



Anatomical Landmarks and Boundaries of the Endoscopic Sublabial Transmaxillary Approach to the Middle Cranial Fossa: A Cadaveric Study

Ebubekir AKPINAR¹, Aysu IYIGUN KABAKCI², Hasan Cagri POSTUK³, Ercan BOSNAK⁴, Akin AKAKIN⁵, Abuzer GUNGOR⁶, Turker KILIC⁶, Bekir TUGCU¹

¹Republic of Türkiye Ministry of Health, Basaksehir Cam and Sakura City Hospital, Department of Neurosurgery, Istanbul, Türkiye

²Republic of Türkiye Ministry of Health, Ankara Etlik City Hospital, Department of Neurosurgery, Ankara, Türkiye

³Trabzon Kanuni Research and Education Hospital, Department of Neurosurgery, Trabzon, Türkiye

⁴Medicalpark Gebze Hospital, Department of Neurosurgery, Istanbul, Türkiye

⁵Bahcesehir University School of Medicine, Department of Neurosurgery, Istanbul, Türkiye

⁶Istinye University Faculty of Medicine, Department of Neurosurgery, Istanbul, Türkiye

Corresponding author: Abuzer GUNGOR ✉ abuzergungor@gmail.com

ABSTRACT

AIM: To demonstrate the anatomical framework of the endoscopic sublabial transmaxillary approach (ESTA) to the middle cranial fossa (MCF).

MATERIAL and METHODS: Six formalin-fixed human cadaveric heads injected with red and blue silicone were used for endoscopic dissections to define the surgical landmarks and anatomical limits of the ESTA. Images were obtained using a 4K high-definition camera, microscope, and video endoscopy systems.

RESULTS: Accessing the MCF via the ESTA involves sublabial mucosal dissection; drilling of the anterior wall of the maxillary sinus; removal of the maxillary sinus mucosa while preserving the infraorbital nerve (ION); opening of the posterior wall of the maxillary sinus, with the ION serving as the medial limit; drilling of the lateral pterygoid process; mobilization and retraction of the superior head of the lateral pterygoid muscle and the temporalis muscle; identification of the foramen rotundum (FR) and foramen ovale (FO), followed by the maxillary and mandibular nerves; drilling of the sphenoid bone, limited medially by the vertical line extending from the FR and inferiorly by the horizontal line extending from the FR; and entry into the temporal pole following dural opening. The ESTA provided a statistically significantly shorter distance to the MCF than the endonasal transmaxillary approach (EETA, $p < 0.001$).

CONCLUSION: The MCF can be accessed through the ESTA while preserving the surrounding neurovascular structures. This approach provides direct access to the temporal pole without the need for craniotomy or brain parenchymal retraction and may serve as an alternative to conventional transcranial approaches.

KEYWORDS: Endoscopic sublabial approach, Middle cranial fossa, Skull base, Transmaxillary approach

ABBREVIATIONS: **ESTA:** Endoscopic sublabial transmaxillary approach, **EETA:** Endoscopic endonasal transmaxillary approach, **EETsA:** Endoscopic endonasal transsphenoidal approach, **MCF:** Middle cranial fossa, **ASAN:** Anterior superior alveolar nerve, **MSN:** Middle superior alveolar nerve, **IOA:** Infraorbital artery, **IOF:** Infraorbital foramen, **ION:** Infraorbital nerve, **V2:** Maxillary nerve, **V3:** Mandibular nerve

Ebubekir AKPINAR : 0000-0002-4069-0021

Aysu IYIGUN KABAKCI : 0009-0005-7637-4513

Hasan Cagri POSTUK : 0000-0001-6491-730X

Ercan BOSNAK : 0000-0001-5026-6884

Akin AKAKIN : 0000-0002-3881-5913

Abuzer GUNGOR : 0000-0002-2792-7610

Turker KILIC : 0000-0003-4237-808X

Bekir TUGCU : 0000-0003-0385-0054



This work is licensed by "Creative Commons Attribution-NonCommercial-4.0 International (CC)".

■ INTRODUCTION

Approaches to the middle cranial fossa (MCF) can be broadly classified into transcranial and endoscopic techniques. Endoscopic approaches are further categorized as transorbital, endonasal, and sublabial transmaxillary approaches. These approaches may be combined and modified in various ways; however, each has inherent limitations related to endoscope maneuverability (15,16,29,30,32). The use of endoscopes in skull base surgery has expanded with advances in surgical instruments and reconstructive techniques (14). The evolution of modern endoscopic skull base surgery has been driven by technological innovations and the application of fundamental neurosurgical principles (26). Collectively, these advances have established endoscopic approaches as a viable alternative to transcranial techniques (9).

The endoscopic sublabial transmaxillary approach (ESTA) has been used to access lesions of the MCF; however, the complexity of the regional anatomy necessitates a thorough understanding of the relevant anatomical structures to perform this approach safely. Because this approach primarily provides access to the anterior pole of the temporal lobe, it is not intended to replace conventional lateral temporal approaches for pathologies involving the entire MCF. Rather, it serves as a complementary, minimally invasive alternative for selected lesions of the anterior temporal region and infratemporal fossa. This study aimed to define the key anatomical landmarks of this surgical corridor, clearly delineate the boundaries of the craniectomy, and provide a detailed anatomical framework of the ESTA to the MCF, supported by detailed morphometric measurements and three-dimensional anatomical modeling.

■ MATERIAL and METHODS

This study was conducted in the laboratory between September and October 2021. Twelve formalin-fixed cadaveric hemispheres, in which the arteries were perfused with red silicone and the veins with blue silicone, were used in this study. The macroscopic and microscopic phases of the dissections were photographed using a Canon EOS 550D camera equipped with 18–55 mm and 100 mm macro lenses, whereas the endoscopic phases were recorded using the Karl Storz 4K and Richard Wolf Logic 4K endoscopy systems. Microscopic dissections were performed using a Carl Zeiss OPMI Vario 700 surgical microscope (Carl Zeiss AG, Oberkochen, Germany) in combination with the Karl Storz 4K and Richard Wolf Logic 4K endoscopy systems. Between dissections, the cadaveric specimens were preserved in 70% alcohol at room temperature.

The specimens were positioned supine to simulate the surgical position. The dissections were performed in three stages: the premaxillary sinus stage, the maxillary sinus stage, and the postmaxillary sinus stage.

Computed tomography (CT) scans were obtained for all cadaveric specimens, and the resulting Digital Imaging and Communications in Medicine (DICOM) datasets were analyzed. Quantitative morphometric measurements were performed using Bee DICOM Viewer software. Measurements

were obtained in the standard axial, coronal, and sagittal planes and evaluated with millimeter-level accuracy. Because the endoscopic endonasal transsphenoidal approach (EETSA) traverses the midline, one measurement was obtained from each cadaver, yielding a total of six measurements. In contrast, 12 measurements were obtained for each bilateral approach, namely the ESTA and the EETA.

Brain magnetic resonance imaging (MRI) and CT datasets were used to segment the cerebral arteries, brain parenchyma, skull, planned craniotomy boundaries, and cranial nerves using three-dimensional (3D) Slicer software. The resulting segmented models were exported in Standard Tessellation Language (STL) format and subsequently imported into Blender for postprocessing. Surface smoothing, mesh optimization, and texture mapping were applied to the reconstructed anatomical structures. A three-dimensional anatomical model of the endoscopic sublabial transmaxillary approach to the MCF was subsequently generated.

Statistical analysis was performed using nonparametric tests because of the small sample size. The corridor lengths of the three surgical approaches were compared using the Friedman test. Pairwise comparisons were performed using the Wilcoxon signed-rank test, with Bonferroni correction applied to adjust for multiple comparisons (significance threshold, $p < 0.017$). Because the EETSA represents a midline corridor with a single measurement per cadaver, the mean bilateral values of the paired approaches were used for matched comparisons. All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). A p value < 0.05 was considered statistically significant.

■ RESULTS

The endoscopic dissections were categorized into three stages: the premaxillary sinus stage, the maxillary sinus stage, and the postmaxillary sinus stage.

