Comparison of Surgical Freedom and Area of Exposure in Three Endoscopic Transmaxillary Approaches to the Anterolateral Cranial Base

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Abstract

Objective Endoscopic ipsilateral endonasal transmaxillary, contralateral endonasal transeptal transmaxillary, and Caldwell-Luc approaches can access lesions within the retromaxillary space and pterygopalatine fossa. We compared the exposure and surgical freedom of these transmaxillary approaches to assist with surgical decision making.

Design Four cadaveric heads were dissected bilaterally using the three approaches just described. Prior to dissection, stereotactic computed tomography (CT) scans were obtained on each head to obtain anatomical measurements. Surgical freedom and area of exposure were determined by stereotaxis.

Main Outcome Measures Area of exposure was calculated as the extent of the orbital floor, maxillary sinus floor, nasal floor, and mandibular ramus exposed through each approach. Surgical freedom was the area through which the proximal end of the endoscope could be freely moved while moving the tip of the endoscope to the edges of the exposed area.

Results The mean exposed area was similar: $9.9 \pm 2.5 \text{ cm}^2$ (Caldwell-Luc), $10.4 \pm 2.6 \text{ cm}^2$ (ipsilateral endonasal), and $10.1 \pm 2.1 \text{ cm}^2$ (contralateral transeptal) ($p > 0.05$). The surgical freedom of the Caldwell-Luc approach ($113 \pm 7 \text{ cm}^2$) was greater than for either endonasal approach, $76 \text{ cm}^2 \pm 15$ ($p = 0.001$) (ipsilateral endonasal) and $83 \text{ cm}^2 \pm 15$ ($p = 0.003$) contralateral transeptal.

Conclusions Our work demonstrates that the Caldwell-Luc endonasal approach offers greater surgical freedom than either approach for anterolateral skull base targets, although these approaches offer similar exposure.

Keywords

- area of exposure
- endonasal
- endoscopy
- surgical freedom
- transmaxillary

Introduction

The infratemporal fossa and pterygopalatine fossa are among the most inaccessible areas of the anterolateral skull base.

Although open approaches have been used to access these domains,^{1–3} these approaches often require extensive craniofacial resection associated with a high degree of morbidity. Less invasive endoscopic approaches that exploit the

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maxillary sinus have gradually replaced traditional open approaches for certain anterior and anterolateral skull base lesions.^{4–10} The armamentarium of endoscopic approaches to this region includes the ipsilateral endonasal transmaxillary approach, sublabial transmaxillary approach (Caldwell-Luc), and the contralateral transseptal transmaxillary approach.⁸

The anterolateral skull base is anatomically complex and has been well described.^{9,11,12} The infratemporal fossa and the pterygopalatine fossa communicate through the pterygomaxillary fissure. They are connected with the orbit through the inferior orbital fissure and with the middle cranial fossa through the foramen spinosum, foramen ovale, and foramen rotundum. The infratemporal fossa and pterygopalatine fossa are bordered superiorly by the squamous temporal bone, the posterior part of the orbital floor, and the inferior surface of the greater wing of the sphenoid. Medially they are bordered by the lateral part of the clivus, first cervical vertebrae, and inferior surface of the petrous bone. Laterally, these areas are bordered by the zygomatic arch, ascending mandibular ramus, mandibular angle, parotid gland, and masseter and temporalis muscles. Inferiorly, they are connected with the peripharyngeal space and posteriorly they continue as the temporal space and, anteriorly, by the posterior wall of the maxillary sinus. Proper understanding of the different approaches through this corridor is important for surgical planning because of the anatomical relationships of the pterygopalatine fossa and the presence of neurovascular structures such as the maxillary artery, maxillary (V2), and mandibular (V3) nerves, pterygopalatine ganglion, and infraorbital nerve and artery. Anterior endoscopic approaches to the lateral skull base typically cross the pterygopalatine fossa. A transmaxillary corridor has been used to access the infratemporal fossa, parapharyngeal space, middle cranial fossa, and anterolateral skull base.^{6,7,9} However, detailed anatomical comparisons of endoscopic approaches with anatomical correlations in these areas are lacking but are necessary for selecting the optimal approach.

Surgical freedom and area of exposure are important surgical concepts in skull base surgery that may influence surgical decision making and approach selection. *Surgical freedom* describes the working area for a surgeon's hands and the instruments necessary to complete the operative goals. Greater working area improves the ease of surgery. *Area of exposure* defines the surgical field and what anatomical targets can be reached with a given exposure.

