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Endoscopic Endonasal Approach to the Lateral Wall of the Cavernous Sinus: A Cadaveric Feasibility Study

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Abstract

Objective: A transcranial extradural approach to the middle cranial fossa (MCF) requires separation of the dural layers of the lateral wall of the cavernous sinus. The authors tested the feasibility of an endonasal approach for this separation.
Methods: A cadaveric feasibility study was conducted on the sides of 14 dry skulls and 10 fresh cadaveric heads. An endonasal, transsphenoidal, transpterygoid approach was taken to the MCF. The maxillary struts and medial greater wing of the sphenoid below the superior orbital fissure were drilled with transposition of the maxillary nerve. The lateral cavernous dural layers were split at the maxillary nerve with separation of the temporal lobe dura and exposure of the MCF bony base. The integrity of the cranial nerves and inner and outer dural layers of the lateral cavernous wall was checked. Different measurements of bony landmarks were obtained.
Results: The integrity of the dural layers of the lateral cavernous wall and the cranial nerves were preserved in 10 heads. The mean area of the bony corridor was 4.68 ± 0.97 cm^2, the V2-to-V3 distance was 15.21 ± 3.36 mm medially and 18.21 ± 3.45 mm laterally, and the vidian canal length was 13.01 ± 3.06 mm.
Conclusions: Endonasal endoscopic separation of the lateral cavernous dural layers is feasible without crossing the motor cranial nerves, allowing better exposure of the MCF.

Keywords

endonasal, endoscopic, cavernous sinus, lateral wall, skull base surgery, middle cranial fossa

Introduction

In the era of expanded endonasal approaches, the middle cranial fossa (MCF) can be approached medially through certain corridors. These corridors include the petrous apex, the quadrangular space to Meckel's cave, the anteromedial triangle between the ophthalmic (V1) and maxillary (V2) divisions, and the anterolateral triangle between V2 and the mandibular division (V3).[1,2] These corridors are narrow and hindered by the internal carotid artery (ICA) and motor nerves in lateral wall of the cavernous sinus and therefore allow addressing only small pathologies in the medial compartment of the MCF.[3] Although the medial compartment of the cavernous sinus is readily approached endonasally, the lateral wall of the cavernous sinus represents an obstacle for medial-to-lateral extension of an endonasal approach to the MCF.[4-6] The lateral wall of the cavernous sinus is formed of outer meningeal and inner membranous dural layers, which can be separated surgically, gaining lateral access to the cavernous sinus and medial access to the temporal lobe in the interdural space. This dural separation is known as the peeling procedure of the outer layer of the lateral wall of the cavernous sinus. The interdural peeling procedure is a widely used surgical technique in transcranial surgery. Transcranial peeling can be initiated at V1, V2, or V3 bounding the anteromedial and anterolateral triangles and is not known to be associated with a risk for motor cranial nerve affection. Transient or permanent cranial nerve affection occurs only if manipulations are done through the triangles between the nerves in the lateral wall of the cavernous sinus.[7-9] Theoretically, an endonasal, interdural peeling

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Table 1. Descriptive Statistics of the Different Measurements Taken.

Measurement	Number of Sides	Minimum	Maximum	Mean
FR-FO MM (mm)	14	8	20	15.21 ± 3.36
FR-FO LL (mm)	14	10	22	18.21 ± 3.45
VC (mm)	14	10.25	21.5	13.01 ± 3.06
Lateral boundary[a]	14	14	21	16.77 ± 2.13
Medial boundary[a]	14	6.5	12	9.41 ± 1.66
Inferior boundary[a]	14	8.5	14.75	11.52 ± 1.82
Superior boundary[a]	14	8.5	20.5	14.89 ± 3.11
Surface area of bony corridor[a]	14	3.5	7.5	4.68 ± 0.97

Abbreviations: FR-FO LL, distance from foramen rotandum to foramen ovale, lateral to lateral end; FR-FO MM = distance from foramen rotandum to foramen ovale, medial to medial end; VC = vidian canal length.
[a]Boundaries in millimeters and surface area in square centimeters of the trajectory of bone removed during the approach.

procedure would allow lateral access to the cavernous sinus without crossing the nerves and hence better exposure of the MCF. Truong et al[10] advocated a transmaxillary approach to the MCF, drilling the greater wing of the sphenoid (GWS) and obtaining cleavage of the dura between the temporal lobe and lateral wall of the cavernous sinus. To the best of our knowledge, the feasibility of endonasal separation of the outer layer of the cavernous sinus has not been assessed in previous studies. This study was conducted to describe an anatomic endonasal instructional model for separation of the dural layers of the lateral wall of the cavernous sinus and the required specific endonasal bony corridor.

