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ORIGINAL ARTICLE - NEUROSURGICAL ANATOMY

# The feasibility of three port endonasal, transorbital, and sublabial approach to the petroclival region: neurosurgical audit and multiportal anatomic quantitative investigation

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## Abstract

**Purpose** The petroclival region represents *the "Achille's heel"* for the neurosurgeons. Many ventral endoscopic routes to this region, mainly performed as isolated, have been described.

The aim of the present study is to verify the feasibility of a modular, combined, multiportal approach to the petroclival region to overcome the limits of a single approach, in terms of exposure and working areas, brain retraction and manipulation of neurovascular structures.

**Methods** Four cadaver heads (8 sides) underwent endoscopic endonasal transclival, transorbital superior eyelid and contralateral sublabial transmaxillary-Caldwell-Luc approaches, to the petroclival region. CT scans were obtained before and after each approach to rigorously separate the contribution of each osteotomy and subsequentially to build a comprehensive 3D model of the progressively enlarged working area after each step.

**Results** The addition of the contralateral transmaxillary and transorbital corridors to the extended endoscopic endonasal transclival in a combined multiportal approach provides complementary paramedian trajectories to overcome the natural barrier represented by the parasellar and paraclival segments of the internal carotid artery, resulting in significantly greater area of exposure than a pure endonasal midline route (8,77 $cm^2$ and 11,14 $cm^2$ vs 4,68 $cm^2$ and 5,83$cm^2$, extradural and intradural, respectively).

**Conclusion** The use of different endoscopic "head-on" trajectories can be combined in a wider multiportal extended approach to improve the ventral route to the most inaccessible petroclival regions. Finally, by combining these approaches and reiterating the importance of multiportal strategy, we quantitatively demonstrate the possibility to reach "far away" paramedian petroclival targets while preserving the neurovascular structures.

**Keywords** Transorbital endoscopic approach · Extended endoscopic endonasal transclival approach · Caldwell-Luc approach · Contralateral transmaxillary approach

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**Abbreviations**

| | |
|---|---|
| ICA | Internal carotid artery |
| TOA | Transorbital approach |
| EEEA | Extended endoscopic endonasal approach |
| CTM | Contralateral transmaxillary |
| CL | Caldwell-Luc |
| CT | Computerized tomography |

## Introduction

The petroclival region is one of the most complex skull base territories. Accordingly, there is no single ideal approach to reach this area, and the neurosurgeon must be confident with many surgical routes. Each operative technique carries the possibility of significant postoperative morbidity and must be weighed against the intrinsic surgical risks [2, 3, 18, 24, 33, 35, 40]. In this scenario, the ventral pathway allows the direct access to the surgical field without the exposure of the main paramedian neurovascular structures and obviating brain retraction.

Many authors [13, 19, 30, 32] stressed the difficulty in reaching paramedian lesions behind the paraclival and parasellar segments of the internal carotid artery (ICA) *by any route*. However, it is possible to reach such complex anatomical areas from both the transsylvian [16] and transpetrous [1, 24] approaches cranially and the cerebellopontine angles [14] or the transtentorial–suboccipital routes caudally. but those neoplasms could be obscured from key neurovascular structures.

Among the alternative surgical routes to access tumors arising from or extending to the petroclival region, the midline endonasal was considered a reasonable choice [9, 10, 29, 30, 32, 37, 38, 41], providing it direct access to the target, avoiding the brain retraction and crossing the plane of cranial nerves. Moreover, the midline transclival route can be also extended to the paramedian petroclival synchondrosis by performing the skeletonization of the carotid canal for additional exposure of the petrous apex posteriorly to the paraclival segment of the ICA [12].

In this scenario, to improve the ventral route to the more inaccessible skull base paramedian regions and to "strengthen" and complement the role of the midline endonasal approach to reach "far away" paramedian anatomical regions with poor working angles and areas, transoral [31] and transorbital [7, 10, 37] ports have been described to bring the surgeon closer to the target.

