"Sagittal Crest": Definition, Stepwise Dissection, and Clinical Implications From a Transorbital Perspective

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Received, July 1, 2021.
Accepted, November 27, 2021.
Published Online, March 1, 2022.

BACKGROUND: The recent development of the superior eyelid endoscopic transorbital approach (SETOA) offered a new route for the management of cavernous sinus and middle cranial fossa tumors. As a result, a constant anatomic landmark of the surgical pathway after drilling the medial edge of the greater sphenoid wing (GSW) is represented by a triangular-shaped bone ridge appearing as a "crest."

OBJECTIVE: To perform an anatomic study to define this surgical landmark, named the "sagittal crest" (SC) as seen from the transorbital endoscopic view.

METHODS: Four adult cadaveric specimens (8 sides) were dissected performing an endoscopic transorbital approach to the middle fossa and the SC was removed to perform interdural opening of the cavernous sinus. Computed tomography scans were made before and after removal of the SC to perform quantitative analysis and building a 3-dimensional model of the bone resection of the GSW via the SETOA.

RESULTS: The SC is a bone ridge triangle shaping dorsally the superior orbital fissure resulting as the residual fragment after drilling the lateral aspect of the greater sphenoid wing. Predissection and postdissection computed tomography scans allowed to objectively assess SC features and dimensions (mean 1.08 ± 0.2 cm).

CONCLUSION: The SC is a constant anatomic landmark constituted of the residual medial portion of the GSW. Complete resection of this key landmark provides adequate working space and appears to be mandatory during SETOA to guide the subsequent interdural dissection of the lateral wall of cavernous sinus.

KEY WORDS: Transorbital approach, Eyelid approach, Surgical anatomy, Middle cranial fossa

Operative Neurosurgery 22:E206–E212, 2022 https://doi.org/10.1227/ons.0000000000000131

In recent years, the development of the superior eyelid endoscopic transorbital approach (SETOA) has emerged as an innovative route to access, from a ventral perspective, the paramedian and lateral areas of the middle fossa.[1-3] Besides, the transorbital route may be thought as a complementary pathway to endoscopic endonasal approach (EEA) to "overcome" its paramedian limitations. In fact, recently, SETOA appeared to be suitable to treat parasellar and paraclival lesions involving the cavernous sinus[4,5] and the Meckel cave,[5-8] alone or in combination with the EEA.[6] As a matter of fact, the SETOA offers a new anatomic perspective of the middle cranial fossa (MCF) that can cause confusion. Furthermore, the authors noted that after a lateral-to-medial drilling of the greater sphenoid wing, a bone ridge with sagittal orientation constantly remains between the temporal dura medially, the periorbita (PO) laterally, and cranially to the foramen rotundum (FR). However, it must be emphasized that, as far as constant, this surgical landmark is created artificially during the approach per progressive drilling of the greater sphenoid wing (GSW) and it is not present in "native anatomy."

This study aims to refine and detail this new landmark, herein named as "sagittal crest" (SC),

ABBREVIATIONS: EEA, endoscopic endonasal approach; **FB,** frontal bone; **FO,** foramen ovale; **FR,** foramen rotundum; **FS,** foramen spinosum; **GG,** gasserian ganglion; **GSW,** greater sphenoid wing; **GWS,** greater wing of the sphenoid; **ICAc,** intracavernous segment of internal carotid artery; **LP,** levator palpebrae; **LWS,** lesser wing of the sphenoid; **MCF,** middle cranial fossa; **MMA,** middle meningeal artery; **MOB,** meningo-orbital band; **OOM,** orbitalis oculi muscle; **OR,** orbital roof; **PO,** periorbita; **SC,** sagittal crest; **SE,** superior eyelid; **SETOA,** superior eyelid endoscopic transorbital approach; **SOF,** superior orbital fissure; **TD,** temporal dura; **TM,** temporalis muscle.

that demonstrated its surgical relevance during the SETOA.[6,7] Finally, another important concept is the reproducibility of the surgical exposure of the SC that could be considered "operator sensitive"; to overcome such limitations, the authors proposed step-by-step dissection, quantitative analysis to calculate the exact dimensions of the SC, using a neurovigation tracking system, and finally an illustrative video.

Considering the above, the depiction of "critical anatomy," refined through laboratory anatomic rehearsal and 3-dimensional (3D) computed tomography (CT)–based reconstructions, stands crucial to achieve proper surgical access to the cavernous sinus via transorbital corridor.