Premaxillary Sinus Stage

The head was positioned supine in a neutral position and secured to a Mayfield head clamp parallel to the horizontal plane to simulate the surgical position. The upper lip was retracted macroscopically using suspension sutures (Figure 1A). The incision line along the dentogingival sulcus was planned to correspond to the projection of the oral vestibule, extending from the left canine tooth to the second molar (Figure 1B). Because the mucosal tissue of the cadaveric specimens was fragile, special care was taken during retractor placement. The mucosa was incised along the planned line using a scalpel.

The mucosal and periosteal layers were dissected to expose the infraorbital foramen, after which the infraorbital nerve (ION) was identified using a periosteal elevator (Figure 1C). The dissection was extended to provide adequate exposure of the anterior wall of the maxillary sinus, after which a self-retaining retractor was placed (Figure 1C). Because the mucosal layer was highly fragile, both the dissection and retractor placement were performed with particular care.

A sublabial anterior antrostomy was performed using the Caldwell–Luc procedure. A maxillotomy measuring approximately

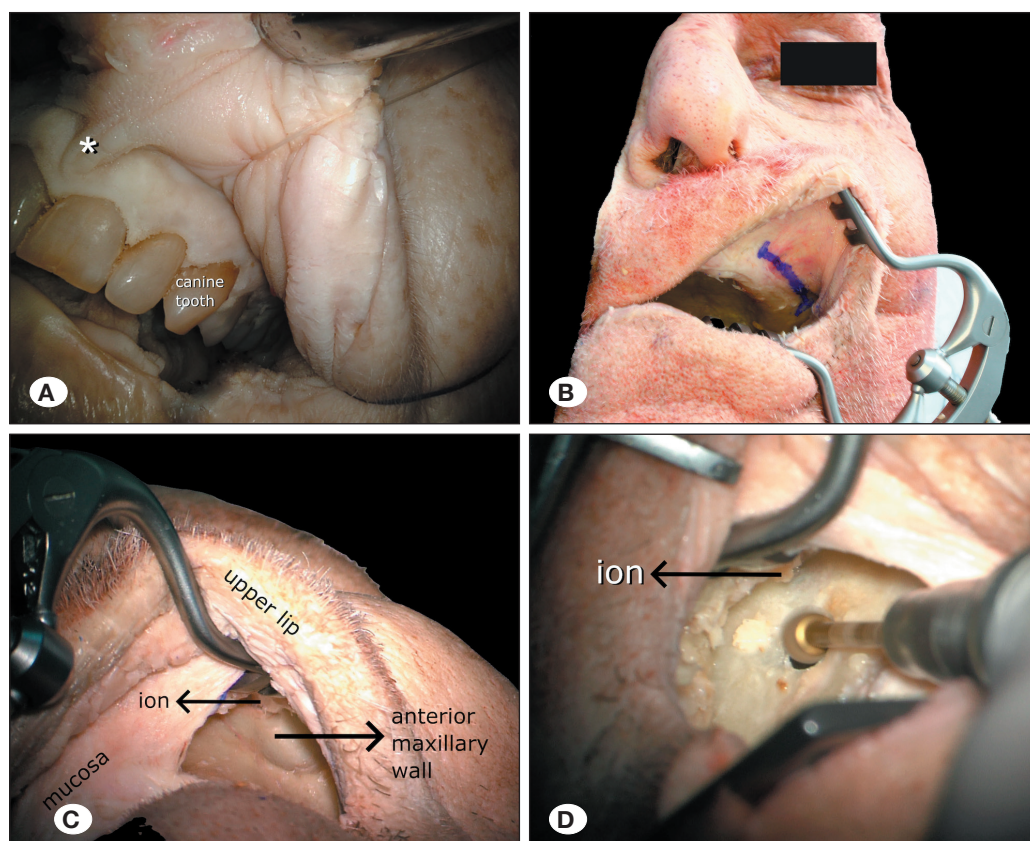


Figure 1: Premaxillary sinusoidal stage. **A)** Opening of the oral vestibule, located between the teeth and the upper lip, after lip retraction. **B)** The mucosal incision was planned along the dentogingival sulcus, as outlined. **C)** After dissection of the mucosal layer and elevation of the periosteum, the infraorbital foramen, infraorbital nerve, and anterior wall of the maxillary sinus were exposed. **D)** Drilling of the anterior wall of the maxillary sinus is shown. Owing to the thin anterior wall of the maxillary sinus, drilling should begin at a safe entry point. An imaginary vertical line extending from the infraorbital foramen (IOF) to the dentogingival sulcus should be considered, and the initial drill point should be located at the midpoint of this line. *: superior labial frenulum, **ION:** infraorbital nerve.

2 × 3 cm was created in the anterior wall of the maxillary sinus using a high-speed drill (Figure 1D). The infraorbital foramen served as the superior boundary of the maxillotomy to protect the adjacent neurovascular structures. After entering the maxillary sinus, the lateral and medial margins were extended to the transition points between the anterior wall and the lateral and medial walls of the maxillary sinus. The floor of the maxillary sinus was preserved as the inferior boundary to avoid injury to the anterior superior alveolar nerve (ASAN), middle superior alveolar nerve (MSON), and branches of the ION, which provide sensory innervation to the maxillary teeth.

Maxillary Sinus Stage

Following entry into the maxillary sinus, the endoscopic stage was initiated (Figure 2A). As the first step of the maxillary sinus stage, the mucosal lining was removed to expose the relevant anatomical landmarks (Figure 2B). Medially, the maxillary ostium opening into the middle meatus, along with the ION and infraorbital artery (IOA) extending from the posterior wall to the superior wall, was identified. Laterally, the apex of the maxillary sinus was visualized. The most critical aspect of this stage is preserving the orbital floor while drilling the posterior wall of the maxillary sinus.

The posterior wall of the maxillary sinus was identified to avoid injury to the orbital floor. The principal anatomical landmarks at this stage were the ION and IOA.

The posterior wall of the maxillary sinus lateral to the ION was drilled while carefully preserving the orbital floor. A bony window was then created through the posterior wall of the maxillary sinus while preserving the surrounding neurovascular and muscular structures. At this stage, the opening could be further enlarged using a Kerrison rongeur to provide adequate surgical exposure.

Postmaxillary Sinus Stage

Through the opening in the posterior wall of the maxillary sinus, the infratemporal fossa and pterygoid fossa were identified. The principal anatomical landmark at this stage was the ION. By following the ION, the maxillary nerve and foramen rotundum (FR) were identified, revealing a region rich in neurovascular and muscular structures (Figure 3A). Laterally, the temporalis and medial pterygoid muscles were identified; medially, the sphenopalatine artery was observed; posteriorly, the superior head of the lateral pterygoid muscle was seen inserting into the infratemporal crest; and inferiorly, the superior head of the lateral pterygoid muscle was visualized. At this stage, the lateral pterygoid plate could be drilled further; however, drilling of the medial pterygoid plate was considered unsafe (Figure 3B).

The vidian canal and vidian nerve were located posterior to the sphenopalatine foramen and artery. In this region, the sphenopalatine artery, located medial to the pterygomaxillary fissure, enters the nasal cavity and supplies the nasal septum.

