments of posterior cerebral arteries (PCAs); 5, PComAs with perforators; 6, right A1 segment of anterior cerebral artery; 7, mamillary bodies; 8, CN3; 9, pituitary stalk; 10, tuber cinereum. **B**, left-side structures. 1, CN3; 2, PComA and perforators; 3, supraclinoid ICA; 4, anterior choroidal artery; 5, superior hypophyseal artery; 6, temporal uncus; 7, P1 segment of PCA; 8, mamillary bodies. **C**, interpeduncular cistern and basilar tip as seen via the right carotico-oculomotor triangle. 1, CN3; 2, ICA; 3, ON; 4, mamillary bodies; 5, dolichoectatic basilar artery (BA); 6, P2 segment of PCA; 7, SCA; 8, anterior petroclinoid fold. **D**, interpeduncular cistern and basilar tip seen through the left carotico-oculomotor triangle. Note the partial obstruction of the BA by the dorsum sellae. 1, dolichoectatic BA; 2, SCA; 3, pituitary stalk; 4, dorsum sellae.
triangle, depending on the relative maneuverability of these structures (Fig. 2D). In comparison to the endonasal approach, the transcranial approach exposes the prechiasmatic and suprasellar cisterns and the lamina terminalis with an extensive additional lateral space. The medial side of the ipsilateral supraclinoid ICA, however, is exposed better via the endonasal approach, especially in pre-fixed chiasms. Similarly, approaching the stalk is much easier using the endonasal approach, which yields a panoramic view of the suprasellar area. Additionally, with the use of the endonasal approach, the lamina terminalis is exposed with no brain retraction, as opposed to the transcranial approaches. The main limitation of the endonasal approach, as demonstrated in our dissections, is exposure of the lateral aspects of the ONs and ICAs.

Area C

Endoscopic Approach

After exposure of area B, the inferior intercavernous sinus is transected, and the posterior clinoids and the superior part of the clivus are removed. The dura on the posterior aspect of the clivus is then opened. This exposes the basilar tip, mamillary bodies, interpeduncular cistern, origin of cranial nerve (CN) 3, proximal posterior cerebral arteries (P1), and superior cerebellar arteries bilaterally. The lateral boundaries of the exposure are CN3 and the posterior communicating arteries (Fig. 3, A and B).

Transcranial Approach

Two approaches to the basilar tip and interpeduncular cistern are performed: subtemporal and orbitozygomatic (OZ). In the subtemporal approach, temporal lobe retraction is needed to achieve sufficient exposure over the tentorial edge, thus exposing P2, CN3, CN4, the ICA and its bifurcation, and the posterior communicating artery. Working through the carotico-oculomotor triangle exposes the interpeduncular cistern from the stalk anteriorly to the brainstem posteriorly. The upper exposure is the third ventricular floor (tuber cinereum), including the mamillary bodies, while the lower limit is bordered by the anterior petroclinoid fold and CN3 (Fig. 3C).
The OZ approach exposes the interpeduncular cistern through the opticocarotid and carotico-oculomotor triangles. Removal of the anterior clinoid enlarges and improves the exposure. The posterior clinoid may also be partially removed to increase the exposure (Fig. 3D). The main difference between the subtemporal and OZ approaches is the angle of view. In the subtemporal exposure, the view is horizontal and upward, toward the tuber cinereum, whereas, in the OZ exposure, the view is horizontal and downward, toward the preoptic area.

Comparing these approaches to the endonasal approach, the working space is limited in the transcranial approaches by the neurovascular structures that form the opticocarotid and carotico-oculomotor triangles. Temporal lobe retraction is needed in the subtemporal approach, and frontal lobe retraction is needed in the OZ approach.

The endonasal approach enables a panoramic view of the interpeduncular cistern and upper basilar artery (BA). In addition, proximal control of the BA is achieved more easily in the endonasal exposure. However, perforators coming off the back of the BA are difficult to appreciate endonasally but are more apparent with lateral transcranial approaches.

