Endoscopic endonasal approach to the ventral brainstem: anatomical feasibility and surgical limitations

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OBJECTIVE Sporadic cases of endonasal intraaxial brainstem surgery have been reported in the recent literature. The authors endeavored to assess the feasibility and limitations of endonasal endoscopic surgery for approaching lesions in the ventral portion of the brainstem.

METHODS Five human cadaveric heads were used to assess the anatomy and to record various measurements. Extended transsphenoidal and translacral approaches were performed. After exposing the brainstem, white matter dissection was attempted through this endoscopic window, and additional key measurements were taken.

RESULTS The rostral exposure of the brainstem was limited by the sella. The lateral limits of the exposure were the intracavernous carotid arteries at the level of the sellar floor, the intrapetrous carotid arteries at the level of the petrous apex, and the inferior petrosal sinuses toward the basion. Caudal extension necessitated partial resection of the anterior C-1 arch and the odontoid process. The midline pons and medulla were exposed in all specimens. Trigeminal nerves were barely visible without the use of angled endoscopes. Access to the peritrigeminal safe zone for gaining entry into the brainstem was medially limited by the pyramidal tract, with a mean lateral pyramidal distance (LPD) of 4.8 ± 0.8 mm. The mean inter-pyramidal distance was 3.6 ± 0.5 mm, and it progressively decreased toward the pontomedullary junction. The corticospinal tracts (CSTs) coursed from deep to superficial in a craniocaudal direction. The small caliber of the medulla with very superficial CSTs left no room for a safe ventral dissection. The mean pontobasilar midline index averaged at 0.44 ± 0.1.

CONCLUSIONS Endoscopic endonasal approaches are best suited for pontine intraaxial tumors when they are close to the midline and strictly anterior to the CST, or for exophytic lesions. Approaching the medulla is anatomically feasible, but the superficiality of the eloquent tracts and interposed nerves limit the safe entry zones. Pituitary transposition after sellar opening is necessary to access the mesencephalon.

KEY WORDS anatomy; brainstem; endonasal; endoscopy; skull base

Brainstem lesions are challenging to manage in neurosurgical practice. The brainstem presents a dense concentration of nuclei and fibers that are responsible for the high rate morbidity when treating brainstem lesions. The safety of approaching these lesions is dependent on the amount of normal tissue overlying the lesion. To minimize manipulation and disruption of any eloquent parenchyma, multiple microsurgical approaches involving safe entry zones have been developed to optimize the exposure and resection in different portions of the brainstem.1–3,5,15,19,28,31,33,42

Recently, with the development of endoscopic endonasal surgery, the enhanced exposure offered by extended endoscopic approaches has encouraged some authors to attempt resection of brainstem tumors, particularly pontine cavernous malformations, with satisfying results.10,22,25,27,29,35 However, while surgical routes and safe entry zones are well described in the literature for anterolateral, lateral, and posterior (dorsal) microsurgical approaches,1–3,5,19,31,42 a purely anterior (ventral) anatomical description of the brainstem from an endoscopic endonasal perspective is still lacking. An evaluation of endoscopic access to the
classic ventral safety zones—anterior mesencephalic sulcus for the midbrain, the peritrigeminal area for the pons, and olivary body for medulla—is also missing.31

In this anatomical work, we attempt to describe the brainstem exposure attainable via an extended endonasal approach. We also describe the different neural pathways at risk from this anterior perspective through endoscopic white matter dissection to help appreciate the anatomical constraints involved in approaching the brainstem ventrally.

Methods

Five formalin-fixed, silicon-injected human cadaveric heads were used for this study. All specimens were placed in a Mayfield head holder. The Karl Storz endoscopy system with a Hopkins rigid 0°, 30°, and 45° endoscopes were used with a Storz flexible endoscope holder. All dissections were performed through the endonasal corridor. In all specimens, an extended transsphenoidal transclival exposure was performed using classic endoscopic instrumentation. Bone drilling was performed using an Anspach pneumatic high-speed drill (DePuy Synthes). Fiducial markers were sutured to the cadavers; scalp and thin-cut head CT scans were obtained in all the specimens. Segmentation and registration were completed using Cranial Planning software (Brainlab AG).