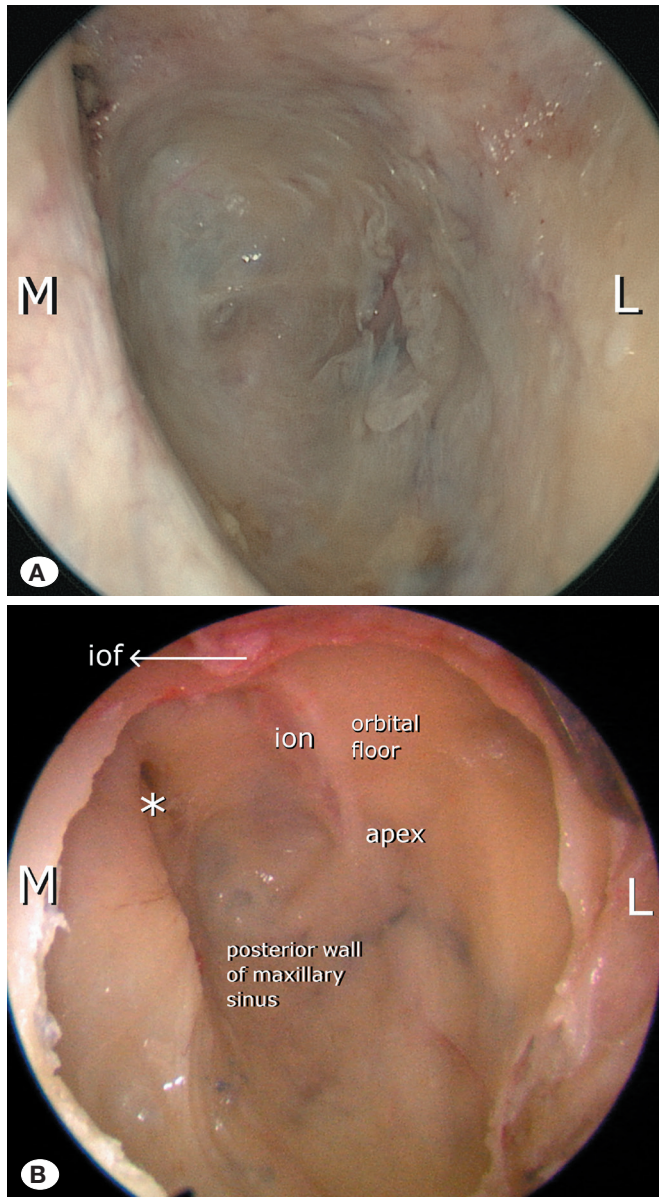


Figure 2: Maxillary sinusoidal stage. **A)** Endoscopic view of the left maxillary sinus with the mucosal lining intact. **B)** Endoscopic view after mucosal elevation, revealing anatomical landmarks, including the maxillary ostium, maxillary apex, posterior wall of the maxillary sinus, infraorbital foramen and nerve, and orbital floor. *: maxillary ostium, **IOF:** infraorbital foramen, **ION:** infraorbital nerve, **M:** medial, **L:** lateral.

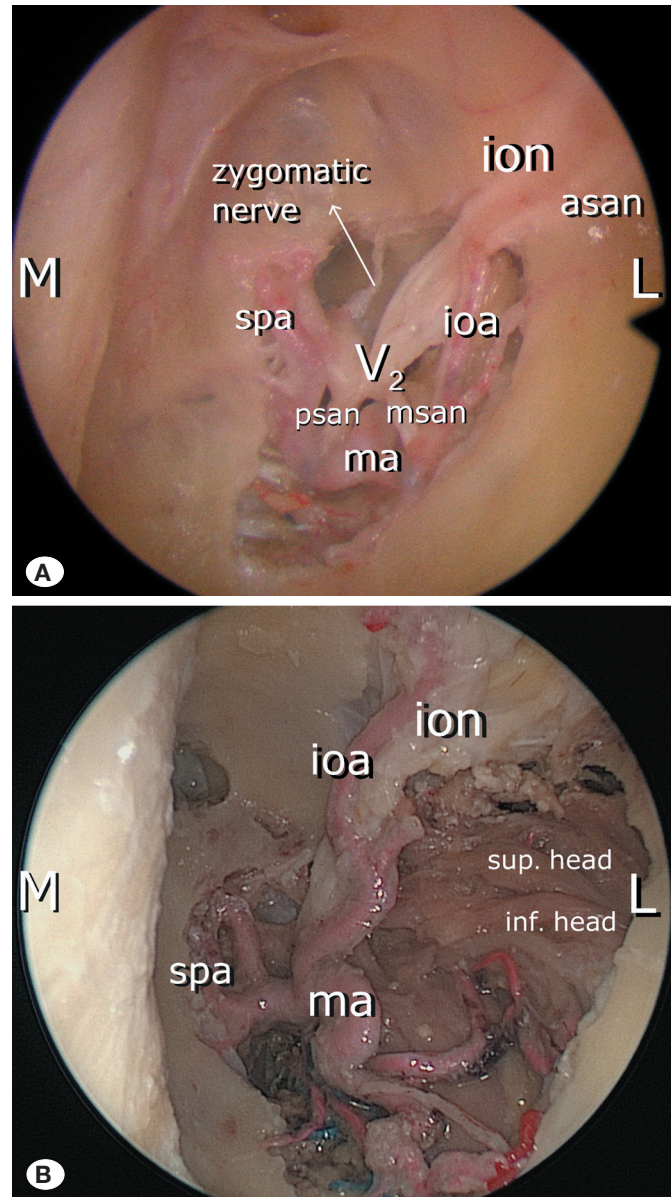


Figure 3: Postmaxillary sinusoidal stage 1. **A)** Endoscopic view after drilling the posterior wall of the maxillary sinus. The two prominent anatomical structures identified are the maxillary artery and the maxillary branch of the trigeminal nerve. The maxillary nerve (V₂) exits the cranium through the FR, gives rise to the anterior, middle, and posterior superior alveolar nerve branches, and then continues to the infraorbital foramen. Two branches of the maxillary artery, the sphenopalatine artery and the IOA, are also visualized. **B)** Endoscopic view showing the infratemporal structures after drilling the lateral pterygoid process and the bony region medial to the infraorbital nerve, in addition to the posterior wall of the maxillary sinus, thereby allowing visualization of the pterygopalatine fossa. **ASAN:** anterior superior alveolar nerve, **L:** lateral, **M:** medial, **MA:** maxillary artery, **MSAN:** middle superior alveolar nerve, **inf. head:** inferior head of the lateral pterygoid muscle, **IOA:** infraorbital artery, **ION:** infraorbital nerve, **PSAN:** posterior superior alveolar nerve, **SPA:** sphenopalatine artery, **sup. head:** superior head of the lateral pterygoid muscle.

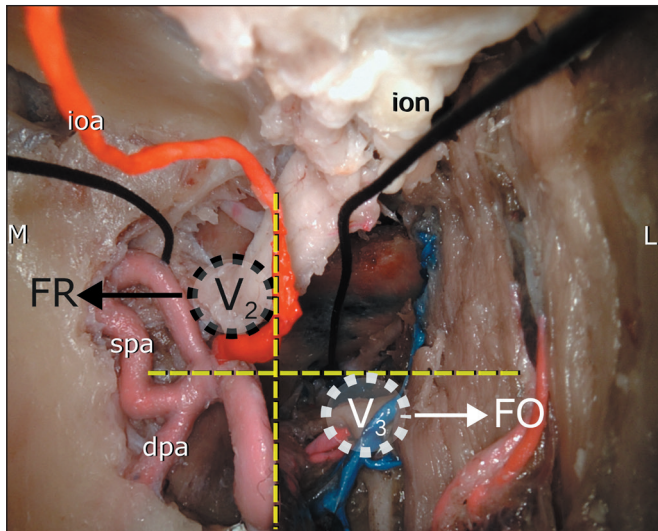


Figure 4: Endoscopic view of the greater wing of the sphenoid bone. The superior head of the lateral pterygoid muscle is incised beginning at the infratemporal crest. The inferior head of the lateral pterygoid muscle and the medial pterygoid muscle are retracted, allowing visualization of the greater wing of the sphenoid bone and the associated anatomical structures. The maxillary branch of the trigeminal nerve serves as a guide for locating the FR, whereas the mandibular branch serves as a guide for locating the FR. The FR is delineated by black dots, whereas the FR is delineated by white dots. To define the boundaries of the rectangular opening into the middle cranial fossa, the quadrant technique is used to avoid damage to adjacent structures. First, a vertical line is drawn through the medial border of the FR, and a horizontal line is drawn through the superior border of the FR, thereby defining the proposed superolateral quadrant for craniectomy. This superolateral quadrant corresponds to the region of the greater wing of the sphenoid bone. Medially, the sphenopalatine artery courses toward the nasal septum, whereas the descending palatine artery courses toward the hard and soft palates. **DPA:** descending palatine artery, **FO:** foramen ovale, **FR:** foramen rotundum, **IOA:** infraorbital artery, **ION:** infraorbital nerve, **M:** medial, **L:** lateral, **SPA:** sphenopalatine artery, **V2:** maxillary branch of the trigeminal nerve, **V3:** mandibular branch of the trigeminal nerve.