Area D

Endoscopic Approach

The remainder of the intrasphenoidal clivus is removed to expose the uppermost aspect of the intradural retroclival venous plexus (10, 31, 42). The dura is opened, exposing the BAs along with the proximal portions of CN6 before they enter Dorello’s canal. Exposure is provided for the anterior aspect of the pons, the basilar perforators, and the lower part of the membrane of Liliequist. The lateral limits of this exposure are: superiorly, the cavernous sinus; and inferiorly, the ICA (lacerum and petrous segments). The superior limit is formed by the pituitary gland, which can be transposed, as described above (Fig. 4, A and B). Caudally, the floor of the sphenoid sinus limits the clival opening.

With the use of an angled endoscope, the fifth nerve origin may be visualized. However, actual tissue manipulation around

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**FIGURE 4.** A, 2D endoscopic image; panoramic view after removal of the dorsum sellae. 1, basilar tip; 2, SCA; 3, P1 segment of PCA; 4, PComAs and perforators; 5, superior hypophyseal arteries; 6, supraclinoid ICA; 7, A1 segment of anterior cerebral artery; 8, mamillary bodies; 9, pituitary stalk; 10, optic nerves, chiasm, and tracts; 11, CN3. B, 3D endoscopic image of basilar tip and interpeduncular cistern area. C, 2D endoscopic image using an angled endoscope, looking laterally to the left beyond the clival opening. 1, CN3; 2, P2 segment of PCA; 3, SCA; 4, tentorial edge; 5, CN5; 6, CN6; 7, petrosal vein; 8, CN4. D, 3D endoscopic image of same area as C, E, and F. E, 3D endoscopic images. E, middle fossa approach, right anterior petrosectomy. 1, tentorial edge; 2, CN4; 3, CN5; 4, CN6. F, right anterior petrosectomy. 1, tentorial edge; 2, PComA; 3, CN3; 4, CN4; 5, CN5; 6, SCA. G, middle fossa approach, left anterior petrosectomy. 1, VA; 2, anteroinferior cerebellar artery (AICA); 3, CN6; 4, inferior petrosal sinus.
the fifth nerve origin is difficult to perform via this exposure (Fig. 4, C and D).

**Transcranial Approach**

A subtemporal anterior petrosectomy approach is performed, including incision of the tentorium. This approach exposes the lateral pons and midbrain, with panoramic exposure of CN4 along the lateral side of the brainstem up to the cavernous sinus and the lateral aspect of CN5 from its origin along the lateral pons to the cavernous sinus and foramen ovale (Fig. 4, E and F). CN6 is exposed from the pontomedullary junction, in the preptontine cistern, entering Dorello’s canal along the clivus, toward the cavernous sinus. With removal of the petrous apex, CN6 in Dorello’s canal serves as a medial limit of the exposure. Caudal exposure is limited by the inferior petrosal sinus (Fig. 4G). More caudal and medial exposure is possible if the pathology creates a wide corridor (such as occurs with a large petroclival meningioma). Midline structures are exposed to a limited degree. Clivus drilling is limited by CN6, and the lateral aspect of the BA is exposed. CN3 to CN5 limit the medial exposure, providing a narrow working space between the nerves and along the upper part of the approach. The ICA is exposed along its petrous and lacerum segments and along the superior and lateral aspects of the intracavernous segment.