The aim of the present anatomical and quantitative study is therefore to establish if these pathways can be combined in new modular "multiportal" and reproducible approach to further improve the surgeon's ability to access the petroclival region.

## Materials and methods

### Anatomic dissections

Anatomical dissections were performed at the Laboratory of Surgical Neuroanatomy of Barcelona, Spain, and at the Laboratory of Neuroscience EBRIS of Salerno, Italy.

Four adult cadaveric embalmed and injected specimens were accessed. One specimen underwent a multi-slice helical CT scan (SOMATOM Sensation 64) for quantitative purposes. The CT scan was performed before and after each modular approach to calculate the exact amount of bony exposure provided by each port and to create a 3D model of the progressively enlarged working area after each step, reducing the BIAS represented by superimposed areas in common by the three routes.

Each cadaver head underwent midline endoscopic endonasal transclival approach (EEEA) [9, 21] (Fig. 1), followed by contralateral transmaxillary approach (CTM) (Caldwell-Luc) [39] (Fig. 2) and finally superior eyelid transorbital endoscopic approach (TOA) [5] (Fig. 3), for a total of 20 endoscopic procedures (4 EEA, 8 CL, 8 TOA) directed to the petroclival region (Fig. 4).

The choice of this sequence of the approaches was based on the decreasing order of exposed volume of petroclival synchondrosis provided, thereby identifying the leading role of the EEEA, considered as the "core," followed by the "complementary" CTM and TOA.

The possibility of performing a half clivectomy to reach only the paramedian petroclival area was discarded due to the impossibility of working properly with surgical instruments in a such deep anatomical region without scarring surgical maneuverability.

### Quantitative analysis

#### Bone removal

Pre- and post-dissection CT scans were independently obtained for each modular approach to exactly assess the volume of bone removal resulting from each, and a 3D model of the progressively enlarged area of bone removal after each step was created using Amira Visage Imaging (Amira Visage Imaging Inc.). The volume of bone drilled during each modular approach was finally quantified as volume of bone removal for further analysis.

#### Working area

For an accurate estimate of the working area, the CT scan of each specimen was loaded in the Medtronic navigation