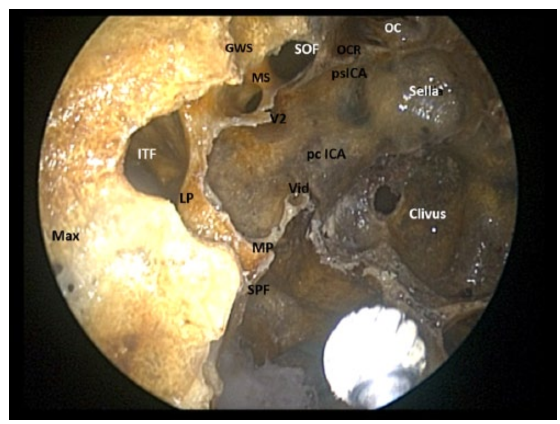

Figure 1. Right side endoscopic drilling of the parasellar region to expose the cavernous sinus medially and anteriorly. Bone between wide sphenoidotomy and superior orbital fissure (SOF), optic canal (OC), and V2 (maxillary canal extending from foramen rotandum at pterygopalatine fossa to middle cranial fossa [MCF]). GWS, greater wing of sphenoid; ITF, infratemporal fossa; LP, lateral pterygoid process; Max, posterior wall of maxillary sinus; MP, medial pterygoid process; MS, maxillary strut; OCR, opticocarotid recess; pc ICA, paraclival internal carotid artery; psICA, parasellar internal carotid artery; SPF, sphenopalatine foramen; Vid, vidian canal.

Methods

This research protocol was approved by the appropriate ethics committee in accordance with the Declaration of Helsinki of 1975 (revised, Hong Kong, 1989). The sides of 14 dry adult skulls and 10 adult cadaveric heads were drilled and/or dissected endonasally. A nasal endoscope (Karl Storz, Tuttlingen, Germany) 4 mm in diameter and 18 cm in length, exclusively with 0°, was used. Digital pictures were reproduced by coupling the endoscope to a video camera and using a computer capture system. Approval from the local ethics committee was obtained.

Dry Skull Drilling Technique

The maximum part of the GWS was exposed without disrupting the orbit. Different measurements between bony landmarks and the surface area of the resulting bony corridor (pterygoid base and adjoining part of the GWS) were obtained using a Vernier caliper (Table 1, Figures 1 and 2).

Cadaveric Dissection

A classic anterior ethmoidectomy, wide middle meatal antrostomy, complete posterior ethmoidectomy, and sphenoidotomy were performed, exposing the skull base. The posterior part of the bony septum was removed together with the intersphenoid septum. The sphenopalatine foramen and the sphenopalatine artery were then identified and carefully dissected. The middle turbinate was resected. The posterior wall of the maxillary sinus was removed starting from its upper medial quadrant, and the fat and branches of the sphenopalatine artery were cut and displaced laterally to expose the vidian canal, foramen rotandum, superior orbital fissure (SOF) and the medial and lateral pterygoid processes. V2 was identified in the pterygopalatine fossa (PPF) and traced anteriorly to the inferior orbital nerve (ION). This necessitated extension of the window in the posterior wall of the maxilla upward to open inferior orbital fissure (IOF).[11] The