Previously, we developed a model system based on neuro-navigation to study the surgical freedom and angle of attack of the ipsilateral endonasal transmaxillary approach and the Caldwell-Luc transmaxillary approach¹³ for surgical targets in the anterolateral skull base. In the current study, we extend our previous work by studying the surgical freedom provided by the contralateral endonasal transseptal transmaxillary approach and also by studying the area of exposure.

Materials and Methods

Three endoscopic transmaxillary approaches were performed bilaterally in four fresh silicon-injected heads

(→ Fig. 1). Dissections were performed using a 0-degree endoscope and standard endoscopic techniques, with heads placed in rigid fixation in a supine position. Burrs, dissector blades, and standard endoscopic instruments (Karl Storz, Tuttlingen, Germany) were used. Visualization was supplemented with 30- and 45-degree endoscopes for lateral visualization. High-resolution computed tomography (CT) scans were performed on each specimen to document the bony facial and cranial anatomy, and the images were uploaded to an image guidance platform (StealthStation Treon Plus with FrameLink Software, Medtronic, Louisville, Colorado, United States). Image guidance was used to obtain anatomical measurements and to confirm anatomical structures.

Ipsilateral Sublabial Transmaxillary Approach

Similar to techniques described previously,^{9,13–15} the upper lip is retracted and a transverse incision is made at the buccogingival sulcus just lateral from the canine and extending laterally to the second molar. The incision is made through the mucosa and periosteum. A subperiosteal plane is developed, exposing the anterior wall of the maxilla. Care is taken to protect the infraorbital nerve, which is the superior limitation of the anterior maxillary wall exposure. An osteotome is used to perform an anterior maxillotomy, and the opening is enlarged using Kerrison rongeurs (Integra, Plainsboro, New Jersey, United States), to create an osteotomy ~ 15 mm wide and 10 mm high. After entering the maxillary sinus (→ Fig. 2A), the mucosa is peeled away and the infraorbital nerve is identified at the junction between the maxillary roof and posterior wall. A second osteotomy is made in the

Fig. 1 Anatomy of the lateral skull base (inferior image). The arrows show the trajectories used for the three endoscopic approaches. (Used with permission from Barrow Neurological Institute.)

Fig. 2 Images for a 0-Degree endoscope from the right side of cadaveric dissections showing the corridors used to access the maxillary sinus. (A) Ipsilateral Caldwell-Luc approach. (B) Ipsilateral endonasal approach. (C) Contralateral (from left nostril) transseptal approach. IT, inferior turbinate; MS, maxillary sinus; MT, middle turbinate; NS, nasal septum; ST, superior turbinate. (Used with permission from Barrow Neurological Institute.)

posterior wall, and the posterior wall is removed using a Kerrison rongeur to expose the periosteum, which is opened to enter the pterygopalatine fossa and expose its contents.

Ipsilateral Endonasal Transmaxillary Approach

The endonasal transmaxillary approach was previously described in detail.^{5,7,10,13,14,16–18} In brief, the middle turbinate bone is removed through the ipsilateral nostril, and the inferior turbinate bone is reflected inferiorly or removed, allowing the ethmoid bulla to be identified. An antrostomy is performed using a Kerrison rongeur to allow access to the maxillary sinus (→Fig. 2B), and the greater palatine nerve and artery are preserved along the junction between the maxillary base and posterior maxillary wall. To increase the intranasal exposure, the ethmoid bulla is removed, exposing the anterior ethmoid artery, and then the sphenopalatine artery is identified and preserved. Next, the infraorbital nerve is identified in the roof of the maxillary sinus, and the posterior maxillary sinus is fractured and carefully removed with Kerrison rongeurs. After removing the posterior maxillary wall, the periosteal membrane is immediately visible and dissected to expose the contents of the pterygopalatine fossa that includes the internal maxillary artery and a complex network of its branches. The pterygopalatine ganglion is identified posterior to the sphenopalatine artery and fat tissue; tracing the pterygopalatine ganglion posteriorly and medially can lead to the vidian canal and the vidian nerve. The approach is extended along the course of the vidian canal to the medial portion of the internal carotid artery genu by drilling the medial pterygoid plate using a 2-mm diamond bit. The infraorbital nerve is followed posteriorly to the maxillary branch of the trigeminal nerve (V2). The lateral plate of the pterygoid is removed to expose the foramen ovale and the mandibular division of the trigeminal nerve (V3).