METHODS

Anatomic dissections were performed at the Laboratory of Surgical Neuroanatomy University of Barcelona, Barcelona, Spain, and at the Laboratory of Neuroscience of the European Biomedical Research Institute of Salerno Institute, Salerno, Italy. The ethics committee approval was obtained by all the institutions involved in this study. Permission was granted for the publication of cadaveric images. Six adult cadaveric embalmed and injected with red latex specimens (12 sides) were accessed. All specimens underwent a multislice helical CT scan (Siemens SOMATOM Sensation 64) before and after SC removal and complete drilling of the greater wing of the sphenoid. Five screws were previously implanted in the specimen's skull as permanent bone reference markers to allow coregistration with the neuronavigation system (Medtronic, Inc. Surgical Technologies).

The initial microsurgical dissections steps were performed under microscopic visualization, for illustrative purposes (OPMI, Zeiss), and then continued under endoscopic visualization by means of a rigid 4-mm-diameter endoscope, 14 cm in length, with 0° and 30° rod lenses (Karl Storz). A critical review of the surgical videos of the most recent cases operated through a SETOA at Neurosurgical Department of the Hospital Clinic, Barcelona, Spain, was performed. Among several surgical cases supporting the technique of this study, the clinical application of the SC crest removal was illustrated in a case of a left trigeminal schwannoma. The idea to choose a pure extra-axial tumor without any osseous or meningeal involvement provides us the opportunity to clearly demonstrate in a realistic scenario the key surgical steps that are needed to perform a total removal of the SC (Video).

Quantitative Analysis

Using the BrainLAB navigation system (BrainLab Curve) and Osirix software (Osirix Software, Osirix Foundation), it was possible to quantify

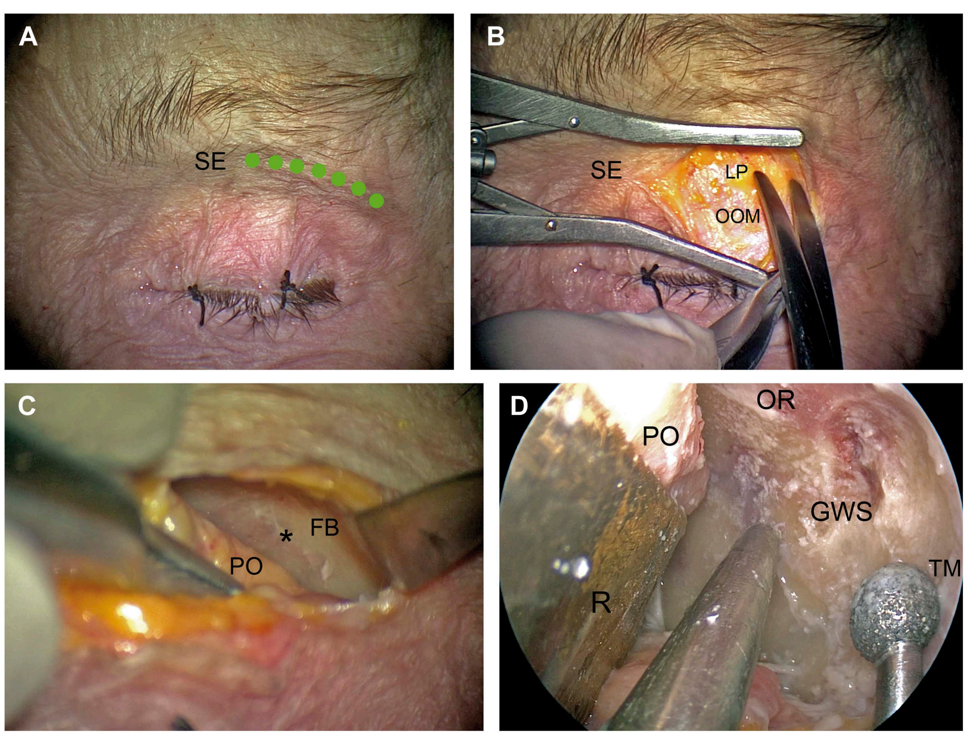

FIGURE 1. *Microscopic view of a left transorbital superior eyelid approach:* **A**, *Skin incision is made through an eyelid wrinkle.* **B**, *Sharp dissection of subcutaneous planes.* **C**, *Lateral orbital wall periosteum is cut and dissected to expose the subperiosteal plane.* **D**, *Lateral aspect of the superior and inferior orbital fissures. A malleable retractor is used to protect and displace the orbital content medially. *Frontozygomatic suture. FB, frontal bone; GWS, greater wing of the sphenoid; LP, levator palpebrae; OOM, orbitalis oculi muscle; OR, orbital roof; PO, periorbita; R, retractor; SE, superior eyelid; TM, temporalis muscle.*