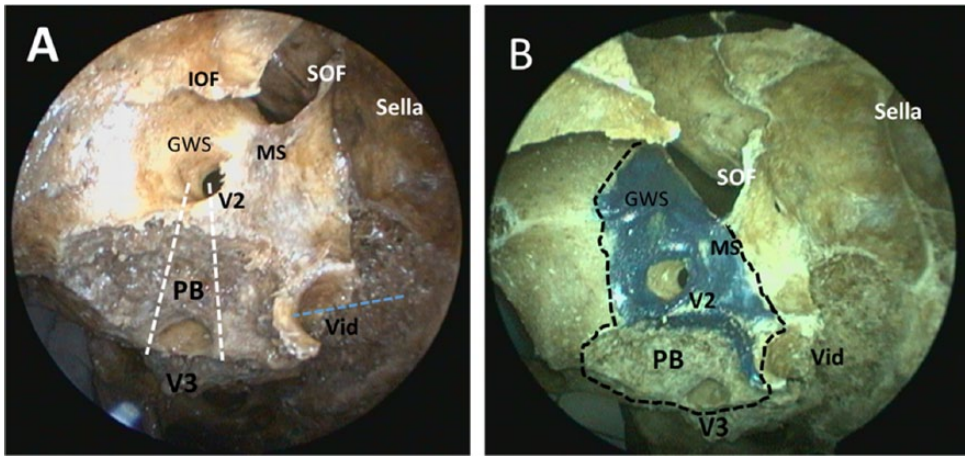

Figure 2. (A) Right side, transpterygoid approach. The medial pterygoid process is drilled to expose the vidian canal (Vid). The pterygoid base (PB) is drilled inferomedial to the Vid to gain more space. Full skeletonization of lacerum internal carotid artery and exposure of quadrangular space are not needed unless necessary. The PB is further drilled below the maxillary division (V2). The lateral pterygoid process is drilled to expose the medial and lateral lips of the foramen ovale containing the mandibular division (V3). The white dotted lines show measurement between V2 and the medial and lateral lips of Foramen ovale containing V3; the blue dotted line shows the length of the Vid. (B) Right side, the inferior orbital fissure (IOF) must be opened to reveal the maximum part of the greater wing of the sphenoid (GWS) that can be drilled without disrupting the orbit. The black dotted area shows the bony corridor formed by the GWS and transpterygoid approach through the PB without violating the pterygoid fossa containing pterygoid muscles. MS, maxillary strut.

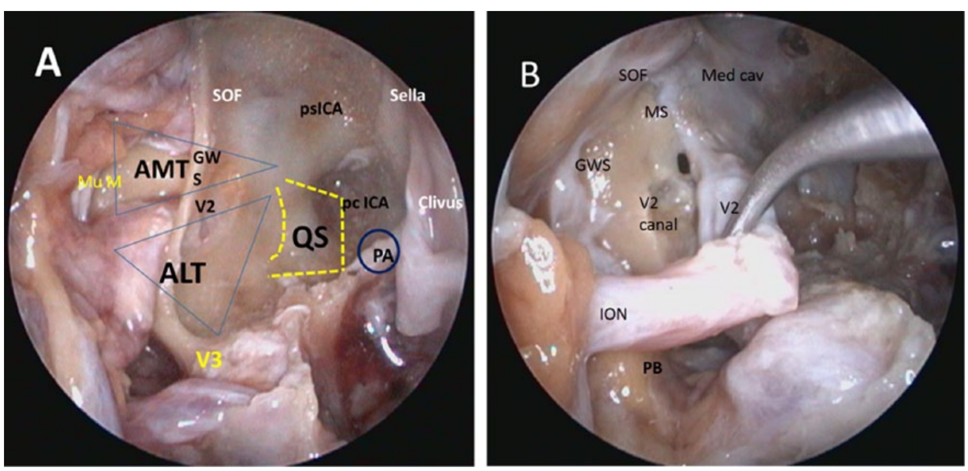

Figure 3. (A) Right side, endonasal corridors to middle cranial fossa: anteromedial triangle (AMT) and anterolateral triangle (ALT) (blue triangles), quadrangular space (QS) (yellow dotted area), and petrous apex (PA) (blue circle). Superior orbital fissure (SOF), parasellar internal carotid artery (psICA), paraclival internal carotid artery (pc ICA), and mandibular division (V3) posterior to lateral pterygoid process. Muller's muscle (Mu M) was dissected to reveal the greater wing of the sphenoid (GWS), the maxillary division (V2). (B) Right side, mobilization of V2 and the proximal part of the infraorbital nerve (ION) with proper exposure of the superior orbital fissure (SOF) and a substantial portion of the greater wing of sphenoid (GWS). V2 was mobilized up and down to allow drilling the pterygoid base (PB) and GWS, respectively. Med cav, medial wall of the cavernous sinus; MS, maxillary strut.

GWS lateral to the maxillary strut (MS) was exposed[12] by blunt dissection of the fibromuscular tissue (Muller's muscle), obliterating the IOF superiorly and laterally.[13] The V2 canal (foramen rotundum at PPF to MCF) was drilled using a diamond burr. The V2 was further exposed distally in the PPF until it became the ION. V2 mobilization was done in all cadaveric heads without transgressing the infraorbital nerve. Figure 3B shows mobilization of V2 and the proximal part of the infraorbital nerve with proper exposure of the SOF and a substantial portion of the GWS. V2 was