Creating a surgical window to the MCF requires sacrifice of the superior head of the lateral pterygoid muscle, which originates from the infratemporal crest and inserts into the capsule and articular disc of the temporomandibular joint. The inferior head of the lateral pterygoid muscle, which originates from the lateral pterygoid plate of the sphenoid bone and inserts into the pterygoid fovea of the mandible, was incised beginning at the infratemporal crest to expose the greater wing of the sphenoid bone. The bony window providing access to the MCF was created through the greater wing of the sphenoid bone.

The external carotid artery gives rise to the superficial temporal artery, whereas the maxillary artery branches just posterior to the mandible. The maxillary artery enters the infratemporal fossa and supplies the structures of the infratemporal and pterygoid fossae, as well as the dura mater, teeth, pharynx, and nasal septum.

The most critical step of this stage was defining the boundaries of the rectangular opening to the MCF, making identification of the foramen ovale (FO) and FR essential (Figure 4A). At this stage, the panoramic view provided by the endoscope facilitated identification of these foramina by enhancing spatial orientation and surgical control. To identify the FR, the proximal ION was followed to the maxillary nerve (V2). After identifying V2, the endoscope was directed inferolaterally toward the exit of the mandibular nerve (V3) at the FO (Figure 4). During drilling, it is important to recognize that the V2–V3 junction lies between the FO and FR. First, a vertical line was drawn through the medial border of the FR, and a horizontal line was drawn through the superior border of the FO, thereby defining the proposed superolateral quadrant for the craniectomy (Figure 4).

After drilling the superolateral quadrant of the greater wing of the sphenoid bone, the dura overlying the temporal pole was visualized (Figure 5A). To obtain a wider field of visualization, the endoscope was advanced distally by shifting its pivot point. From this point onward, the dural incision could be planned according to the location and characteristics of the lesion (Figure 5B).

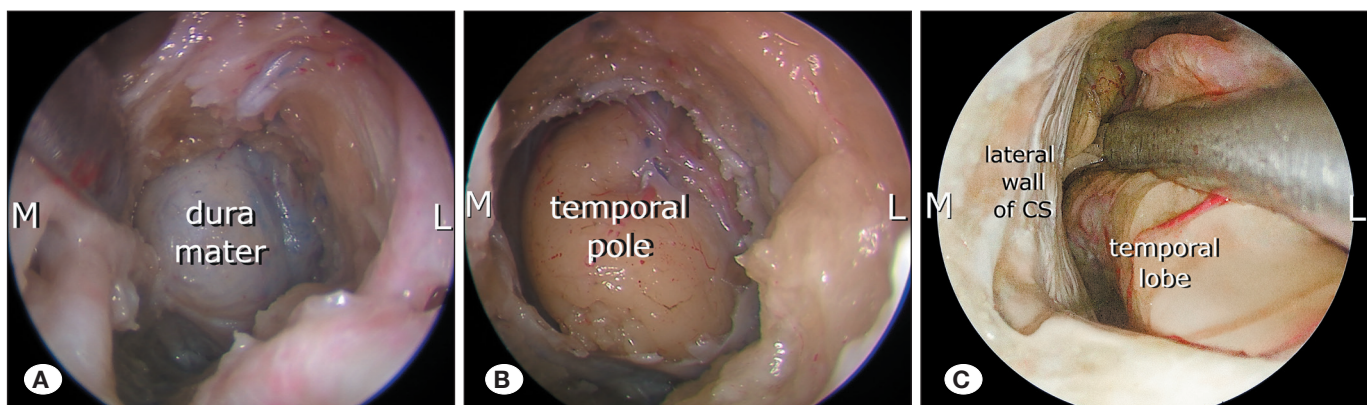


Figure 5: Endoscopic view of the MCF after drilling the greater wing of the sphenoid bone. **A)** Following the creation of an opening through the greater wing of the sphenoid bone, the dura mater of the temporal lobe is first encountered. During the procedure, this opening can be expanded laterally. **B)** After dural opening, the parenchyma of the temporal pole is visualized. **C)** Following lateral retraction of the temporal lobe, the lateral wall of the cavernous sinus and the medial aspect of the temporal lobe are visualized. **M:** medial, **L:** lateral, **CS:** cavernous sinus, **MCF:** middle cranial fossa.

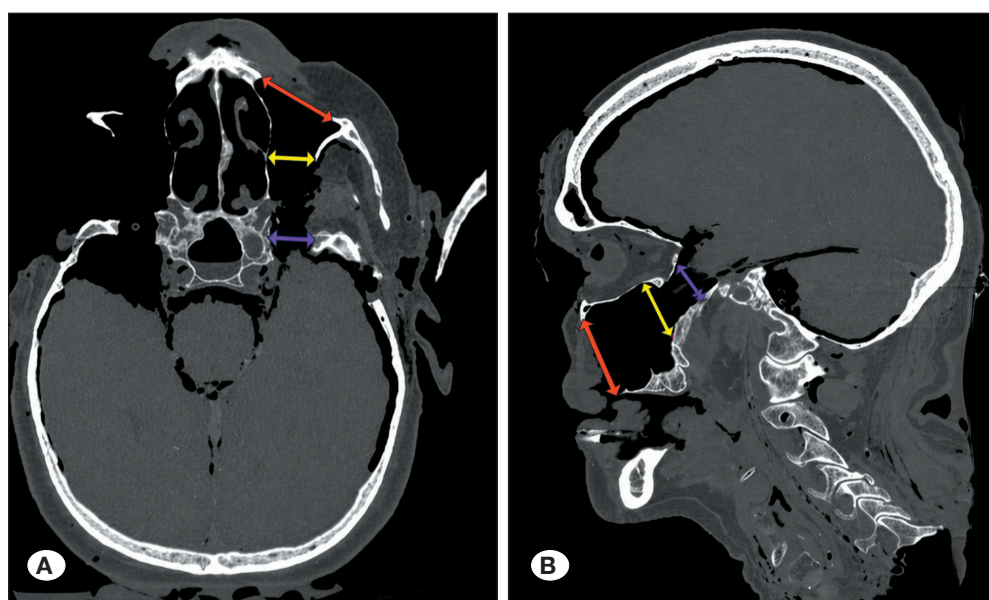


Figure 6: Axial (A) and sagittal (B) bone-window CT images demonstrating the morphometric measurements of the surgical access. The red, yellow, and purple arrows indicate the linear distances between the defined segments (the anterior wall of the maxillary sinus, the posterior wall of the maxillary sinus, and the temporal skull base bony windows, respectively) in both imaging planes. The quantitative data for these measurements are presented in Table I.

Table I: Morphometric Measurements of Surgical Corridors and Bony Windows (n = 12 sides)

Measurement	Parameter	Value (mean ± SD) (mm)	Area (mm ²)*
Maxillary sinus (anterior wall bony window) (Fig.6 red arrows)	Vertical length	30.24±0.88	850.16±40.17
	Horizontal length	28.10±0.51	
Maxillary sinus (posterior wall bony window) (Fig.6 yellow arrows)	Vertical length	24.32±0.51	425.09±20.34
	Horizontal length	17.47±0.47	
Middle cranial fossa bony window (Fig. 6: purple arrows)	Vertical length	14.74±0.43	222.52±10.03
	Horizontal length	15.09±0.24	
Sublabial Transmaxillary Approach (Fig.7, orange arrows)	Anterior wall of the maxillary sinus-temporal pole linear distance (mm)	51.03±1.89	—
Endonasal Transmaxillary Approach (Fig.7, blue arrows)	Naris- temporal pole linear distance (mm)	62.87±2.43	—
Endonasal Transsphenoidal Approach (Fig.7, green arrows) (Reference Measurement)	Naris-Anterior wall of the sella turcica linear distance (mm)	72.99±3.52	—

*Areas were approximated assuming a rectangular geometry (vertical × horizontal dimensions). Length values are presented as mean ± SD.

Following the dural incision, the parenchyma of the temporal pole was visualized, and the cavernous sinus could be exposed medial to the temporal pole (Figure 5C).

All linear and area measurements of the bony windows created during the dissections were obtained from CT images of the cadaveric specimens. In Figure 6, the red, yellow, and purple arrows indicate the bony windows created in the anterior wall of the maxillary sinus, the posterior wall of the maxillary sinus, and the sphenoid bone providing access to the skull base, respectively. The dimensions of the bony windows are presented in Table I.