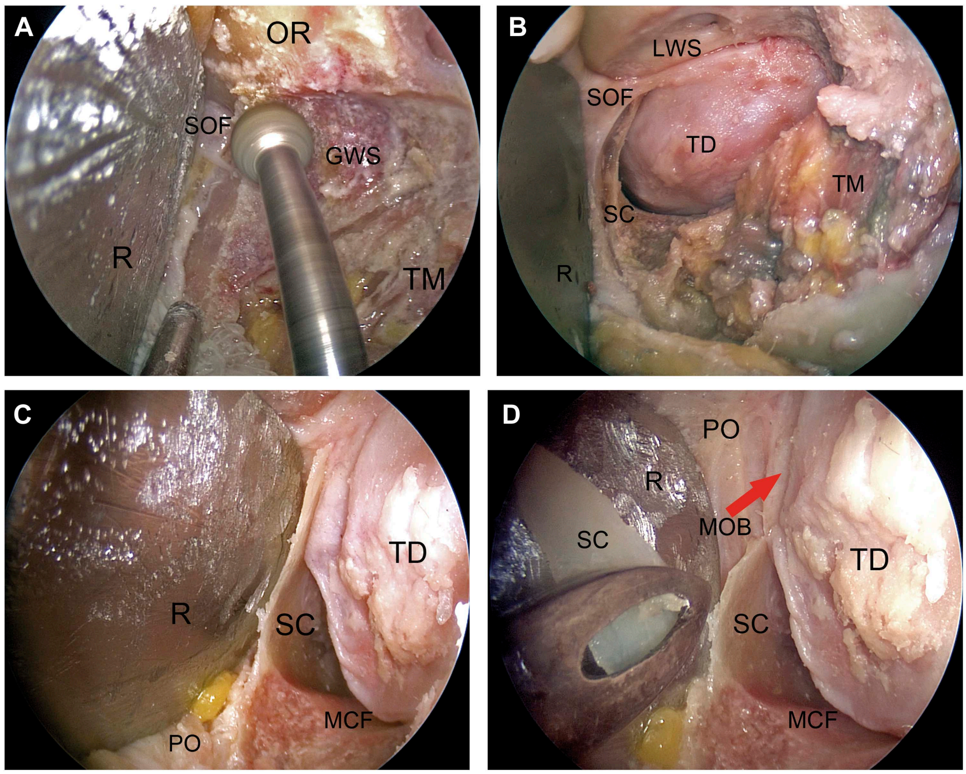

FIGURE 2. *Endoscopic view of a left transorbital approach:* **A**, *Drilling the GWS in a supero-lateral to infero-medial direction toward the lateral margin of the SOF.* **B**, *Exposure of the temporal dura and the SOF; the SC is located in between.* **C**, *A surgical retractor is placed between SOF and SC.* **D**, *Partial removal of SC, fracturing the apex, to identify the meningo-orbital band to perform "interdural" dissection. GWS, greater wing of the sphenoid; LWS, lesser wing of the sphenoid; MCF, middle cranial fossa; MOB, meningo-orbital band; OR, orbital roof; PO, periorbita; R, retractor; SC, sagittal crest; SOF, superior orbital fissure; TD, temporal dura; TM, temporalis muscle.*

the exact dimension of the SC, based on the amount of bone removal of the GSW. All data were retrieved from predissection and postdissection CT scans. Furthermore, the virtual 3D model related to GSW removal via the transorbital pathway was created using Amira Visage Imaging (Amira Visage Imaging Inc).