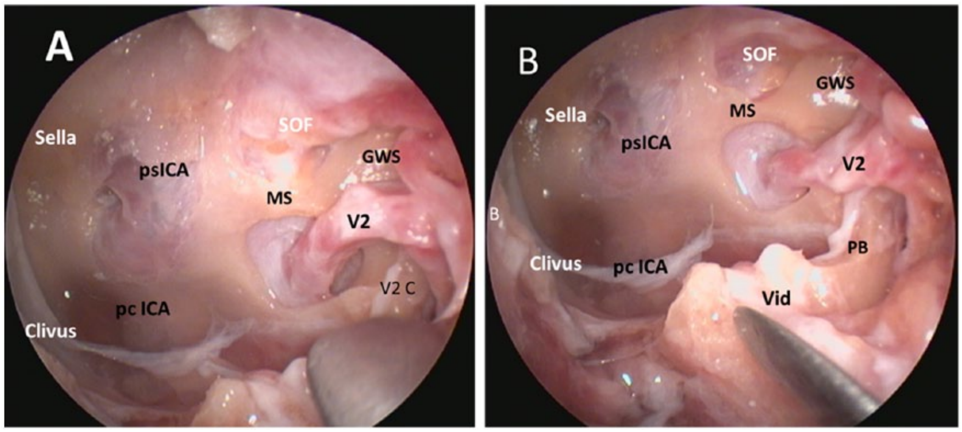

Figure 4. (A) Left side, after removal of posterior wall of maxilla, the maxillary division (V2) is mobilized and transposed after drilling V2 canal (V2 C). The superior orbital fissure (SOF) and medial part of the greater wing of the sphenoid (GWS) and maxillary strut (MS) are exposed to gain space to the middle cranial fossa (MCF) and lateral to the cavernous sinus. (B) Left side, pterygoid base (PB) is better exposed after mobilization of V2 outside its canal. The vidian canal (Vid) represents the medial boundary of transpterygoid approach. pc ICA, paraclival internal carotid artery; psICA, parasellar internal carotid artery.

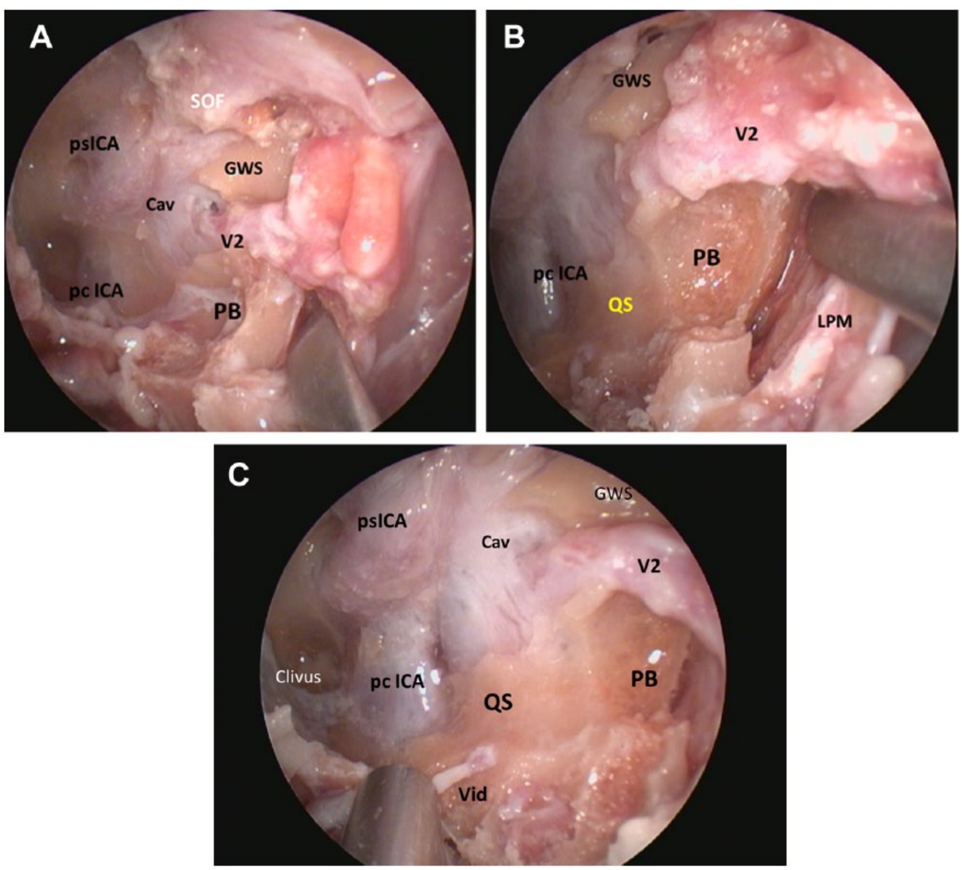

Figure 5. (A,B) Left side, the medial wall of the cavernous sinus (Cav) and maxillary strut were removed. The pterygoid base (PB) is partially drilled, and the lateral pterygoid muscle (LPM) is displaced subperiosteally to allow drilling of the lateral pterygoid process and exposure of the mandibular division. (C) Left side, medial extension of transpterygoid approach inferomedial to the vidian canal (Vid) and nerve. The quadrangular space (QS) is not fully exposed unless necessary. GWS, greater wing of the sphenoid; pc ICA, paraclival internal carotid artery; psICA, parasellar internal carotid artery; QS, quadrangular space. V2, maxillary division.