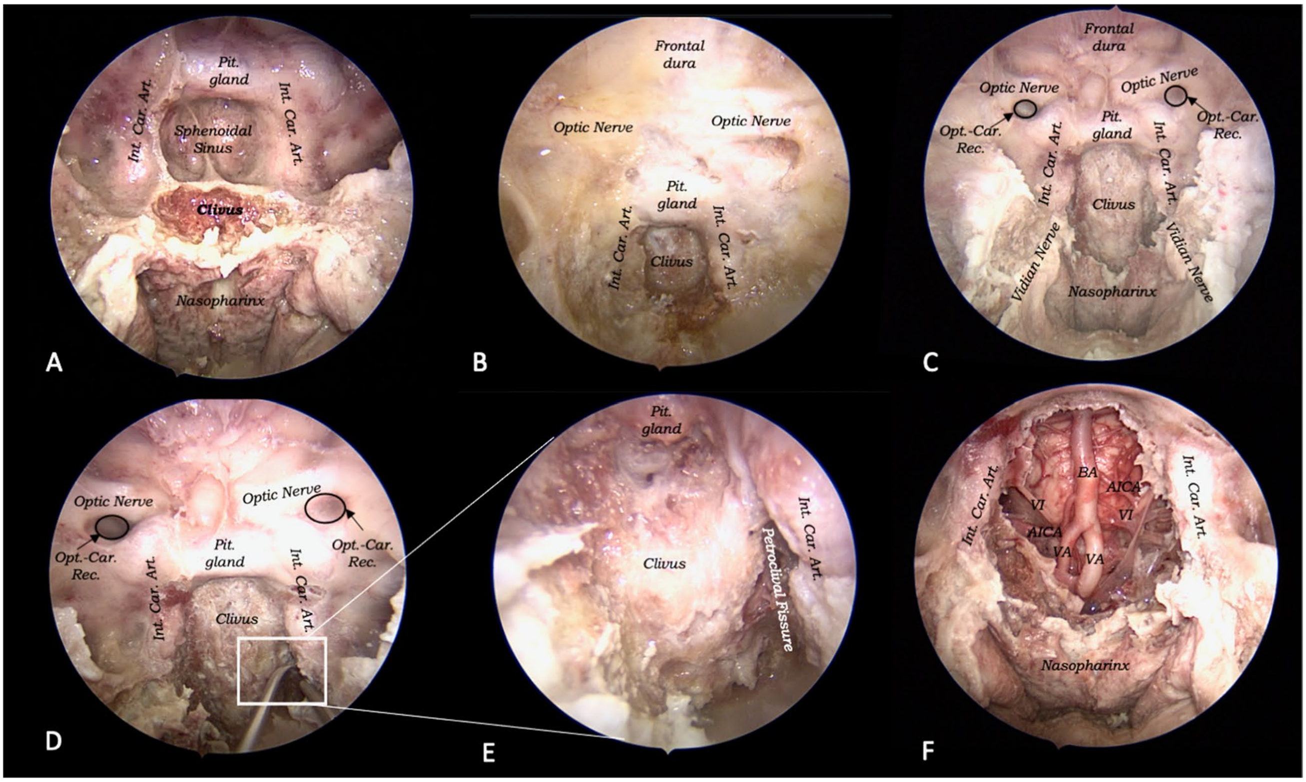


**Fig. 1** Extended endoscopic endonasal transclival approach (EEEA) to the petroclival region. **A** Exposure of the upper segment of the clivus, after partial removal of the vomer and sphenoid sinus floor. **B** Exposure of the clival region up to first cervical vertebral body (C1), after total removal of the vomer, the floor of the sphenoid sinus, and the clival bone. **C–F** Exposure of the main anatomical landmarks of the petro- and retro-clival region (BA, basilar artery; FL, foramen lacerum; C3–C4, segments of the paraclival ICA)

system station (Medtronic, Inc. Surgical Technologies). After co-registration, four extreme peripheral points that can be reached after bone removal, through each approach, were recorded to obtain maximal cardinal references (north, south, east, and west). This procedure was then repeated both extradurally and intradurally. Subsequentially, all the data points were loaded on Amira Visage Imaging, and a bidimensional planar area of exposure was obtained for each approach.

## Results

### Quantitative analysis

The data of the exposure area resulting from each approach were calculated and combined to evaluate the advantages in terms of progressive increment of exposure.

The average bone removal resulting from the EEEA was represented by a *median* rectangular area of 3.84 $cm^3$ bounded by the posterior clinoid and dorsum sellae, superiorly; the anterior arch of the atlas, inferiorly; and the paraclival segment of ICA and six cranial nerve superior-laterally and the foramen lacerum and hypoglossal canal infero-laterally (Fig. 5). The resulting working area within the *median* aspect of the posterior fossa was 4.68 $cm^2$ extradurally and 5.83 $cm^2$ intradurally, respectively (Fig. 6).

The CTM approach allowed us to reach the *paramedian* posterior fossa by drilling the ventral surface of the petrous apex passing just behind the paraclival segment of the ICA through a bone window of 1.18 $cm^3$ (Fig. 5). The average working area provided by this route was 3.15 $cm^2$ extradurally, and 4.12$cm^2$, intradurally (Fig. 6).

Finally, the TOA allowed us to reach the paramedian aspect of the posterior fossa by drilling the petrous apex just above the internal acoustic meatus through 1.47 $cm^3$ of bone window removal (Fig. 5). The average achieved working area was 0.94 $cm^2$ extradurally, and 1.19 $cm^2$, intradurally (Fig. 6).

These data are summarized in Table 1 and showed in Fig. 7.