RESULTS

Stepwise Anatomic Description of the Endoscopic Transorbital Route to Middle Fossa—Role of the SC

A superior eyelid (SE) approach was performed, as previously described by our group in previous publications.[1,2] A tarsorrhaphy was routinely performed before dissection. Skin incision was made through an eyelid crease. Dissection was made in the suborbicularis plane sparing the orbicularis muscle and raising the skin-muscle flap superolaterally to expose the lateral orbital rim and the frontozygomatic suture. The periosteum was cut, at the level of the orbital rim, and dissected sharply toward the orbit, where it becomes continuous with the PO, proceeding the dissection in the subperiosteal plane until the lateral aspect of the superior and inferior orbital fissures were reached. A malleable retractor was used to protect and displace the orbital content medially. From this point, the procedure was run under endoscopic assistance, using a 0° lens endoscope as the sole visualization tool (Figure 1A-1C).

Step 1

After a proper window has been created to obtain an orbital corridor, a diamond drill was used to perform the orbital craniectomy, started on the lateral orbital wall, through the body of the zygoma, until the temporalis muscle, covered by its fascia, was exposed in the temporal fossa. This step is crucial to create adequate work room for further dissection (Figure 1D).

Step 2

The ventral aspect of the GSW was drilled in a superolateral to inferomedial direction toward the lateral margin of the superior orbital fissure (SOF). The limits of GSW drilling are the following:

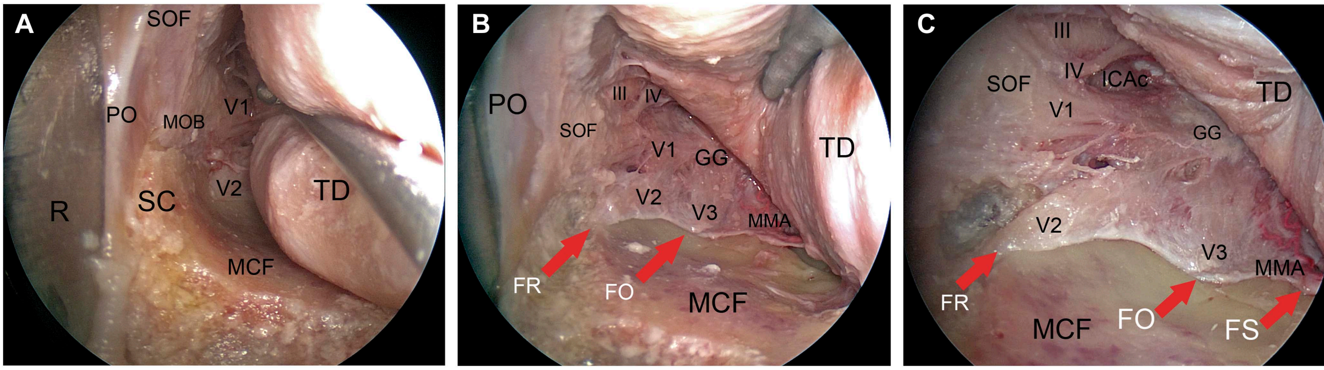

FIGURE 3. *Endoscopic view of a left transorbital approach:* **A**, *Partial removal of SC apex. Initial interdural dissection is performed to show the posterior limit of SC corresponding to the exit of V2 branch from the FR.* **B**, *Complete resection of SC allows a straightforward interdural dissection of the cavernous sinus.* **C**, *Dissection of the lateral wall of the cavernous sinus exposing the gasserian ganglion and the middle meningeal artery exiting the foramen spinosum. FO, foramen ovale; FR, foramen rotundum; FS, foramen spinosum; GG, gasserian ganglion; ICAc, intracavernous segment of internal carotid artery; III, third cranial nerve; IV, fourth cranial nerve; MCF, middle cranial fossa; MMA, middle meningeal artery; MOB, meningo-orbital band; OR, orbital roof; PO, periorbita; R, retractor; SC, sagittal crest; SOF superior orbital fissure; TD, temporal dura; V1, ophthalmic nerve; V2, maxillary nerve; V3, mandibular nerve.*

superiorly the lesser sphenoid wing, inferiorly the floor of the MCF, and laterally the temporal fossa (Figure 2A).

Step 3

The sphenoidal bone drilling was ultimate in a lateral to medial direction removing the lateral margin of the SOF and obtaining a complete exposure the dura mater of the temporal pole (Figure 2B). At this point, the SC can be easily identified. It is a bone ridge, triangular in shape, projecting in an anteroposterior direction dividing the meningo-orbital band form the medial temporal dura (Figure 2C). Subsequently, dissections were stopped and CT scans were performed to obtain a predissection volumetric CT-based reconstruction of the SC.