Contralateral Endonasal Transseptal Approach

The contralateral endonasal transseptal approach provides access to the maxillary sinus through the contralateral nasal cavity^{8,19} with a nasoseptal mucosal flap pedicled posteriorly on the septal branch of the sphenopalatine artery (→Fig. 2C). An additional ipsilateral flap may also be per-

formed but was not done in this study. Once access is gained to the ipsilateral nasal cavity, the transmaxillary dissection is performed in a similar manner to the ipsilateral endonasal transmaxillary approach described previously. The endoscope is advanced until it reaches the posterior third of the nasal septum of the contralateral nasal cavity and is then directed through the transseptal window. The endoscope and an instrument are advanced to the maxillary sinus and retromaxillary space.

Area of Exposure

To calculate the area of exposure, four points were identified. The first point (ION) was a fixed anatomical landmark that is the point at which the infraorbital nerve enters the infraorbital canal and is crossed by the infraorbital artery. The other three points were determined relative to the infraorbital nerve: (1) a medial point (MP) that was defined as the point at the junction between the vomer and the sphenoid crest; (2) a lateral point (LP) that was defined as the point directly lateral to the infraorbital nerve after removal of the posterior wall of the maxillary sinus and represented the most lateral point of exposure; and (3) an inferior point (IP) directly inferior to the ION and slightly lateral to the inferior part of the junction between the base of the maxillary sinus and the posterior maxillary wall, just lateral to the greater palatine nerve and vessel. The MP, LP, and IP were used to determine the medial, lateral, and inferior extent of the exposure, respectively. Although the extent of each approach can be increased by using curved instruments and angled endoscopes or using other maneuvers to increase the angle of attack, in our dissections we used only standardized approaches with a standard antrostomy, septectomy, or medial maxillotomy.

Three other anatomical landmarks were identified and further dissected for anatomical reference. The first landmark was the eustachian tube (ET) at the level of the nasopharynx just anterior to the posterior choana. The second landmark was the second genu of the internal carotid artery that was exposed after drilling the sphenoidal wall. The third landmark was the second division of the trigeminal nerve (V2) as it exits the foramen rotundum.

Fig. 3 An endoscopic image from an ipsilateral endonasal (right side) approach showing the area of exposure as the sum of two areas; a rectangular area (highlighted in blue) and a triangular area (highlighted in red). IP, Inferior point representing the inferior extent of a registered blunt tip; LP, lateral point representing the lateral extent of a registered blunt tip; MP, medial point that represents the medial extent of a registered blunt tip; ION, infraorbital nerve as it enters the infraorbital canal. (Used with permission from Barrow Neurological Institute.)

Screen captures from the neuronavigation system were used to measure the area of exposure. The area of exposure was identified as the sum of two areas (►Fig. 3). The first is a rectangular area bounded by a line between the ION and IP laterally, by a line between the ION and MP superiorly, by a line between the IP and the medial border of the posterior choana inferiorly, and by the junction between the septum and the vomer medially. The second area is a triangular area between the ION, IP, and LP.

Surgical Freedom

Surgical freedom was defined as the maximal oval area along which the surgical (proximal) end of the endoscope can be freely and easily moved. This area was calculated by measuring the vertical and transverse limits that can be reached by the proximal end of the endoscope (►Fig. 4A).

The neuro-navigation system was used to measure the transverse limit (►Fig. 4B–D), determined by identifying two points in space. The first point corresponded to the position of the proximal end of the endoscope while placing the distal end of the endoscope as closely as possible to the midpoint of the line between the IP and LP and moving the proximal end of the endoscope as medially as possible, sometimes even crossing the midline. The second point was determined at the

Fig. 4 Method used to calculate the area of surgical freedom. (A) Cone that represents the volume where the endoscope can be freely moved. The oval area at the base of the cone is the area of surgical freedom for (B) ipsilateral sublabial approach, (C) ipsilateral endonasal approach, and (D) contralateral transseptal approach. (Used with permission from Barrow Neurological Institute.)

Fig. 5 Endoscopic images using a 0-degree endoscope for the three different approaches (right side). (A) Sublabial. (B) Ipsilateral endonasal. (C) Contralateral transseptal. (Used with permission from Barrow Neurological Institute.)

proximal end of the endoscope while placing the distal end of the endoscope at the midpoint between the MP and medial border of the posterior choana and moving the endoscope as far laterally as possible.