In addition to the morphometric measurements of the surgical corridors, the corridor lengths of the ESTA (anterior wall of the maxillary sinus to the temporal pole) and the endoscopic endonasal transmaxillary approach (EETA; naris to the temporal pole) were measured as 51.03±1.89 mm and 62.87±2.43 mm, respectively. The measurement values for the EETsA (naris to the anterior wall of the sella turcica) are also provided in Table I as reference measurements.

Figure 7 illustrates the endoscopic measurements of the sublabial transmaxillary corridor (Figure 7A), the endonasal transmaxillary corridor (Figure 7B), and the endonasal transsphenoidal

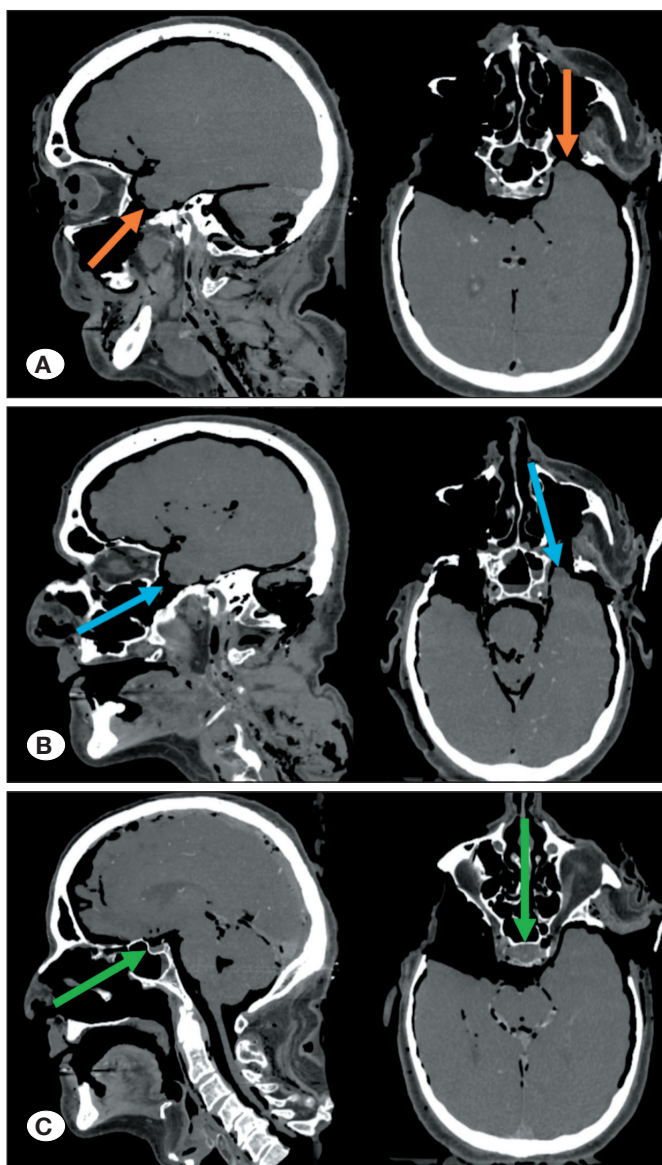


Figure 7: Morphometric measurements were performed on sagittal (left) and axial (right) CT images obtained from cadaveric specimens following anatomical dissection. The corresponding figures illustrate the surgical corridors, with the orange arrow indicating the sublabial transmaxillary corridor (A), the blue arrow denoting the endonasal transmaxillary corridor (B), and the green arrow representing the endonasal transsphenoidal corridor (C). **CT:** computed tomography

noidal corridor (Figure 7C), the latter serving as the reference approach.

The corridor lengths differed significantly among all three surgical approaches. The mean corridor length was 51.03 ± 1.89 mm for the ESTA, 62.87 ± 2.43 mm for the EETA, and 73.00 ± 3.56 mm for the EETsA. The Friedman test demonstrated a statistically significant difference among the three approaches ($\chi^2=12.0$, $p<0.001$). Pairwise comparisons demonstrated that the EETA had a significantly longer corridor than the ESTA

($p<0.001$), whereas the EETsA also had a significantly longer corridor than the ESTA ($p = 0.031$).

3D Model of the Technique

3D anatomical modeling was used to illustrate each stage of the procedure. Initially, the mucosal tissue was elevated through a sublabial approach to the level of the infraorbital foramen (IOF), where the ION was identified at its superior margin (Figures 8A,B). A bony window was then created in the anterior wall of the maxillary sinus to expose the sinus cavity (Figure 8C). Subsequently, the posterior wall of the maxillary sinus was removed while maintaining the surgical plane lateral to the course of the ION (Figure 8D). The FR and FO were subsequently identified, and a bony window was created in the greater wing of the sphenoid bone to provide access to the temporal pole (Figures 8E,F).

DISCUSSION

MCF lesions have traditionally been accessed through transcranial approaches that have been widely used in neurosurgical practice for many years. However, with the increasing adoption of endoscopic techniques in skull base surgery, several novel surgical approaches have been introduced.

MCF lesions can be accessed through transcranial routes, including the pretemporal, pterional, and orbitozygomatic approaches. However, particularly with the pretemporal approach, access to the rostral MCF requires retraction of the anterior portion of the temporal lobe. In addition, the temporalis muscle must be incised and elevated to perform a temporal craniotomy, which may result in temporalis muscle atrophy and consequently reduce the patient's quality of life (5,25,26).

In addition to transcranial approaches, numerous techniques have been developed to access the MCF (2,30,33). The MCF can be accessed using either endoscopic or microscopic approaches. Among the endoscopic techniques, the ESTA and endoscopic EETA are notable examples (3,4,10,16,31,32). Furthermore, endoscopic endonasal, sublabial, and transorbital approaches have been used to access the infratemporal fossa and the MCF (19,29).

Although the endoscopic transorbital approach provides a more direct route to the temporal pole, it is limited by its lateral exposure and requires orbital manipulation (7,18,24). In contrast, the ESTA provides a wider surgical corridor through the natural pneumatic space of the maxillary sinus, enables simultaneous access to the orbit, pterygopalatine fossa, and infratemporal fossa, and avoids orbital retraction (8,13). This approach is particularly advantageous for lesions with infratemporal extension or those requiring exposure of both the FR and FR.

The EETA has been used to access MCF lesions and provides a minimally invasive route to the pterygopalatine fossa, infratemporal fossa, sphenoid sinus, cavernous sinus, petrous apex, and Meckel's cave (14). With this approach, the sphenopalatine artery is cauterized and transected, the palatine bone is drilled, and the lateral recess of the sphenoid sinus and the pterygopalatine fossa are subsequently exposed