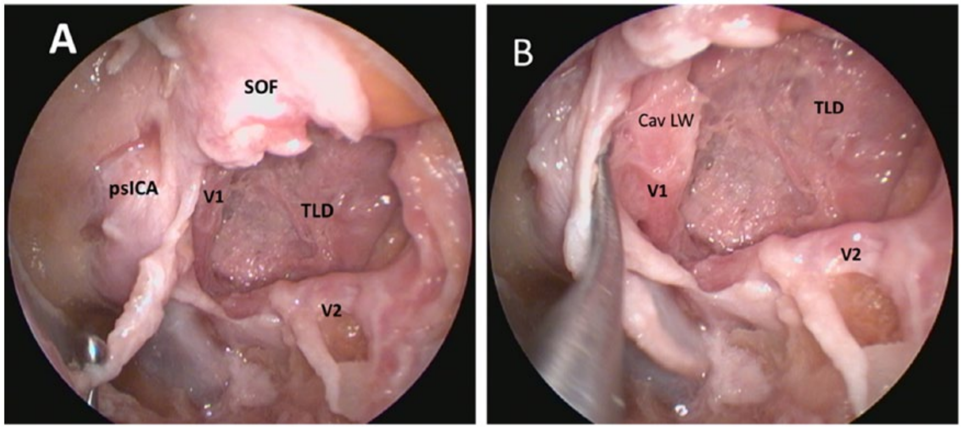

Figure 6. (A,B) Left side, the endonasal peeling procedure. The dura is cut lateral to the maxillary division (V2) to separate the temporal lobe dura (TLD) from the lateral wall of the cavernous sinus (Cav LW). The ophthalmic division (V1) is first encountered and together with V2 followed to the gasserian ganglion. psICA, parasellar internal carotid artery. SOF, superior orbital fissure.

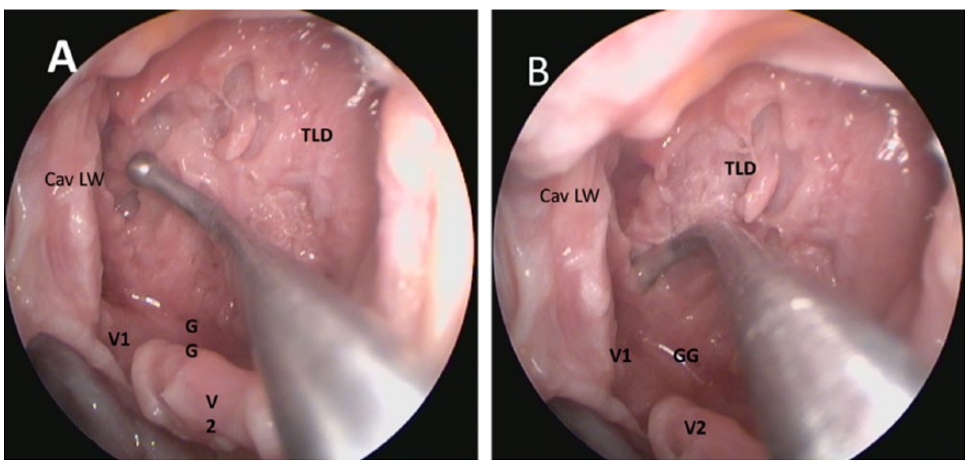

Figure 7. (A,B) Sharp dissection is needed to complete separation of lateral wall of the cavernous sinus (Cav LW) after encountering the ophthalmic division (V1). Trochlear and oculomotor nerves are not exposed unless the inner dural layer is interrupted. The gasserian ganglion (GG) becomes more apparent after complete separation of the 2 dural layers of the Cav LW. TLD, temporal lobe dura; V2, maxillary division.

mobilized up and down to allow drilling of the pterygoid base and the GWS, respectively.