In a similar fashion, the vertical limit of the surgical freedom was determined by identifying two points in space. The first point was determined by the position of the proximal end of the endoscope while placing the distal end of the endoscope at a point along the ION and IP as superiorly as possible and moving the proximal end of the endoscope gently as inferiorly as possible. The second point was identified as the position of the proximal end of the endoscope while placing the distal end of the endoscope on a point along the line between the ION and IP as inferiorly as possible while moving the proximal end of the endoscope gently and superiorly. These two points were considered to determine the vertical limit of the surgical freedom.

Results

The mean area of exposure for the three endoscopic approaches was similar (►Fig. 5 and ►Table 1). The sublabial approach had an area of $9.92 \pm 2.5 \text{ cm}^2$, the endoscopic endonasal approach had an area of $10.47 \pm 2.65 \text{ cm}^2$, and the transseptal approach had an area of $10.01 \pm 2.16 \text{ cm}^2$.

When the triangular lateral area of exposure was compared between approaches, the transseptal approach provided $\sim 2.7 \text{ cm}^2$ of exposure, the endonasal approach provided 2.45 cm^2 of exposure, and the sublabial approach provided 2.02 cm^2 of exposure. The increase in the lateral area of exposure in the transseptal approach was accompanied by a decrease in medial exposure and vice versa, with the sub-

labial approach resulting in similar quantities for total area exposed. Anatomical structures limiting exposure were the orbital floor and superior border of the sphenoid sinus superiorly, the nasal floor and maxillary sinus floor inferiorly, the nasal septum medially, and the lateral wall of the maxillary sinus laterally.

The mean areas of surgical freedom were $112.82 \pm 7 \text{ cm}^2$ for the sublabial approach, $76.3 \pm 14.5 \text{ cm}^2$ for the ipsilateral endonasal approach, and $83.51 \pm 15.13 \text{ cm}^2$ for the contralateral transseptal approach. The sublabial approach provided significantly more surgical freedom when compared with the ipsilateral endonasal approach ($p < 0.01$) and the transseptal approach ($p < 0.01$; ►Table 2). No significant difference was found in the surgical freedom afforded between the endonasal ipsilateral and transseptal approaches ($p = 0.20$). The mean transverse (T) and vertical (V) axis of the three approaches were $12.8 \text{ cm} \pm 1.2$ (T) and $11 \text{ cm} \pm 0.6$ (V) for the sublabial, $8.9 \text{ cm} \pm 1$ (T) and 10.5 ± 1.1 (V) for the endoscopic endonasal, and $10.6 \text{ cm} \pm 1.2$ (T) and $9.7 \text{ cm} \pm 1$ (V) for the transseptal.

Discussion

Endonasal endoscopic approaches have been used with good results to access midline lesions of the pituitary, and suprasellar and clival lesions.^{20–24} They have been used widely for benign tumors^{14,25,26} and were recently applied to malignant lesions.^{14,27} The morbidity of open surgical approaches to this region have allowed for a natural expansion of the endoscopic technique to the lateral anterior skull base regions.^{3,28} Although they were initially used only for diagnostic and palliative treatment, endoscopic techniques are now

Table 1 Comparison of the area of exposure for the three endoscopic transmaxillary approaches

	Area mean, mm ² + SD	p value compared with ipsilateral Caldwell-Luc approach
Ipsilateral endonasal	1047 ± 265	0.2
Ipsilateral Caldwell-Luc	992 ± 249	NA
Contralateral endonasal transseptal	1001 ± 216	0.3

Abbreviations: NA, not applicable; SD, standard deviation.

Table 2 Comparison of surgical freedom for three endoscopic transmaxillary approaches

	Area mean, mm ² + SD	p value compared with ipsilateral Caldwell-Luc approach
Ipsilateral endonasal	7630 ± 1454	0.0005
Ipsilateral Caldwell-Luc	11282 ± 696	NA
Contralateral endonasal transseptal	8351 ± 1513	0.001

Abbreviations: NA, not applicable; SD, standard deviation.

routinely being used in the primary treatment of antero-lateral skull base lesions such as inverted papillomas and juvenile angiofibromas.^{4,7} The maxillary sinus has been used as a corridor to access the lateral skull base. The sinus is a natural route, and its large volume permits a great deal of surgical freedom and access to critical neurovascular structures. Several transmaxillary approaches have been used in the treatment of retromaxillary lesions.^{9,14}