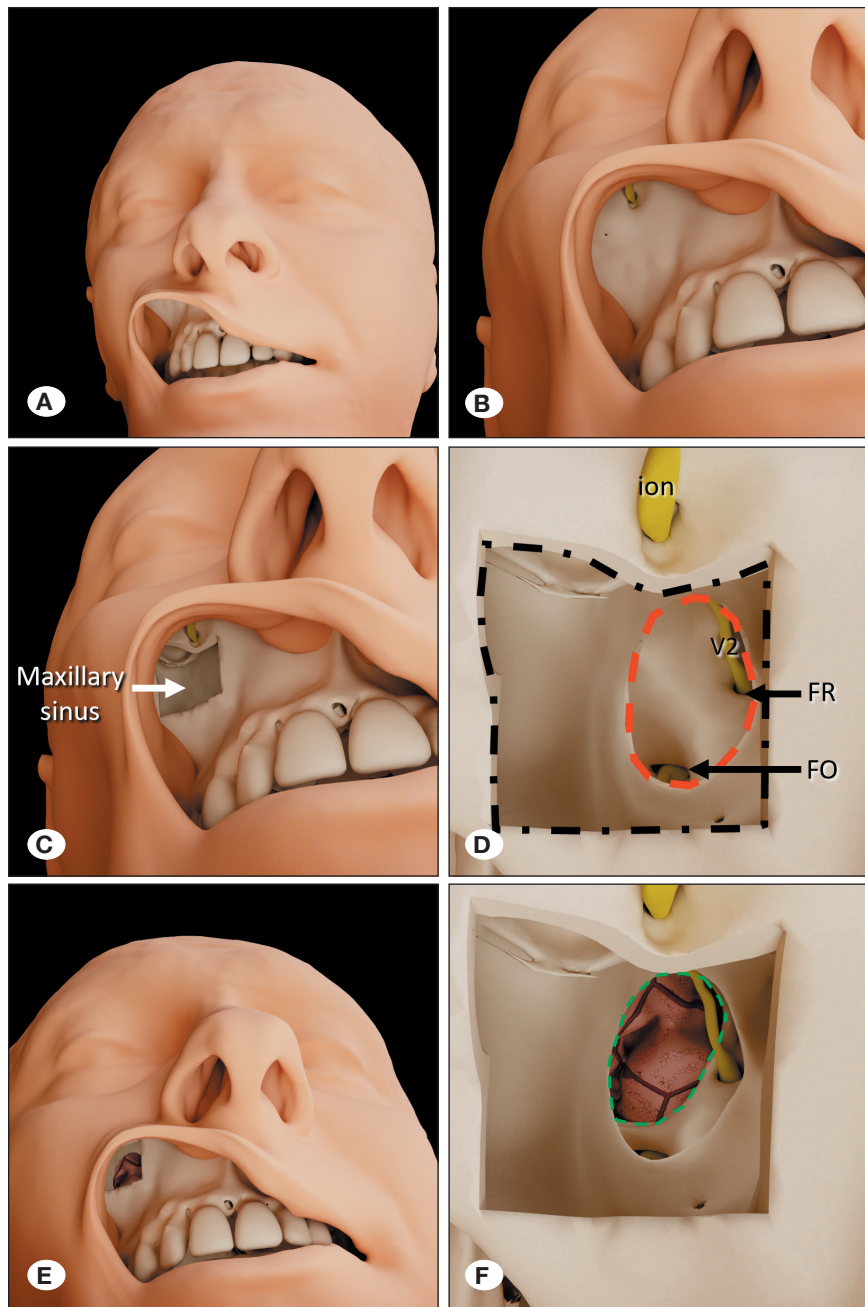


Figure 8: Three-dimensional anatomical models and stepwise cadaveric dissections are presented as paired distant and close-up views. **A)** Following incision of the dentogingival sulcus, the anterior wall of the maxillary sinus was exposed via a sublabial approach (distant view). **B)** Following the sublabial mucosal incision, the periosteal layer was elevated to expose the exit of the ION from the IOF. To preserve the neurovascular structures, the IOF served as the superior boundary for the maxillotomy (close-up view). **C)** The anterior wall of the maxillary sinus was removed to gain access to the maxillary sinus cavity. Care should be taken not to extend the inferior boundary of the maxillotomy to the floor of the maxillary sinus to avoid injury to the upper dentition (distant view). **D)** Following removal of the anterior wall of the maxillary sinus (black dashed lines), the course of the ION exiting the IOF was traced from superior to posterior. A window was created in the posterior wall of the maxillary sinus lateral to the course of the maxillary nerve (V2) (red dashed lines), with the FR and mandibular nerve (V3) visible inferolaterally (close-up view). **E)** A window was created in the sphenoid bone, as described in Figure 4, providing access to the temporal lobe (distant view). **F)** The FR and FR were used as the primary anatomical landmarks for skull base access. The spatial relationship between these two foramina was defined using the “quadrant technique,” in which a vertical line drawn lateral to the foramen rotundum and a horizontal line drawn superior to the FR together delineated the superolateral quadrant. This quadrant constitutes the target zone for craniectomy through the greater wing of the sphenoid bone, providing surgical access to the temporal pole (green dashed line). **IOF:** infraorbital foramen, **ION:** infraorbital nerve, **FO:** foramen ovale, **FR:** foramen rotundum, **MCF:** middle cranial fossa, **V2:** maxillary nerve, **V3:** mandibular nerve

(27). In contrast, the sublabial transmaxillary approach does not require opening of the medial wall of the pterygopalatine fossa; therefore, the nasal barrier in this region remains intact. Furthermore, sacrifice of the sphenopalatine artery is not required. Because the medial wall of the maxillary sinus is preserved, we anticipate that normal sinus physiology is less affected than with the EETA.

Previous studies have demonstrated that the ESTA to the MCF provides better sagittal-plane exposure than endoscopic endonasal approaches. Furthermore, during exposure of the FR and FR, the ESTA offers advantages over endoscopic endonasal approaches with respect to the surgical field of view and operative ergonomics (9,34). In the present study,

morphometric analysis demonstrated statistically significant differences in trajectory lengths among the three endoscopic surgical corridors evaluated ($p < 0.001$), highlighting the distinct anatomical characteristics and potential clinical advantages of each approach. Notably, one of the most important findings was the significantly shorter working distance provided by the sublabial transmaxillary corridor. With a mean trajectory length of 51.03 ± 1.89 mm, this approach provided the most direct access to the target region among the surgical corridors evaluated. In skull base surgery, a shorter working trajectory reduces the physical distance between the surgeon and deeply situated anatomical targets, thereby improving ergonomic comfort, instrument maneuverability, and the endo-



Figure 9: The surgical corridor providing access to the MCF via the ESTA was simulated on a three-dimensional anatomical model using an endoscopic trajectory. **MCF:** middle cranial fossa, **ESTA:** endoscopic sublabial transmaxillary approach

scopic field of view. Collectively, these findings suggest that, from a surgical perspective, the ESTA provides geometrical and ergonomically superior exposure compared with the EETA.

Although the EETA is better suited for lesions involving the medial nasal cavity and medial orbit, the ESTA provides superior exposure for lateral MCF lesions. In selected cases, these two approaches can be combined. Kassam et al. described an expanded endonasal approach for accessing the MCF and infratemporal fossa (16). The EETA and ESTA may be combined to access the pterygopalatine fossa and orbital apex. The EETA provides limited lateral exposure of the pterygopalatine fossa and infratemporal fossa because it is constrained by the nasal septum, nasolacrimal duct, and pterygoid plates (1,20). Improved exposure through the endonasal route requires ethmoidectomy and sphenoidotomy or inferior turbinectomy, which may be associated with additional complications (1). Therefore, greater surgical exposure can be achieved by combining the endonasal approach with the sublabial approach, which is not limited by the nasal septum or nasolacrimal duct (1,20,22). This combined approach requires endoscopic middle turbinectomy and the use of a 45°–70° endoscope, thereby increasing the technical complexity of the procedure and the risk of complications (1,16). The present study demonstrates that the temporal pole can be accessed through a single anterior-to-posterior trajectory without the need for an angled endoscope. We believe that maintaining a single anterior-to-posterior working axis not only facilitates dissection but also promotes a more neurovascular-preserving surgical technique.

The least invasive approach for treating trigeminal nerve pathologies, including squamous cell carcinoma, basal cell carcinoma, melanoma, and adenoid cystic carcinoma, is the endoscopic transmaxillary approach (2,28,30,33). DeMonte et al. described a microneurosurgical approach for malignant tumors of the maxillary nerve with perineural extension and suggested the use of an endoscope because of its advantages (6).

Ong et al. listed the potential complications of the endoscopic sublabial transmaxillary transpterygoid approach to the MCF as complications related to the sublabial incision and maxillotomy, injury to the retromaxillary neurovascular structures, masticatory dysfunction resulting from manipulation of the lateral pterygoid muscles, and cerebrospinal fluid (CSF) fistula (26). Consequently, facial anesthesia or dysesthesia, dental anesthesia, and oroantral fistula may occur (35). CSF fistula, reported as the most common complication in the first 800 cases of endoscopic endonasal skull base surgery performed by Kassam et al., remains a significant limitation of the present approach. Therefore, meticulous reconstruction is essential to minimize the risk of postoperative CSF leakage (17). Furthermore, fat graft fixation techniques, as described by Luzzi et al., can also be applied (21).

Yağmurlu et al. described the sublabial transmaxillary approach to Meckel's cave in a cadaveric study. The boundaries of the craniectomy were defined as follows: the craniectomy begins at the FR and extends laterally in the 6- to 12-o'clock direction toward the FR. The superior boundary is formed by the superior head of the lateral pterygoid muscle, whereas the inferior boundary is defined by an imaginary line connecting the inferior margins of the FR and FR. The FO is drilled superolaterally to protect the eustachian tube (35). In the present study, we propose that the superolateral quadrant defined by an imaginary horizontal line drawn superior to the FR and an imaginary vertical line drawn lateral to the FR provides an appropriate surgical corridor for accessing the MCF, thereby simplifying the approach and enhancing its clinical applicability.