This wide exposure of V2 allows its mobilization downward and further exposure of the GWS, MS, foramen rotandum, and pterygoid base. The bone over the medial wall of the cavernous sinus is removed, exposing the dura. The MS and maximum medial part of the GWS were drilled to open the SOF using Kerrison forceps. The remaining part of the pterygoid base, containing the V2 canal, is drilled to a maximum without violating the pterygoid muscles. Finally, the dura lateral and medial to the cavernous sinus is exposed and pedicled on the mobilized V2 (Figures 3-5).

The Peeling Procedure. The dura was cut lateral and very close to V2 to begin the separation of the dural layers of the lateral wall of the cavernous sinus. This was done by blunt dissection, elevating the dura away from V2 using a small septal dissector to establish a plane between the 2 layers of lateral wall of cavernous sinus to avoid entering either the cavernous sinus or the thecal space. The process was continued from distal to proximal until the junction of V2 and the gasserian ganglion was reached. At this point, peeling continued in the superior direction to expose V1 (early branching of V1 makes this step difficult). Here, the plane must be continued in a sharp manner, using long microscissors to continue the exposure of V1. Maintaining the outer layer of

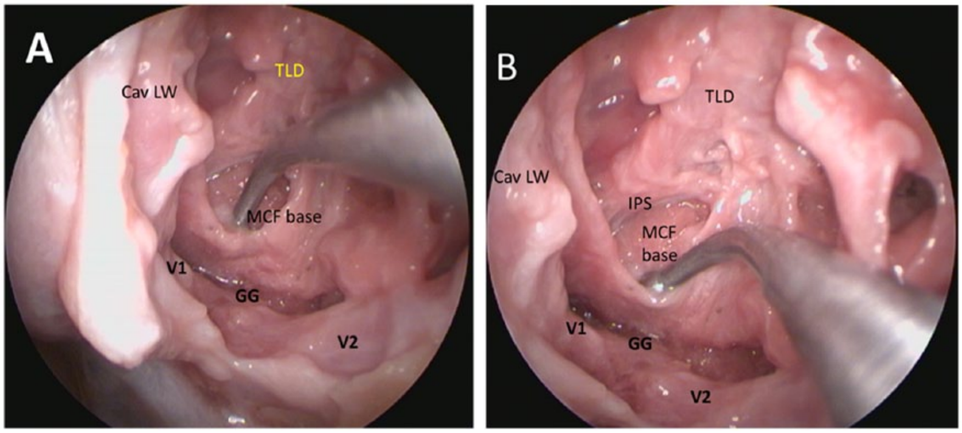

Figure 8. (A,B) Left side, exposure of middle cranial fossa (MCF) bony base. The inferior petrosal sinus (IPS) is the posterior limit of dissection. Cav LW, cavernous sinus lateral wall; GG, gasserian ganglion; IPS, inferior petrosal sinus; TLD: temporal lobe dura; V1, ophthalmic division; V2, maxillary division.

the lateral wall of the cavernous sinus helps protect V1 along with the abducent nerve and the trochlear nerve, which is usually very thin. Dissection was continued medially and superiorly until the lateral border of the anterior clinoid process was reached. The outer layer of the cavernous sinus together with the temporal dura was dissected and displaced posteriorly, superiorly, and laterally, while the cavernous sinus was gently countertracted and medially pedicled on V2. Dural dissection can extend posteriorly above the anterior surface of the petrous bone to the superior petrosal sinus and laterally in a subtemporal plane to V3 (Figures 6-8).

Finally, the medial wall of the cavernous sinus was incised along an imaginary line starting from the decussation of V2 with the paraclival ICA to the SOF. The integrity of the oculomotor, abducent, and trochlear nerves in the motor triangle as well as the inner dural membranous layer of the cavernous sinus was checked. The sensory triangle contains V1, V2, adipose tissue, and the venous connection with the orbit (Figure 9).

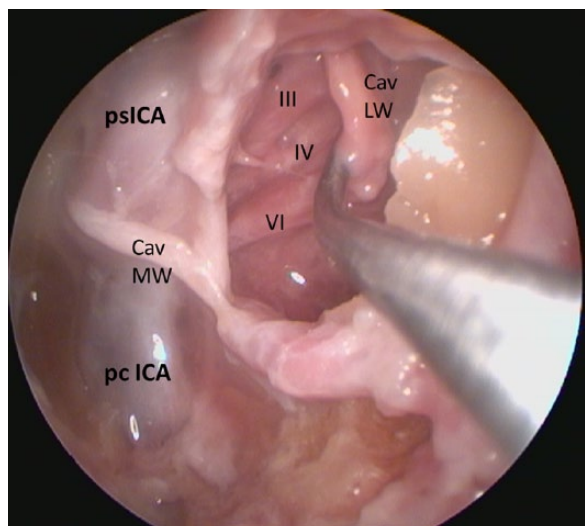

Figure 9. Left side, opening of medial wall of cavernous sinus (Cav MW) to check integrity of the motor cranial nerves, oculomotor (III), trochlear (IV), and abducent (VI), and the lateral wall of cavernous sinus (Cav LW). pc ICA, paraclival internal carotid artery; psICA, parasellar internal carotid artery.