In all 5 specimens, an extended endonasal transclival approach was performed to attain the maximum exposure possible of the brainstem. The anterior wall and floor of the sphenoid sinus were removed, exposing the clival region. The drilling was extended from the base of the sella floor to the basion in the midline. While opening the sella and transposing the pituitary gland would have helped us in achieving more direct exposure of the midbrain, especially of the anterior mesencephalic sulcus, it would pose a significant risk of causing pituitary dysfunction. We, therefore, decided to conduct our experiment by using the sellar floor as the cephalad limit of our exposure. Laterally, both intrapetrous carotid arteries were skeletonized and exposed, and the intercarotid distance (ICD) at this level was measured. The basilar venous plexus and the dura mater were cut around the bone, exposing the pontine and medullary region of the brainstem. After dural opening, navigation was used to localize and quantitate the exposed neurological structures and surgical targets.

The pontobasilar midline index (PBMI) was defined as the length of pontine midline covered by the basilar artery divided by the full length of the pons (Fig. 1 left). Further white matter dissection was attempted through this endoscopic window, and additional key measurements were acquired. The maximum interpyramidal distance was measured just under the pontomesencephalic sulcus. The pyramidal tract width was reported at the level of the midpons. The lateropyramidal distance was defined as the maximum exposure of the pons, lateral to the pyramidal tract, attained by a 0° endoscope at the level of midpons (Fig. 1 right).

Results

As the sella was not opened, the rostral exposure of the brainstem was limited by the sellar floor. The lateral limits of the exposure were the proximal intracavernous carotid arteries at the level of the sellar floor. The distal intrapetrous segment of the carotid arteries at the level of the petrous apex represented the narrowest point of the exposure, with a mean (± SD) ICD 5.8 ± 1.5 mm. Along the lateral edge of the clivus, the attainable exposure was limited by the inferior petrosal sinuses (Fig. 2). After reaching the foramen magnum, further caudal extension necessitated laborious dense soft-tissue removal to reach and partially resect the anterior C-1 arch and the odontoid process.

The origin of both oculomotor nerves at the pontomesencephalic sulcus represented the upper limit of the exposure without drilling of the sella. The lateral limits of the

![FIG. 1. Pontine exposure before (left) and after (right) vessels displacement and white matter dissection. a/b = PBMI; IPD = interpyramidal distance; LPD = lateral pyramidal distance; PTW = pyramidal tract width; SCA = superior cerebellar artery; III = oculomotor nerve; V = trigeminal nerve; VI = sixth cranial nerve.](image-url)
exposure on the pons allowed visualization of the cisternal trigeminal nerve at the edge of the exposure, and the caudal extension exposed the inferior limits of the medulla (Figs. 3 and 4).

At the level of the pontomesencephalic sulcus, the corticospinal tracts (CSTs) extended laterally further than the visible origin of the oculomotor nerve, with a mean interpyramidal distance of 3.6 ± 0.5 mm. This distance does progressively decrease to practically no separation at the level of the pontomedullary junction (Fig. 5). The depth of the CSTs was variable across the pons and averaged at 4.1 ± 0.9 mm at the pontomesencephalic sulcus; then they progressively get more shallow from cranial to caudal, becoming almost superficial at the pontomedullary junction.

The CSTs were superficial and medial to the sixth cranial nerve exit point at the pontomedullary sulcus. Trigeminal nerves could just barely be viewed directly without use of angled endoscopes. Via the anterior route, access to the peritrigeminal area safe zone is medially limited by the pyramidal tract, with a lateral pyramidal distance of 4.8 ± 0.8 mm (Fig. 6A). Inferiorly, at the level of the pontomedullary junction, the roots of the sixth cranial nerve medially and seventh and eighth cranial nerve laterally represent the caudal exposure limit of the peritrigeminal area (Figs. 4 left and 5C).

Inferiorly, the relative small diameter of the medulla allowed the visualization of the hypoglossal nerve roots and partial exposure of the olivary bodies and caudal cranial nerve roots (Fig. 3). The small caliber of the medulla with very superficial CSTs leaves no room for a safe ventral dissection.

The course of the basilar artery in relation to the midline is highly variable, covering less then half of the midline surface, as shown by a PBMI that averaged at 0.44 ± 0.1.

All reported measures are summarized in Table 1.