**Area E**

**Endoscopic Approach**

To fully expose the cavernous sinus and the adjacent branches of CN5, as well as CN3 and CN4, a more lateral exposure of the sphenoid sinus is facilitated by removing more of the ethmoid sinuses. The bone over the anterior and inferior aspects of the cavernous sinus is removed while preserving the dura. The bony borders of the cavernous sinus are: anteriorly the lamina papyracea and the posterior ethmoidal cells, inferiorly, the pterygoid bone; and superiorly, the optic canal. Care must be taken while removing this bone, which may be extremely thin or even absent. This is followed by a dural opening and removal of the venous latex surrounding the ICA. At this stage, CN6 is
identified just lateral to the ICA and on the medial side of the V1 branch of the trigeminal nerve. The interneural spaces of the lateral cavernous sinus, as described by Cavallo et al. (8) and Alfieri and Jho (1), are identified. The nerves CN3, CN6 (overriding CN V1), and CN V2 form an "S" shape, forming a superior triangular area and a quadrangular area. Inferolateral dissection reveals V2 just under the cavernous sinus and extending up to the foramen rotundum. On the upper side, CN3 is identified. Only a short segment of the CN4 may be seen from this angle, as it passes over CN3 within the cavernous sinus (Fig. 5, A–C). The carotid artery is exposed from the lacerum segment (in the lower lateral area of the exposure, just above the sphenoïd sinus floor) to the clinoid segment (which is obstructed by the optic canal and medial OCR on the anteromedial aspect, and the optic strut, marked at its base as the lateral OCR, on the lateral aspect). Opening of the optic canal and removal of the bone over the medial OCR exposes the medial side of the clinoid and supraclinoid segments, as well as the proximal part of the ophthalmic artery (Fig. 5, D and E).

Transcranial Approach

An OZ approach to the cavernous sinus is performed. After cutting the temporo-orbital ligament, the dura of the middle fossa is peeled off the lateral wall of the cavernous sinus, and an anterior clinoectomy is performed. The lateral cavernous sinus is exposed, thus revealing the oculomotor, clinoid, supra- and infratrochlear, anteromedial, and lateral triangles (Fig. 5F) (38). The superolateral and medial aspects of the clinoidal segment and the superior and lateral aspects of cavernous segment of the ICA are exposed. CN4 is exposed along its course entering the cavernous sinus and overriding CN3. CN6 is exposed lateral to the ICA.

The main conceptual difference between the transnasal and transcranial approaches to the cavernous sinus is the medial/lateral exposure (8). As the cavernous sinus contains dense neurovascular structures, the surgical approach should use the most direct route to the relevant pathology. Lesions extending from lateral medially (such as a medial sphenoid meningioma) should be approached transcranially. However, lesions invading the medial aspect of the cavernous sinus (such as some pituitary adenomas) would probably be more securely resected transnasally (20).

Area F

Endoscopic Approach

Exposure of the inferior clivus and cervicomedullary junction can be achieved completely below the sphenoid sinus, passing only through the nasal cavity parallel to the palate. However, opening the floor of the sphenoid superiority is useful in providing landmarks for orientation. A wide, inferior based U-flap consisting of nasopharyngeal mucosa, prevertebral musculature, and clival periosteum is created to expose the middle and lower clivus. The flap extends between the eustachian tubes, down to the base of C2. The muscles in this flap include the longus capitis, attached to the clivus, and longus colli, inserting on C1. The pharyngeal tubercle is noted in the midline; it marks the junction between the middle and lower
thirds of the clivus. Elevation of soft tissue and exposure of the clivus continue laterally through the thick periosteal attachments and along the grooves of the lateral clivus. The floor of the sphenoid sinus is then drilled down to the floor of the nasal septum to provide visualization of the clivus from the floor of the sella to the caudal basiocciput.

The clivus is drilled in a rostral to caudal direction, with the carotid arteries (lacerum segments) and vidian nerves marking the lateral extent of the dissection. The occipital tubercles are preserved bilaterally to preserve CN12. All of the bone of the posterior clivus is removed to expose the tectorial membrane behind the middle and lower clivus. This is incised, along with the external layer of dura from the sella superiorly to the inferior retroclival region, revealing the inferior intercavernous sinus superiorly and the basilar venous plexus. The borders of the clival opening are: superiorly, the sella; inferiorly, the tectorial membrane between the foramen magnum and anterior arch of C1; laterally, in the upper clivus, the ascending carotid arteries; in the middle clivus, the vidian nerves and the interdural segments of CN6 (Dorello’s canals); and at the lower clivus, the hypoglossal canals (9). The dura is opened in an "H" fashion to prevent injuring of neurovascular structures (mainly the vertebral artery [VA], BA, and CN6).