Step 4

The approach is then continued with a complete bone drilling of the GSW: the SC removal was accomplished biting off the apical portion of the crest (Figure 2D) and then drilling the base until the anterior aspect of FR (Figure 3A and 3B). Then, an interdural dissection was carried out, detaching the dura proper layer of the temporal pole off the lateral wall of the cavernous sinus up to the exposure of the trigeminal nerve (Figure 3C). Finally, a postdissection CT scan was performed to create a CT-based model of the SC as a result of the superimposition of predissection and postdissection digital imaging and communications in medicine images of specimens. This computer-based depiction helped defining the exact 3D boundaries of SC, created by the progressive drilling of the greater sphenoidal wing.

According to those anatomic findings, the SC can be defined by 3 key landmarks: (1) the base, ie, located at the exit of the maxillary nerve from the FR; (2) the anterior edge, ie, an imaginary line passing where the GSW turns from a coronal to a sagittal plane; and (3) the posterior edge ie, free, pointing toward the interdural plane of cavernous sinus (Figure 4).

Quantitative Assessment of Sagittal Crest

Quantification of the SC dimensions was based on the amount of bone removal between the CT scans performed before, during, and after dissections. The average area of SC was found to be 1.08 ± 0.2 cm (Amira Visage measurement tool; Amira Visage Imaging Inc), considering the crest as a scalene triangle. Virtual 3D model of the bone reconstruction corresponding to the SC is shown in Figure 5.

DISCUSSION

In the past decades, remarkable advances in the endoscopic endonasal techniques have paved the way toward a safer and more effective access to the skull base.[9-15] On one hand, the endonasal approach has added extra versatility in terms of exposure and surgical freedom for the treatment of midline lesions[10,16-19]; on the other, it presents some limitations when approaching the lateral skull base, mostly because internal carotid arteries and cranial nerves represent a tough anatomic barrier.[20-22]

Therefore, a continuous progress of anatomic knowledge and advances in surgery and technology have allowed and encouraged the development of multiportal approaches for alternative, minimally invasive access to the skull base.[23-25] However, the "multiportal" access concept perfectly fits the recent paradigm shift of skull base surgery: the achievement of the maximum efficacy with a minimal approach-related morbidity.[26-29] Optimizing surgery by combining multiple ports allows to optimize visualization, trajectory, and working distance, and to maximize the working space between the surgeon's hands and instruments.[6,25,30] In this context,