**Discussion**

Multiples approaches to the brainstem have been described in the literature.1–3,5,28,33,42 Statistically, pontine cavernomas are the most frequently reported surgical lesions.1–3,5,42 Depending on the tumor location and the spe-
specific anatomy, various approaches and safe entry zones have been described—anterolaterally, laterally, and posteriorly. In a recent paper by Cavalcanti et al., the authors summarize 13 different safe entry zones in the brainstem: the anterior mesencephalic zone (sulcus), lateral mesencephalic sulcus, intercollicular region, peritrigeminal zone, supratrigeminal zone, lateral pontine zone, supracollicular zone, infracollicular zone, median sulcus of the fourth ventricle, anterolateral and posterior median sulci of the medulla, olivary zone, and lateral medullary zone. The entry zones that are visualized anteriorly are mainly the anterior mesencephalic sulcus of the midbrain, the peritrigeminal area at the level of the pons, and the olivary body of the medulla. These so-called “safe entry zones” are not a substitute for choosing an approach that transgresses as little normal parenchyma as possible to reach the tumor. Some recent reports have described endoscopic endonasal removal of ventrally situated brainstem tumors. The rationale in these surgeries is to access the tumor where it is the most superficial to the cortical surface. Exophytic lesions present a natural corridor to gain entry into the brainstem and debulk the lesions from within.

Historically, transoral transclival removal of such ventrally located tumors have been attempted, but the transoral approach has certain limitations—namely, a lengthy time to extubation, delayed feeding, and risk of CSF leakage. Expanded endonasal endoscopic approaches currently permit us to safely extend the exposure to the clivus and craniovertebral junction. As surgical mastery
has evolved, endonasal endoscopically treated pathologies have ranged progressively from extradural to intradural, and now, from extraaxial to intraaxial. However, as classical approaches to the brainstem have been exclusively microscopic, only posterior, lateral, and anterolateral approaches to brainstem lesions have been described. The anterior perspective on the anatomy, limitations, and surgical feasibility of the endonasal endoscopic approach is still missing.

In line with previous results, we found that endonasal endoscopic access to the mesencephalon necessitates opening the sella. To access the anterior mesencephalic zone (AMZ) through an endonasal route, the pituitary gland has to be transposed. Multiple descriptions of pituitary transposition techniques have been published in the literature\textsuperscript{13,20,39} with varying levels of morbidity. While complete transposition often causes hypopituitarism,\textsuperscript{20} unilateral or extradural transposition can be done with minimal morbidity.\textsuperscript{13,36} Even with pituitary transposition, the exiting third cranial nerve from the brainstem can block access to the AMZ. To access the anterior mesencephalic zone (AMZ) through an endonasal route, the pituitary gland has to be transposed. Multiple descriptions of pituitary transposition techniques have been published in the literature.\textsuperscript{13,20,39} With varying levels of morbidity. While complete transposition often causes hypopituitarism,\textsuperscript{20} unilateral or extradural transposition can be done with minimal morbidity.\textsuperscript{13,36} Even with pituitary transposition, the exiting third cranial nerve from the brainstem can block access to the AMZ. Laterally, the limitation to access is the cavernous carotid artery. The ICD can be highly variable between individuals and thus requires a careful preoperative evaluation.\textsuperscript{8} A medially coursing cavernous carotid artery can effectively close off this anterior window into the AMZ. The use of intraoperative navigation is mandatory during such extensive transclival drilling.

When exposing the pons, sufficient lateral exposure is vital for identifying the relevant anatomy. It facilitates the identification of the pontine midline and partially exposes the peritrigeminal area. The fifth cranial nerve is difficult to visualize laterally at the edge of the exposure when the \(0^\circ\) endoscope is used but can be visualized using angulated endoscopes. The downward trajectory of the abducens and facial nerve fibers through the pons mandates an upward direction for any dissection, lateral and superior to the abducens nerve exit point (Fig. 7). Therefore, the anterior endoscopic approach is inadequate for approaching any deep lesions in this area. However, this small window to the peritrigeminal area might represent a feasible route for removing small superficial lesions located lateral to the CSTs or for biopsy of larger lesions.

Caudally, a wider lateral exposure is usually attainable, limited only by the inferior petrous sinuses. However, care must be paid to the abducens nerve as it courses upward

<table>
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Mean ± SD 18 ± 1.5 3.6 ± 0.5 4.8 ± 0.8 5.8 ± 0.8 0.44 ± 0.1

IPD = interpyramidal distance; LPD = lateral pyramidal distance; PTW = pyramidal tract width. All values except PBMI are in millimeters.
from medial to lateral, through the basilar plexus and dura mater, to reach Dorello’s canal at the level of the petrous apex. Exposure of the superior segment of the medulla is easily attainable, but exposure of its inferior part can be laborious. The hard palate limits the entry angle of the endoscope, while thick soft tissue covers the posterior nasopharynx, obscuring visibility. Preoperative radiological evaluation and planning are vital to defining the caudal extent of this exposure. This extension can be attained endonasally, as discussed in multiple recent reports on endoscopic odontoid resections. The anterior arch of C-1 and the dens was resected partially in all our cadaver specimens. Recent reports found no evidence that a partial resection causes occipitocervical instability in patients with good cervical lordosis and alignment. The relatively small size of the medulla and the superficiality of the CSTs limit any surgical maneuverability at this level. A midline approach through the caudal anterior median fissure is not recommended because of the decussating pyramidal fibers (CST plus corticobulbar tract) in the medulla. The medullary arcuate nuclei, which are located on the anterior surface of the CST at this level, are associated with respiratory control and might also limit any safe approach at this level.