Results

Dry Skulls

The mean area of the bony corridor resulting from drilling of the MS, GWS, and pterygoid base was 4.68 ± 0.97 cm^2, the mean V2-to-V3 distance was 5.21 ± 3.36 mm medially and 18.21 ± 3.45 mm laterally, and the mean vidian canal length was 13.01 ± 3.06 mm (Table 1).

Cadaveric Dissection

Separation of the outer meningeal and inner membranous dural layers of the lateral wall of the cavernous sinus at the MCF was feasible with a combination of blunt and sharp dissection in the 10 cadaver head sides. The integrity of the dural layers of the lateral cavernous wall and cranial nerves were also preserved in the 10 head sides (Figure 9).

Discussion

The endonasal corridors to the MCF include the petrous apex, quadrangular space, and the anteromedial and anterolateral triangles. The petrous apex corridor requires displacement of the paraclival ICA and probably allows drainage and biopsy. The quadrangular space offers a limited exposure to

Meckel's cave tumors, and its size is much affected by the protrusion of the ICA in the cavernous sinus.[14] The anteromedial triangle is very small and close to the motor nerves of the cavernous sinus.[15] The anterolateral triangle is the largest corridor but requires violation of the muscular compartment of the infratemporal fossa.[2] The cavernous sinus represents an obstacle to medial to lateral extension of endonasal MCF approaches.[1] Amin et al[12] proposed description of the medial wall into anteroinferior sensory and posterosuperior motor triangles. The motor triangle of the medial wall of the cavernous sinus contains relatively dense motor nerves and their blood supply. Dissection and/or crossing through these motor nerves to the lateral wall of the cavernous sinus intradurally is impractical, as it may lead to cranial neuropathy or even ICA injury. On the other hand, the sensory triangle is the anteroinferior part of the medial wall of the cavernous sinus, showing relatively spaced sensory branches V1 and V2 of the trigeminal nerve. Proper knowledge of the dural layers, cavernous sinus ligaments, venous channels, and cavernous ICA allowed radical resection of pituitary adenomas invading the medial compartment of the cavernous sinus.[15-17] Transcranial separation of the 2 dural layers of the lateral wall of the cavernous sinus (peeling procedure) allows access to the medial MCF bony base.[7-9]

Endonasal access to the extra- and intradural MCF demands crossing the dura of medial and lateral walls of the cavernous sinus.[1,2] The anteromedial triangle is bounded anteriorly by a small bone trajectory (known as the MS) between the SOF and V2 canal. Grewal et al[18] estimated the anteroposterior length of the MS to be approx. 5 mm, whereas Amin et al[12] estimated approximately 10 mm in the vertical dimension. The small dimensions of the MS prevent safe medial-to-lateral drilling of the greater wing below the SOF and exposure of its vital neurovascular structures. Consequently, it is safer to perform complete mobilization of V2 outside its canal and its inferior displacement to allow better exposure of the GWS and pterygoid base. The V2 along its whole course is an important landmark in skull base surgery, as it represents the lower boundary of the medial wall of cavernous sinus. Amin et al[12] described V2 into the cavernous part and the V2 canal. Abhinav et al[19] classified V2 into 3 segments: interdural, intracanalicular, and pterygopalatine. Their technique became the standard for dissection of V2 including the intracanalicular segment in endoscopic transpterygoid approaches.[19,20] V2 makes a dip along the dissection course in the PPF before becoming the ION.[21] Proper exposure of the IOF and removal of Muller's muscle will help in dissection of the proximal part of the ION. The authors did not need to transect the ION to expose the SOF or GWS in the dissection. In this study, V2 mobilization allowed safe drilling of the MS and GWS, comfortable drilling of the pterygoid base, and eventually expansion of the inferior and anterior limbs of the anteromedial triangle.[22]

In this study, endonasal dural separation started at V2, which is relatively easy to approach and less risky in comparison with V1 and V3. Further dural separation was lateral to V1 in the interdural plane and therefore is not expected to risk the abducent and trochlear nerves, which are medial to V1. Furthermore retraction during dural separation was mainly toward the temporal lobe dura, away from the cavernous sinus.