Intradurally, a panoramic view of the VA, lower two-thirds of the BA, and proximal anteroinferior cerebellar arteries is achieved. The intradural segment of CN6 is the lateral border of the intradural working field at the level of the middle clivus (Fig. 6, A and B). In the lower clivus, the jugular tubercle obstructs the jugular foramen and exiting CNs; thus it needs to be drilled to gain access to the jugular foramen. The anteromedial parts of the occipital condyles are drilled up to the hypoglossal canals, serving as the lateral limits of the exposure in the lower clivus (Fig. 6, C–E). The corresponding brainstem exposure from rostral to caudal is the anterior pons (limited laterally by CN6), pontomedullary junction, and medulla. CN9–CN11 and CN12 are seen exiting the brainstem; however, the jugular tubercle and hypoglossal canal need to be drilled, as mentioned, to gain access to their contents.
Transcranial Approach

Approaching the lower two-thirds of the clivus and cervicomедullary junction is achieved, in its upper aspect, by a presigmoid retrolabyrinthine transpetrosal approach. Posterior retraction of the sigmoid sinus enlarges the exposure, enabling access to the lateral midbrain and pons and exposing CN4 in the ambient and crural cisterns; the lateral and inferior parts of the cisternal segment of CN5; and the lateral, superior, and inferior aspects of CN7–CN8 and CN9–CN11 between their origins at the brainstem and the jugular foramen. CN6 and the midclival region may be seen through the corridor between CN5 and CN7–CN8. However, access is limited by the more lateral neurovascular structures (i.e., CN5, CN7–CN11, and the anteroinferior cerebellar artery) (Fig. 6F). The jugular tubercle obstructs access to the clivus and VA. The lower clivus is exposed via a far lateral approach (Fig. 6G). After opening of the dura, the lateral medulla is revealed; CN9–CN11, including the ascending accessory branch, are fully exposed up to the jugular foramen. The VA is exposed between the transverse foramen of C1 and the premedullary cistern, including the posteroinferior cerebellar artery from its origin to its ascending segment, beyond the tonsil. Retraction of the VA exposes the lower clivus below the level of the jugular tubercles.

The main limitations of the various transcranial approaches to the lower clivus are the narrow working spaces between the lower CNs and the jugular tubercle, which limits the working angle when approaching posterolaterally. The lateral brainstem is exposed; however, working on the anterior brainstem is limited. The transnasal approach enables direct access to the midline structures, including the anterior brainstem; however, the lateral working space is limited by the lower CNs.

DISCUSSION

The field of cranial base surgery has evolved as a result of an ongoing close collaboration between neurosurgery and otolaryngology. The philosophical motivation for the development of the extended transcranial approaches was that additional removal of
bone would minimize the degree of brain retraction and potential brain trauma. These principles remain valid for paramedian-based pathology. However, pathology arising from the midline is often surrounded by CNs and by vital vascular structures, which limit the working corridors to this region provided by the transcranial approaches. In addition, midline pathology often extends to the both sides of the cranial base, and lateral approaches may still require significant brain retraction to achieve adequate exposure of the contralateral extent of the tumor. In certain cases, the expansive nature of a lesion may provide a “natural” retraction by posteriorly displacing the brainstem, thus forming a corridor to the contralateral side. In response to these limitations of the transcranial cranial base approaches, the endonasal approaches were developed to provide a more direct midline approach to midline pathology (10, 30, 31, 42). With these approaches, the CNs and ICA lie lateral and superior to the pathology. The epicenter of the pathology can be exposed and decompressed before extrapapular dissection of neurovascular structures is required. However, given the relative novelty of the endonasal approaches, the indications and limitations of these approaches, compared with the more traditional transcranial approaches, have not been well described. For this reason, we elected to perform this study using cadaveric dissections to directly compare the endoscopic with the transcranial approaches to reach variety cranial base targets. By implementing 3D technology the spatial relationships, as well as the relative advantages and limitations provided by each approach, can be more easily appreciated.