While the basilar artery does not always course in the pontine midline, we invariably identified the presence of basilar perforators along the entire pontine midline (Fig. 3). These perforators should not be sacrificed since they vascularize not only the superficial CSTs, but also deeper structures such as the medial lemniscus, medial longitudinal fasciculus, and sixth nerve nuclei. The conjunction of a narrow window between CSTs, as well as the presence of these perforators, limits the use of the anterior midline window as a safe entry zone to deeper lesions of the anterior pons. Therefore, we propose that endoscopic procedures should only be indicated for medial and paramedial lesions strictly anterior to the CSTs.

Thorough preoperative imaging can be used to predict the attainable exposure and the eventual anatomical obstacle while studying the relationships between the tumor and sensitive structures. The latest advances in MRI fiber tracking techniques can help identify those pontine lesions where the pyramidal tracts are pushed back and lateral, thereby closing off or narrowing the traditional anterolateral safe zones. These lesions can be approached ventrally (Fig. 6). The exactitude of the reported measurements is limited to a macroscopic view of the fibers and consequently should not be regarded as assertions of true histological or physiological safety margins. The use of neuronavigation and intraoperative electrophysiological monitoring should be mandatory in these cases for accurate localization of the cortical incision and real-time feedback during the dissection. Direct cortical stimulation of the ventral brainstem could also be used to identify the descending CSTs along with distal electromyography as is done with motor evoked potentials.

At the level of the pons, the anterior half of the pons is occupied by the corticospinal fibers, the pontine nuclei, and the pontocerebellar fibers, which represent the most superficial structures. They are implicated in multiple functions, mainly coordinating intended movement, but further functions are still under investigation. The other important functional tracts and nuclei occupy the dorsal half of the pons but progressively get closer to the CSTs as we progress caudally to the pontomedullary junction. While the pontocerebellar fibers run in a transverse direction, inci-
sions along the anterior aspect of the pons should still follow a longitudinal course parallel to the CSTs coursing under them (Fig. 5C). Using bimanual techniques, endoscopic microsurgical dissection becomes possible, allowing safe exposure and resection of intraaxial lesions.

The risk of a CSF leak and meningitis is inherent in extended skull base surgery. However, the recent development of endoscopic closure techniques, along with the systematic use of perioperative lumbar drainage, has dramatically decreased the incidence of such complications.

Conclusions

Extended endoscopic endonasal transclival approaches offer adequate access to the pons, while the exposure of the mesencephalic region necessitates more aggressive bony opening of the sella and transposition of the pituitary gland. The access to the medulla frequently requires partial removal of the anterior arch of C1 and the tip of the odontoid process and might be limited by the hard and soft palate. Dissection at the level of the medulla is limited by the superficial location of the CSTs and their decussation. The use of classic anterolateral safe entry zones, such as peritrigeminal area in the pons and olivary bodies in the medulla, are not easily accessible when using the anterior endoscopic trajectory. This endoscopic window is safe only for approaching midline exophytic pontine lesions, but it might also be extended to nonexophytic lesions strictly anterior to CSTs. To our knowledge, this is the first cadaveric anatomical study of the endoscopic endonasal perspective on intraaxial brainstem surgery. Further clinical evaluation in very selective cases will be necessary to validate this approach.

References

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Disclosures
Dr. Schwartz reports holding stock in VisionSense and consulting for Karl Storz.

Author Contributions
Conception and design: Schwartz, Essayed, Singh, Lapadula. Acquisition of data: Essayed, Lapadula, Almodovar-Mercado. Analysis and interpretation of data: Schwartz, Essayed, Singh. Drafting the article: Essayed, Singh, Lapadula, Almodovar-Mercado. Critically revising the article: Schwartz, Singh. Reviewed submitted version of manuscript: Schwartz, Singh, Anand. Approved the final version of the manuscript on behalf of all authors: Schwartz. Study supervision: Schwartz.

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