The most limiting structure for peeling is the convergence of the motor nerves with V1 anterolaterally at the SOF and annulus of Zinn. The V1, which represents the upper limb of the anteromedial triangle, was estimated to be approximately 15 mm long from the gasserian ganglion to the SOF.[23] In contrast, the V2 is approximately 4 cm long from the gasserian ganglion to the PPF and can be extended in the IOF up to the ION.[12] However, V1, as part of the sensory triangle, protects the abducent and trochlear nerves running above and medial during the separation of the outer layers of the dura.

Several anatomic studies have advocated the feasibility of the anteromedial triangle as the main endonasal entry for the MCF.[23] In the present study, the transposition of V2, expansion of the anteromedial triangle, and separation of the outer meningeal dural layer of the cavernous sinus from the temporal lobe dura led to a substantial increase in the surgical field. Additionally, the floor of the MCF was exposed. In the present study, the mean area of the endonasal bony corridor was 4.68 ± 0.97 cm^2, in comparison with the small area of the anteromedial triangle. The endoscopic peeling procedure allowed protection of the motor nerves while gaining access to the lateral wall of the cavernous sinus. A wider portion of the MCF and the anterior surface of the petrous bone could be exposed. In this study, most of the dissection was of bony structures, apart from V2 mobilization and interdural dissection of the lateral wall of the cavernous sinus. Manipulation of V2 in transpterygoid approaches is associated with hypoesthesia in the face and hard palate, which usually subsides in a few months.[24] The interdural dissection of the lateral wall of the cavernous sinus is a common surgical transcranial technique that is not associated with cranial nerve affection. However, the technique requires high expertise and cadaveric training. Its main disadvantage is marked retraction of the temporal lobe. One advantage of endonasal separation will be avoiding marked temporal lobe retraction.

Truong et al[10] approached the lateral cavernous wall through a transmaxillary approach through the anterolateral triangle. They reported cleavage of the dura between the temporal lobe and cavernous sinus. However, there was limited exposure of the upper and anterior part of the cavernous sinus, which was attributed to defective medial drilling, including the MS. Exposure of the anterolateral triangle necessitated muscular dissection of the infratemporal fossa through at least its medial part, which might be associated with troublesome bleeding from the pterygoid venous plexus during in vivo surgery.

The endoscopic transorbital approaches expose the medial compartment of the MCF and the lateral wall of the cavernous sinus, but these approaches necessitate orbital retraction with fat herniation because of the breach in the orbital periosteum. In addition, these transorbital approaches offer a narrower corridor than the endonasal approaches.[25]

In this study, the bony corridor was fashioned to the maximum size that could be drilled without manipulating the pterygoid muscles. The bony corridor to the MCF could have extended further beyond V3 and the anterolateral triangle, but this would necessitate violating the muscular compartment of the infratemporal fossa, with possible troublesome pterygoid muscle bleeding in vivo.[26]

The area between V2 and V3 forms a triangle representing the pterygoid base. The vidian canal exhibited wide side-to-side variation in our study, which was similarly documented in other studies. These dimensions are important for understanding and performing the transpterygoid component of this approach to its maximum.[27,28]

In live surgery, the transcranial separation of the 2 layers of the lateral wall of the cavernous sinus is associated with some bleeding. This bleeding could be controlled with intracavernous injection of fibrin glue or local hemostatic materials. Similarly, the same procedures for bleeding control can be done endonasally.[29,30] In addition, the peeling procedure done in the endonasal MCF approaches leads to devascularization of pathologies in this region, with early control of the tumor-nurturing blood supply. We emphasize that in endonasal peeling, displacement of the outer cavernous dural layer should be directed laterally toward the temporal lobe to minimize manipulation on the cavernous sinus. The keystone of transcranial and endonasal peeling is preservation of the inner and outer cavernous dural layers. Cavernous motor neuropathies, including the oculomotor, are unlikely to happen if the inner dural layer is not breached. The peeling procedure again needs high expertise and extensive cadaveric training.

We emphasize again that this is a cadaveric feasibility study. Further studies are needed to evaluate the feasibility of this endonasal peeling procedure in live surgery.

Conclusions

This study provides a better understanding of the endonasal MCF approach. Application of the peeling procedure will allow access to the lateral wall of the cavernous sinus and exposure of the MCF base without crossing the nerves.

Declaration of Conflicting Interests

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