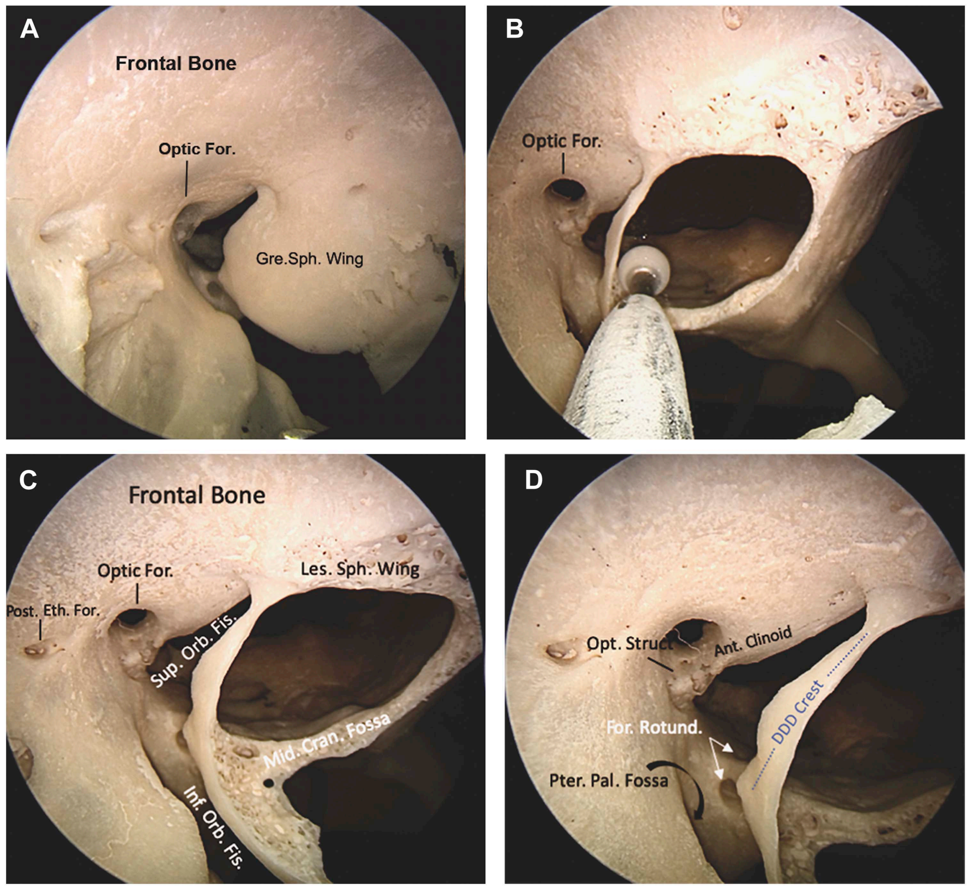

FIGURE 4. *Skull dissection, showing the anatomic relationships of the sagittal crest on the left side.* **A**, *Intraorbital view of the bone anatomy.* **B**, *Resection of the greater sphenoid wing until the lateral margin of the superior orbital fissure is reached.* **C**, *Magnification, showing the middle cranial fossa access through GSW drilling, and the residual medial bony ridge of the GSW known as the "sagittal crest."* **D,** *Sagittal crest or "DDD" crest (from the surnames of the senior authors: de Notaris, Di Somma, and Dallan) anatomic relationships. GSW, greater sphenoid wing.*

the SE transorbital approach appeared to be a natural complementary route to the endonasal pathway, providing an avenue that gets access to paramedian space. These ideas, well defined in the anatomic laboratory setting,[1,2,4,8,31-33] boosted the endoscopic transorbital approach to access, in clinical practice, the lateral portion of the middle skull base, particularly cavernous sinus and Meckel cave lesions.[5-7] In selected clinical situations, this technique has been reported as safe, offering better access and visualization compared with transcranial or EEAs, and retains the benefits of minimally disruptive surgery.[7,34,35]

Anatomic and Clinical Relevance of the SC

The SETOA allows to gain a favorable access to the MCF through a minimally invasive SE approach and the bone drilling of the lateral orbital wall. Bone drilling starts from the zygomatic bone exposing the temporalis muscle to earn enough space to accommodate the surgical instrument, and thereafter, complete removal of the ventral aspect of the GSW, ie, a crucial step to gain access to MCF. However, the ventral surface of the GSW ends medially with the SC, separating the PO from the dura mater of the mesial temporal pole. Thus, at the end of the GSW drilling, this "last" bone plate is at high risk to be unrecognized and left in place, making it difficult to disclose the cavernous sinus. Moreover, the SC appears to be a constant surgical landmark to find the meningo-orbital band.

Indeed, the lateral wall of the cavernous sinus is composed of 2 layers: the outer layer is made of the medial temporal dura, whereas the inner layer is composed of the perineurium and connective tissue of the cranial nerves. Those 2 layers split from each other at the level of the SOF, where the cranial nerves comprising the inner layer continue inside the posterior orbit.

Along the lateral margin of the SOF, where the GSW changes its orientation to a sagittal plane, the meningeal layer of the dura mater became contiguous with the periosteal layer of the PO.[36-38]