Paramedian cranial base regions were exposed well through both transcranial and endonasal approaches in a complementary manner. The main limitations of the endonasal approaches are the lateral margins. Endoscopic endonasal corridors provide excellent and direct access to midline structures (10, 30, 31, 42). However, the neurovascular anatomy along the cranial base acts to impede the extension of these corridors in the lateral direction. In particular, the ONs, the ICAs, the cavernous sinus, the vidian nerves, the abducens nerves, the jugular tubercles, and the hypoglossal canal’s create lateral boundaries, through which extension of endoscopic approaches will be difficult (10, 32, 34, 46). However, it is important to note that specific pathologies may distort these anatomic “boundaries”; displacement of these structures by the pathology may alleviate their role as lateral impediments. Alternatively, transcranial approaches most often provide excellent lateral-to-medial trajectories to midline cranial base targets. Pathologies that project along these trajectories and extend laterally can be most directly addressed with transcranial techniques. In addition, endoscopic assistance may enhance the deep view achieved transcranially enabling an around-the-corner view beyond the linear view supplied by the microscope (11, 19, 36). However, other limitations of the transcranial approach remain: brain retraction and working through narrow neurovascular spaces, especially when the lesion is medial to these structures.

Ultimately the choice of optimal approach to a given location will vary on the basis of specific size, extent, and consistency of the pathology. Endonasal approaches are more favorable for lesions that are midline with little lateral extent. Lesions whose epicenters are lateral to the CNs and ICA will be more easily exposed through transcranial approaches. If the pathology creates a large working corridor, it is often possible to reach farther than expected, as the pathology may provide a dissection corridor around the normal anatomy. In addition, staging the removal of large tumors may capitalize on combined approaches that use both endonasal and transcranial corridors. In such a situation, the medial extent of the tumor can be removed through an endonasal approach, while the lateral extent removed through a transcranial approach, with the choice of initial approach based on the patient’s symptoms and the location of the highest degree of neurological compression. Although our cadaveric dissections provide views of the surgical anatomy that support such principles in patient selection, clinical studies are needed to compare these corridors in vivo for specific pathologies.

The 3D endoscope provided high-resolution images that detailed the depth relationships of vital neurovascular structures. Qualitatively, 3D endoscopy also provided spatial orientation during the cadaveric dissections, making them easier to perform. Early pilot clinical studies with this technology support its use in aiding in depth-oriented tasks (21). In addition, the use of 3D neuroendoscopy during pituitary tumor surgery provides subjectively improved depth perception for both the neurosurgeon and the otolaryngologist (3, 48). Previous studies in laparoscopic surgery demonstrate that a 3D system improves dexterity, decreases errors, and improves the speed of novice as well as experienced surgeons (4, 49). This study highlights the utility of 3D endoscopy in appreciating anatomic relationships, which is useful not only for educational purposes but also in assisting in depth perception and manual dexterity during surgery.

Limitations of the Study

This study describes a qualitative comparison of various approaches. However, quantitative comparisons were not performed. Future studies should focus on specific quantitative comparisons, both of the exposure area and of the surgical limitations, i.e., the actual working space that is achieved by every exposure. It is important to state that a surgical corridor is dictated not only by the actual visual exposure, but also by the actual instrumentation and optic system used. The closer the optical tip to the field (endoscope versus microscope), the wider and less obstructed the visual exposure is, and by applying suitable microinstruments, the working space may change.

In addition, we focused on the main transcranial approaches. We acknowledge that more complex cranial base approaches may enable a wider exposure, with additional exposure of the clivus and anterior cranial base. These include, for example, the frontal transbasal transphenoidal approach to the anterior base including the interpeduncular cistern (44); the transcochlear and transotic approaches to the upper and middle clival area (2, 45); and a combined subtentorial, presigmoid petrolaryngeal transtentorial approach, which provides a wide exposure to the entire clivus, from the dorsum sella to the foramen magnum (23). Other approaches that provide larger exposures are a transtentorial or a transotic or retrolaryngeal approach combined with a transtentorial incision for superior exposure (18, 24).

**Endoscopic Exposure of Midline Cranial Base Targets**
An additional surgical maneuver that may widen narrow working corridors is opening of the oculomotor porus and incision of the dural carotid rings (35, 40). This enables mobilization of these structures, widening the corridor to the interpeduncular cistern.