3D digital and printed models have been increasingly used in anatomical neurosurgical studies because they facilitate the understanding of complex cerebral and skull base anatomy, enhance resident training, improve the accuracy of surgical planning, and provide a safe environment for surgical simulation (12,23). In the present study, three-dimensional modeling was used to illustrate the sequential stages of the described approach in a more comprehensive and reproducible manner (Figure 8,9).

In our cadaveric study, we demonstrated that the endoscopic sublabial transmaxillary approach (ESTA) to the MCF, performed through a sublabial incision, resulted in minimal brain parenchymal retraction. Furthermore, because the approach is performed primarily through the sublabial incision without an incision in the temporalis muscle, the risk of temporalis muscle atrophy and the associated cosmetic sequelae is expected to be minimized. During the dissections, following the maxillotomy, the lateral branches of the maxillary artery and the branches of the maxillary nerve were exposed, consistent with previous reports. In addition to providing excellent visual-

ization of the lateral infratemporal fossa, this approach allows potential injuries to the maxillary artery to be readily identified and controlled.

In addition, the safe surgical zone was defined according to the principal anatomical landmarks. Because the anatomy of the MCF and the endoscopic approaches used to access it are highly complex, we aimed to define the boundaries of the craniectomy more simply by using two prominent anatomical landmarks: the FR and the FR. In this way, we sought to establish a safe surgical corridor that provides adequate exposure. The volume of the maxillary sinus forms a natural corridor leading to the retromaxillary space, thereby allowing unrestricted movement of surgical instruments.

Limitations

This study has several limitations. It is a purely cadaveric anatomical investigation without clinical validation. Formalin-fixed specimens may not fully replicate the tissue characteristics and surgical conditions encountered *in vivo*. The sample size of six cadaveric heads, although sufficient for anatomical description, may not fully capture the anatomical variability observed across different populations. In addition, similar to endoscopic transsphenoidal pituitary surgery, the ESTA to the MCF carries a potential risk of CSF leakage and subsequent infection. Although this risk may be reduced through meticulous multilayer reconstruction techniques that are well established in pituitary surgery (11,17,21) and are also applicable to this approach, it remains an important consideration. Furthermore, the complex anatomy of the infratemporal and pterygopalatine fossae presents a significant technical challenge, particularly for neurosurgeons with limited experience in this region, and may necessitate extensive laboratory training before clinical implementation. Finally, although this approach does not directly compromise the temporomandibular joint, partial sacrifice of the lateral pterygoid muscle fibers may be required, which could potentially affect postoperative mandibular function.

CONCLUSION

The optimal surgical approach to MCF pathologies depends on the location of the lesion and the required surgical trajectory. This study demonstrates that the ESTA provides a statistically significantly shorter surgical corridor than alternative endoscopic approaches, offering a potential ergonomic advantage. Through the detailed characterization of the anatomical landmarks and maxillotomy boundaries, the sublabial transmaxillary approach represents a viable, reproducible, and minimally invasive corridor to the MCF while providing adequate surgical exposure.

ACKNOWLEDGEMENTS

This study was conducted at the Prof. Rhoton Applied Anatomy and Surgical Training Center, Bahcesehir University School of Medicine.

The authors sincerely thank those who donated their bodies to science so that anatomical research could be performed. Results from such research can potentially increase mankind's overall knowledge that can then improve patient care. Therefore, these donors and their families deserve our highest gratitude.

Declarations

Funding: This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest: The authors declare that they have no conflicts of interest. They certify that this manuscript, in whole or in part, has not been submitted to any other journal in any form and that its publication has been approved by all co-authors.

Availability of data and materials: The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Ethics approval and consent to participate: This study was approved by the Research Ethics Committee of Basakşehir Cam and Sakura City Hospital (approval date: 08.09.2021; protocol no: 2021-201). The ethics committee application explicitly stated that the study involved the use of cadaveric specimens, and consent for the use of cadaveric material was covered under this institutional ethics approval.

AUTHORSHIP CONTRIBUTION

Study conception and design: EA, HCP

Data collection: AIK, EA

Analysis and interpretation of results: EB, HCP

Draft manuscript preparation: AIK, EA

Critical revision of the article: AG, AA, EB

Other (study supervision, fundings, materials, etc...): AG, BT, TK

All authors (EA, AIK, HCP, EB, AA, AG, TK, BT) reviewed the results and approved the final version of the manuscript.

REFERENCES

1. Alimohamadi M, Hajiabadi M, Gerganov V, Fahlbusch R, Samii M: Combined endonasal and sublabial endoscopic transmaxillary approach to the pterygopalatine fossa and orbital apex. *Acta Neurochir* 157: 919-929, 2015. <https://doi.org/10.1007/s00701-015-2402-z>
2. Amit M, Eran A, Billan S, Fridman E, Na'ara S, Charas T, Gil Z: Perineural spread in noncutaneous head and neck cancer: New insights into an old problem. *J Neurol Surg B Skull Base* 77: 86-95, 2016. <https://doi.org/10.1055/s-0036-1571834>
3. Cavallo LM, Messina A, Gardner P, Esposito F, Kassam AB, Cappabianca P, Divitiis E de, Tschabitscher M, Cavallo LM, Messina A, Gardner P, Esposito F, Kassam AB, Cappabianca P, Divitiis E de, Tschabitscher M: Extended endoscopic endonasal approach to the pterygopalatine fossa: Anatomical study and clinical considerations. *Neurosurg Focus* 19: 1-7, 2005. <https://doi.org/10.3171/FOC.2005.19.1.6>
4. Couldwell WT, Sabit I, Weiss MH, Giannotta SL, Rice D: Transmaxillary approach to the anterior cavernous sinus: A microanatomic study. *Neurosurgery* 40: 1307-1311, 1997. <https://doi.org/10.1097/00006123-199706000-00040>