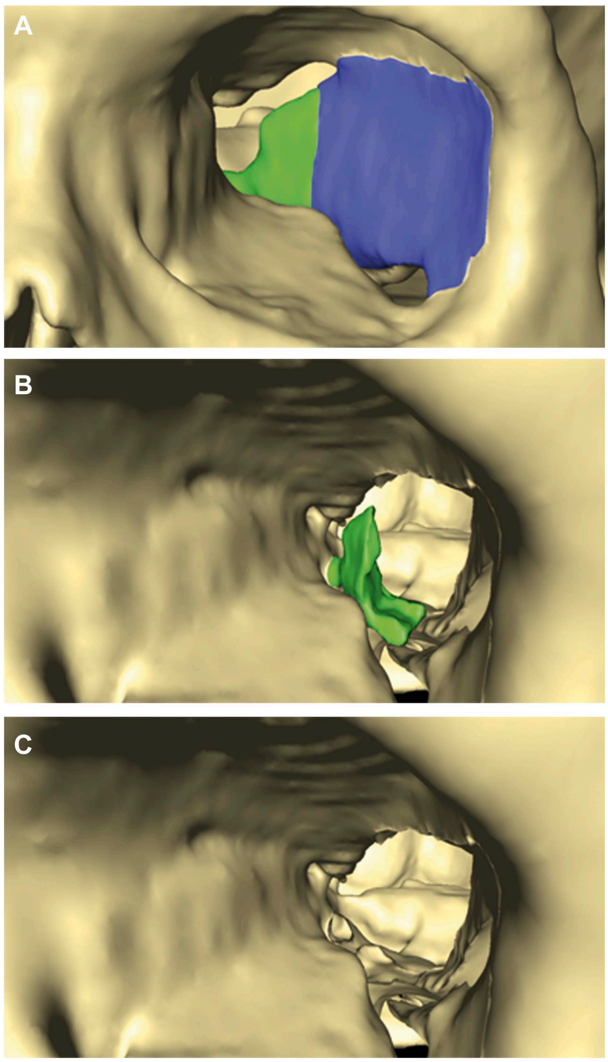

FIGURE 5. *Virtual 3-dimensional model based on the specimen's CT scans performed before and after dissection illustrates different amount lateral orbital wall removal.* **A**, *Lateral orbital walls are shown from a ventral perspective. Blue-colored bone corresponds to the lateral orbital wall resection obtained in the first steps of dissection, exposing the temporal dura until the superior orbital fissure. Green bone corresponds to the sagittal crest before,* **B** *and after its complete resection,* **C**.

Therefore, resection of the SC opens the gate to the starting point to dissect the lateral wall of cavernous sinus in a pure interdural fashion. The favorable working angle offered by the ventral transorbital perspective allowed a "natural" dissection of this interdural plane; indeed, working accurately in this plane, it is possible to inspect the cavernous sinus lateral wall without opening the venous spaces or manipulating cranial nerves.

When considering the clinical setting, it has to be underlined that the most complex step of the SETOA, for both intradural and extradural pathologies invading the cavernous sinus, is to find the starting point to enter the interdural space to avoid cranial nerve injury. The identification of the SC represents the key "anatomic point" to split the meningeal and the periostal layers and find a clear interdural plane to accomplish the dissection. Having a clear bone marker, to localize the interdural plane, plays a very important role whether in case of extradural pathology, such as meningiomas or schwannomas, or even in case of lesions that invade the inner cavernous membrane, such as tumors of the orbital apex or the Meckel cave, in which the invasion of the interdural plane might preclude a clear and safe peeling. Indeed, the understanding and recognition of this "key anatomic landmark," for the SETOA, can guide the surgical treatment for those pathologies, located in a region of difficult surgical access, even when there is a major "subversion" of the anatomy.

Limitations

Our study harbors some limitations related to cadaveric study. The first is the stiffness that may occur to the cadaveric specimens, that, by the way, affects more the cerebrum compared to soft tissues (as the orbital content) or bones. Therefore, despite the changes in tissue characteristics, cadaveric stiffness seems to have a lesser impact on the anatomical structures involved in this study. Second, anatomical studies focusing on TONES could not properly evaluate the pressure of orbital content retraction, despite several clinical studies confirmed the feasibility of these approaches and the remarkable tolerance of the orbit to retraction. Third, the number of cadaveric specimens used in this study could be not sufficient as a sample. Nonetheless, we were able to find our landmark constantly, and to validate our data in the clinical setting, demonstrating the feasibility and the applicability of our results. Four, despite the clinical validation of this anatomical study, a single case supports our anatomical findings and further clinical studies focusing on this topic should strength the significance of the present paper.

CONCLUSION

The SE endoscopic transorbital approach is a valid surgical path for access of several skull base pathologies. The SC is a bone ridge shaping dorsally the medial margin of the greater sphenoid wing separating medial temporal dura from the posterior PO. The complete resection of this osseous structure is a key step of this surgical approach to obtain adequate working space to perform interdural dissection of the cavernous sinus route and therefore providing a "privileged" perspective to manage paramedian skull base lesions.

Funding

This study did not receive any funding or financial support.

Disclosures

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

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VIDEO. The anatomical step-by-step dissection of the sagittal crest is compared with a surgical case of a trigeminal schwannoma as seen through a superior eyelid endoscopic transorbital approach.