CONCLUSIONS

Direct comparison of endoscopic endonasal approaches and traditional transcranial approaches to the median and paramedian cranial base illustrates the respective advantages and disadvantages of each approach in relation to target structures. Understanding the anatomic limits of each approach aids the surgeon in providing a full surgical armamentarium to address cranial base pathology. Three-dimensional visualizations aid in understanding the depth relationships of the densely packed, highly sensitive neural and vascular elements in the paramedian cranial base. Clinical studies may be helpful in comparing surgical corridors for cranial base targets. Ultimately, however, the use of one or multiple approaches must be tailored to the patient and the pathology.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

REFERENCES

This is another excellent article from this distinguished cooperative group of neurosurgeons and otolaryngologic surgeons. Of special value is the comparison between transcranial (also, in part, endoscopic) and transnasal approaches to the midline cranial and the evaluation of advantages and limitations of both approaches. In recent years, more and more reports are being published on the advantage of the extended endonasal approaches in this area. However, the existing advantages of “traditional” transcranial approaches, which today are also performed as “minimally invasive” procedures with neuronavigation and endoscopic assistance, are often not considered in these reports on the “modern” extended transnasal approach. But some of the advantages of transcranial approaches are obvious: the small risk of cerebrospinal fluid leakage, which continues to be a significant challenge in intracranial transnasal approaches; no damage to nasal airflow, with often minimal side effects of precise transcranial approaches using limited retraction; and, especially, the advantage of binocular stereoscopic microsurgery in a more familiar anatomic environment for the neurosurgeon.

Here, this article presents another highlight: the use of 3-dimensional (3D) endoscopy for the preparation, which, however, can be used not only transcranially, but also in transnasal approaches. The authors have previously reported on the use of 3D endoscopes; in this study, they used 3D endoscopy in the transnasal as well as transcranial approaches, so that the comparison of both ways is quite evident (with the additional combination of 3D endoscopy and microscopy in most of the transcranial approaches).

This article presents very illustrative figures of excellent anatomic preparations in vascular injections of fresh cadaver heads; the 3D endoscopic images are given with the “insect eye” Visionense technology (Visionense, Petach Tikva, Israel), whose features are briefly mentioned and are given in greater detail in the authors’ 3D pituitary study (1). The results (advantages and limitations) of each approach are divided into the areas A, B (pre- and postchiasmatic), C (posterior aspect of the clivus), D (lower clivus, to below the abducens nerve), E (lateral to the internal carotid artery), and F (to the cervicomedullary junction); also, the different possibilities with the transcranial approaches in pre- and postfixed chiasms are addressed.

The conclusions are convincing and well illustrated; the main “conceptual difference” is defined as medial/lateral exposure; thus, lesions expanding from lateral to medial should be approached transcranially, so this approach retains its value; however, lesions invading the medial basal structures (such as pituitary lesions, which are “classic” transcranial targets, but today extending also to more complex lesions) are favored for the transnasal route, which has its limitations at the lateral margins, as presented by the internal carotid artery cavernous sinus, abducens nerves, and hypoglossal canal. Also, a combination of both methods (medial parts of the lesion transnasally, lateral parts transcranially) is convincingly described; the limitations of such anatomic studies and the focus on only selected transcranial approaches are frankly admitted. As the authors stress, clinical studies ultimately must define the surgical corridors, and approaches must be individually tailored for each patient. However, this study is very useful for the individual decision; the high-quality figures can even be used by the neurosurgeon for the preparation of the clinical operation.

Michael R. Gaab
Hannover, Germany

Roth et al. present an interesting anatomic study comparing the exposure provided by expanded endonasal and transcranial cranial base approaches. The investigation was performed in 10 fresh cadaver heads. Access to various areas of the midline cranial base was evaluated. The authors conclude that the endonasal approaches achieved a wide and direct exposure of the midline, whereas transcranial approaches were limited by narrow operative corridors formed by neurovascular structures. Additionally, a comparison of 2D and 3D endoscopic visualization was performed.