Our data show that the sublabial approach provides the best horizontal working space, and the endonasal approach has the least horizontal working space; therefore, a sublabial approach may be superior in the case of tumors that extend in the same axial plane. In addition, we found that the transseptal approach has the least vertical working space; as a result, it may not be the best option in the case of tumors or lesions that extend in the same sagittal plane. The approaches we describe in this study were previously described with a detailed anatomical overview,^{9,19} but an analysis of the exposed working space, including the surgical freedom and the area of exposure, has not been previously described. These concepts are important in planning the appropriate surgical approach for a specific lesion and for understanding the limitations of each of the approaches. Theodosopoulos et al⁹ concluded in an anatomical study that a combined ipsilateral sublabial and ipsilateral endonasal approach can provide a full exposure to the infratemporal fossa and pterygopalatine fossa, but the lateral aspect of the infratemporal fossa was challenging to access and required traumatic traction to the nose. Eloy et al¹⁹ demonstrated that the transseptal approach provided more posterolateral exposure for the infratemporal fossa. Our study confirms this: Combining any of these approaches with a contralateral endonasal transseptal approach will provide a lateral shift of the area of exposure. This shift in exposure will assist in the removal of lesions that extend as far laterally as the mandibular ramus and temporalis muscle. In our study, the quantitative exposed area for each approach was similar; however, the areas exposed were not the same. Therefore, combining any two approaches will allow for a larger exposure. Combining the ipsilateral sublabial approach with the transseptal approach provides an additional 1.2 cm² of exposure and adds increased maneuverability, permitting a four-handed technique to be used. Adding an ipsilateral endonasal approach increases the exposed area by 0.6 cm², which may be of great value in approaching large challenging lesions.

In their cadaveric study, Harvey et al⁸ determined that surgical access was increased 14.7 ± 2.5% when a trans-

septal approach is used compared with ipsilateral approaches. According to our data, the contralateral transseptal exposure will lead to an increase of ~ 12% and 11% in the area of exposure when compared with ipsilateral endonasal and ipsilateral sublabial approaches, respectively.

In cadaveric studies, Hartnick et al²⁹ and Eloy et al¹⁹ approached the infratemporal fossa via a temporal hairline incision and concluded it is a limited approach that can be used only for targeted cerebrospinal fluid leak treatment or lesion biopsy. Eloy et al concluded that adding this approach to any of the previously described approaches may lead to an increased surgical freedom for the superior portion of the infratemporal fossa.¹⁹ With the increased experience of the surgical team, the use of angled endoscopes and angled instruments can be helpful in increasing the size of the accessible operative field and leading to improved tumor resections.^{30,31} Although these angled instruments and endoscopes would greatly increase the extent and application for each approach, in our comparison we used only straight instruments and a 0-degree endoscope, so that we could study the approaches in a standard manner.

Other maneuvers can be used to increase surgical freedom. For example, in the sublabial approach, the anterior maxillary antrostomy can be widened, but care should be taken with the superior extension of the antrostomy so as not to injure the infraorbital nerve and artery.⁹ For the endonasal approach, the medial maxillotomy can be enlarged and the piriform aperture drilled (Denker approach), but the lacrimal duct should be identified and spared to prevent postoperative complications. For the contralateral endonasal approach, a larger septectomy allows easier introduction of other endoscopic instruments.⁸

The difference in surgical freedom among the three approaches, with similar exposed areas, is attributed to the pivot point (Pinch point; ► Fig. 6). The pivot point is the fixed point between the tip of the endoscope and the base of the endoscope where the direction of movement is changed. The movement of the proximal end of the endoscope to one direction results in a movement of the distal end to the opposite direction. The pivot point was closer to the tip in the sublabial approach (1–3 cm); thus a larger movement of the proximal end results in a smaller and finer movement at the distal end of the endoscope. The pivot point ranged from 4.5 to 7 cm in the ipsilateral endonasal approach; thus a movement of the proximal end would lead to a larger movement of the distal end when compared with the sublabial approach.

Fig. 6 Diagram showing the importance of the pivot point in the three different approaches, which when changed (depending on the approach) with a fixed area of exposure affect the degree of surgical freedom. (Used with permission from Barrow Neurological Institute.)

Conclusion

The sublabial, ipsilateral endonasal, and contralateral transseptal endoscopic transmaxillary approaches provide excellent exposure to the retromaxillary area. The quantity of area exposed is similar for the three approaches, but the transseptal approach offers greater lateral exposure. Surgical freedom is greatest with the sublabial approach and least in the ipsilateral endonasal approach. This information may benefit practitioners in surgical planning and decision making for lesions of the infratemporal fossa and pterygopalatine fossa.

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