5. De Andrade FC, De Andrade FC, De Araujo Filho CM, Carcagnolo Filho J: Dysfunction of the temporalis muscle after pterional craniotomy for intracranial aneurysms. Comparative, prospective and randomized study of one flap versus two flaps dieresis. *Arq Neuropsiquiatr* 56: 200-205, 1998. <https://doi.org/10.1590/S0004-282X1998000200006>
6. DeMonte F, Hanna E: Transmaxillary exploration of the intracranial portion of the maxillary nerve in malignant perineural disease: Technical note. *J Neurosurg* 107: 672-677, 2007. <https://doi.org/10.3171/JNS-07/09/0672>
7. De Rosa A, Mosteiro A, Guizzardi G, Roldán P, Torales J, Matas Fassi J, Cavallo LM, Solari D, Prats-Galino A, Di Somma A, Enseñat J: Endoscopic transorbital resection of the temporal lobe: Anatomic qualitative and quantitative study. *Front Neuroanat* 17: 1282226, 2023. <https://doi.org/10.3389/FNANA.2023.1282226>
8. Düz B, Secer Hİ, Gonul E: Endoscopic approaches to the orbit: A cadaveric study. *Minim Invasive Neurosurg* 52: 107-113, 2009. <https://doi.org/10.1055/s-0029-1220931>
9. Elhadi AM, Almefty KK, Mendes GAC, Kalani MYS, Nakaji P, Dru A, Preul MC, Little AS: Comparison of surgical freedom and area of exposure in three endoscopic transmaxillary approaches to the anterolateral cranial base. *J Neurol Surg B Skull Base* 75: 346-353, 2014. <https://doi.org/10.1055/s-0034-1372467>
10. Elhadi AM, Zaidi HA, Yagmurulu K, Ahmed S, Rhoton AL, Nakaji P, Preul MC, Little AS: Infraorbital nerve: A surgically relevant landmark for the pterygopalatine fossa, cavernous sinus, and anterolateral skull base in endoscopic transmaxillary approaches. *J Neurosurg* 125: 1460-1468, 2016. <https://doi.org/10.3171/2015.9.JNS151099>
11. Erkan B, Demir S, Akpinar E, Hasimoglu O, Baskan F, Cirak M, Postalci LS, Tanriverdi O, Gunaldi O: Effectiveness of a sellar reconstruction algorithm in transsphenoidal pituitary surgery: Insights from 490 cases. *World Neurosurg* 189: e1098-e1108, 2024. <https://doi.org/10.1016/j.wneu.2024.07.093>
12. Erol G, Güngör A, Sevgi UT, Gülsuna B, Doğruel Y, Emmez H, Türe U: Creation of a microsurgical neuroanatomy laboratory and virtual operating room: A preliminary study. *Neurosurg Focus* 56: E6, 2024. <https://doi.org/10.3171/2023.10.FOCUS23638>
13. Gönül E, Erdogan E, Düz B, Timurkaynak E: Transmaxillary approach to the orbit: An anatomic study. *Neurosurgery* 53: 935-942, 2003. <https://doi.org/10.1227/01.NEU.0000084164.22028.10>
14. Hofstetter CP, Singh A, Anand VK, Kacker A, Schwartz TH: The endoscopic, endonasal, transmaxillary transpterygoid approach to the pterygopalatine fossa, infratemporal fossa, petrous apex, and the Meckel cave. *J Neurosurg* 113: 967-974, 2010. <https://doi.org/10.3171/2009.10.JNS09157>
15. Karınzada G, Evleksiz Karınzada D, Erol G, Gülsuna B, Kuzuçu P, Güngör A, Kutlay AM, Şahin MM, Çeltikçi E: Transorbital neuroendoscopic surgery for treatment of sphenoid wing meningiomas extending to the cavernous sinus: Clinical implications and a technical illustration. *Neurosurg Focus* 56: E8, 2024. <https://doi.org/10.3171/2024.1.FOCUS23857>
16. Kassam AB, Gardner P, Snyderman C, Mintz A, Carrau R: Expanded endonasal approach: Fully endoscopic, completely transnasal approach to the middle third of the clivus, petrous bone, middle cranial fossa, and infratemporal fossa. *Neurosurg Focus* 19: 1-10, 2005. <https://doi.org/10.3171/FOC.2005.19.1.7>
17. Kassam AB, Prevedello DM, Carrau RL, Snyderman CH, Thomas A, Gardner P, Zanation A, Duz B, Stefko ST, Byers K, Horowitz MB: Endoscopic endonasal skull base surgery: Analysis of complications in the authors' initial 800 patients - A review. *J Neurosurg* 114: 1544-1568, 2011. <https://doi.org/10.3171/2010.10.JNS09406>
18. Lin BJ, Ju DT, Hsu TH, Chen YA, Chung TT, Liu WH, Hueng DY, Chen YH, Hsia CC, Ma HI, Liu MY, Tang CT: Quantitative comparison of endoscopically assisted endonasal, sublabial and transorbital transmaxillary approaches to the anterolateral skull base. *Clin Otolaryngol* 46: 123-130, 2021. <https://doi.org/10.1111/coa.13559>
19. Lin BJ, Ju DT, Hsu TH, Chung TT, Liu WH, Hueng DY, Chen YH, Hsia CC, Ma HI, Liu MY, Hung HC, Tang CT: Endoscopic transorbital approach to anterolateral skull base through inferior orbital fissure: A cadaveric study. *Acta Neurochir* 161: 1919-1929, 2019. <https://doi.org/10.1007/s00701-019-03993-3>
20. Little AS, Nakaji P, Milligan J: Endoscopic endonasal transmaxillary approach and endoscopic sublabial transmaxillary approach: surgical decision-making and implications of the nasolacrimal duct. *World Neurosurg* 80: 583-590, 2013. <https://doi.org/10.1016/J.WNEU.2012.01.059>
21. Luzzi S, Doğruel Y, Güngör A, Gurses ME, Rahmanov S, Türe H, Türe U: Clival dural reconstruction via transnasal approaches: Fat graft fixation technique. *Neurosurg Focus* 58: E4, 2025. <https://doi.org/10.3171/2024.11.FOCUS24560>
22. Matheny KE, Duncavage JA: Contemporary indications for the Caldwell-Luc procedure. *Curr Opin Otolaryngol Head Neck Surg* 11: 23-26, 2003. <https://doi.org/10.1097/00020840-200302000-00005>
23. McGuire LS, Fuentes A, Alaraj A: Three-dimensional modeling in training, simulation, and surgical planning in open vascular and endovascular neurosurgery: A systematic review of the literature. *World Neurosurg* 154: 53-63, 2021. <https://doi.org/10.1016/j.wneu.2021.07.057>
24. Mongkolkul K, Salem EH, Alsavaf MB, Prevedello DM, Vankovering K, Kelly K, Carrau RL: Advantages and caveats of endoscopic to the infratemporal fossa as isolated and combined techniques. *Laryngoscope Invest Otolaryngol* 9: e1242, 2024. <https://doi.org/10.1002/lio2.1242>
25. Nitzan DW, Azaz B, Constantini S: Severe limitation in mouth opening following transtemporal neurosurgical procedures: Diagnosis, treatment, and prevention. *J Neurosurg* 76: 623-625, 1992. <https://doi.org/10.3171/JNS.1992.76.4.0623>
26. Ong BC, Gore PA, Donnellan MB, Kertesz T, Teo C: Endoscopic sublabial transmaxillary approach to the rostral middle fossa. *Neurosurgery* 62: 30-36, 2008. <https://doi.org/10.1227/01.NEU.0000317371.92393.33>
27. Schwartz TH, Fraser JF, Brown S, Tabaei A, Kacker A, Anand VK: Endoscopic cranial base surgery: Classification of operative approaches. *Neurosurgery* 62: 991-1002, 2008. <https://doi.org/10.1227/01.NEU.0000325861.06832.06>

28. Singh FM, Mak SY, Bonington SC: Patterns of spread of head and neck adenoid cystic carcinoma. *Clin Radiol* 70: 644-653, 2015. <https://doi.org/10.1016/j.crad.2015.01.013>
29. Tabari A, Nasirmohtaram S, Mohammadi HR, Zeinalizadeh M, Sadrehosseini SM: Anterior endoscopic sublabial transmaxillary access to middle cranial base lesions. *Head Neck* 46: 1028-1042, 2024. <https://doi.org/10.1002/hed.27725>
30. Truong HQ, Sun X, Celtikci E, Borghei-Razavi H, Wang EW, Snyderman CH, Gardner PA, Fernandez-Miranda JC: Endoscopic anterior transmaxillary "transalisphenoid" approach to Meckel's cave and the middle cranial fossa: An anatomical study and clinical application. *J Neurosurg* 130: 227-237, 2019. <https://doi.org/10.3171/2017.8.JNS171308>
31. Van Rompaey J, Suruliraj A, Carrau R, Panizza B, Solares CA: Meckel's cave access: Anatomic study comparing the endoscopic transantral and endonasal approaches. *Eur Arch Oto-Rhino-Laryngol* 271: 787-794, 2014. <https://doi.org/10.1007/s00405-013-2581-2>
32. Wang X, Zhang X, Hu F, Yu Y, Gu Y, Xie T, Ge J: Image-guided endoscopic endonasal transmaxillary transpterygoid approach to Meckel's cave. *Turk Neurosurg* 26: 309-314, 2016. <https://doi.org/10.5137/1019-5149.JTN.6430-12.0>
33. Warren TA, Nagle CM, Bowman J, Panizza BJ: The natural history and treatment outcomes of perineural spread of malignancy within the head and neck. *J Neurol Surg B Skull Base* 77: 107-112, 2016. <https://doi.org/10.1055/s-0036-1579777>
34. Wilson DA, Williamson RW, Preul MC, Little AS: Comparative analysis of surgical freedom and angle of attack of two minimal-access endoscopic transmaxillary approaches to the anterolateral skull base. *World Neurosurg* 82: e487-e493, 2014. <https://doi.org/10.1016/j.wneu.2013.02.003>
35. Yağmurlu K, Mooney MA, Almetty KK, Bozkurt B, Tanrıöver N, Little AS, Preul MC: An alternative endoscopic anterolateral route to Meckel's cave: An anatomic feasibility study using a sublabial transmaxillary approach. *World Neurosurg* 114: 134-141, 2018. <https://doi.org/10.1016/j.wneu.2018.02.128>