Although I agree with most of the statements in the article, I do not generally agree that “transcranial approaches...do not visualize the contralateral paramedian cranial base very well,” as stated in the Abstract. In transcranial approaches to the frontal cranial base, for example, much more overview of the cranial base can be achieved than with the endonasal approach. With proper positioning of the head and early release of cerebrospinal fluid, significant brain retraction is not required to visualize the contralateral paramedian cranial base. Furthermore, in most transcranial tumor operations, visualization of the contralateral cranial base is easily possible because the tumors often displace the brain posteriorly or superiorly and provide wide space when being resected.

I agree that endonasal approaches have several advantages, compared with transcranial approaches to the cranial base. First of all, there is no brain retraction. Especially in subchiasmatic lesions with pre-fixed chiasm, the endonasal approach is much better than the transcranial route, because retraction of the neurovascular structures, which is clearly necessary in transcranial resection, can be avoided completely. However, a major limitation of the endonasal approach is the poor overview of the entire cranial base. Only the midline can be visualized from below. Lesions with significant extensions to one side or the other cannot completely and safely be resected by the endonasal approach.

I have had a chance to test the 3D endoscope used by the authors, and I was very impressed by the image quality and the stereoscopic view. Much progress has been made, in comparison to the 2D endoscopes I have used in the past. However, my impression is that the image resolution and, in particular, the color fidelity of the recently introduced high-definition video cameras is significantly better. Today, high-definition imaging is the state-of-the-art in endoscopic visualization. It provides excellent resolution (1920 × 1080 = approximately 2 Mio. pixels) and superb color information. I would never accept a decrease in resolution and color fidelity as the price for obtaining a 3D view.

Nevertheless, I am sure that, in the future, high-resolution 3D endoscopes will replace our current 2D endoscopic equipment. Neuro-navigation will be easily integrated while superimposing segmented magnetic resonance imaging data on the endoscopic images, and this information will be displayed on a single screen.

That said, the authors have presented a nice study. This article is well written and adds important information to the growing body of literature on endonasal cranial base surgery.

Henry W.S. Schroeder
Greifswald, Germany

The authors have presented a fine anatomic study. They compared endonasal and transcranial approaches to the cranial base on cadaver specimens. These approaches have been well documented using 3D video and still images. This article takes us one step further to defining the optimal surgical approaches to cranial base lesions. My only criticism is the glaring omission of the use of endoscopic assistance with the transcranial approaches. Many of the limitations of the transcranial approaches may well have been overcome with the use of angled endoscopes. I have removed a brainstem cavernoma that extended down to the midmedulla using a subtemporal approach and endoscopic assistance.

My other issue is more a warning than a criticism. Having become familiar and comfortable with both transcranial and endonasal approaches to the cranial base, I still favor the transcranial approach in the majority of cases. I have formulated this surgical algorithm for the following reasons: 1) standard microsurgical techniques are more familiar; 2) if one uses endoscopic assistance, the size of the craniotomy can be limited, and many previously hidden areas are adequately visualized; 3) endonasal instrumentation is still suboptimal; 4) stereoscopic vision is better with the microscope than with current 3D endoscopes; and 5) the cerebrospinal fluid leakage rate is lower.

There are, however, several specific tumors of the cranial base that I believe are clearly better removed endonasally. The first is the suprasellar/infrachiasmatic craniopharyngioma. The second is an olfactory groove meningioma that does not extend laterally past the optic nerves nor posteriorly to the tuberculum sellae. The third is the purely extradural chordoma of the clivus. A questionable fourth lesion is the schwannoma or meningioma of the medial cavernous sinus. I truly believe that this list will rapidly expand with the development of endonasal instruments, especially bipolar coagulators.

In conclusion, although this elegant study shows us that the endonasal approach exposes the midline and paramedian anatomy better than some transcranial approaches, this should not be extrapolated to the clinical setting, because of other practical considerations such as instrumentation and surgeon familiarity.

Charles Teo
Sydney, Australia