We hypothesized to divide our surgical target area in four compartments by two ideal perpendicular planes, one passing along the major axis of the paraclival segment of ICA and the other one passing along the major axis of the horizontal segment of the petrous ICA (Fig. 8); these regions

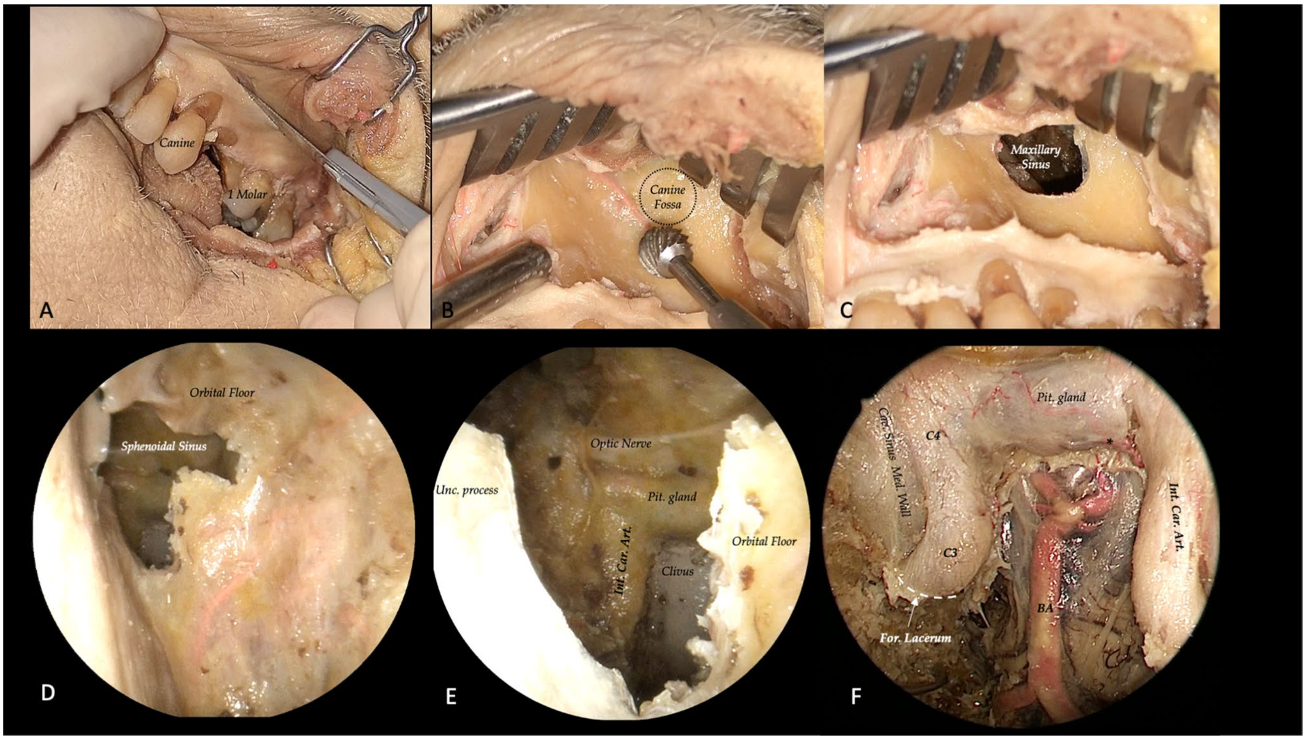


**Fig. 2** Contralateral sublabial transmaxillary (CTM) approach (Caldwell-Luc) to the petroclival region. Left side. **A** Identification of anatomical landmarks (canine, first 1 molar). Sublabial transverse incision with a 15 blade, about 1.5 cm up the superior gingiva, extended from the canine to the first/second molar. **B** Identification of canina fossa at intersection of the mid-pupillary line with a horizontal line from the nasal alar base and subsequent anterior maxillotomy with high speed microdrill. **C** Circumferential widening of the maxillotomy through Kerrison Rongeur allowing access to maxillary sinus. **D** Inside maxillary sinus, with preserved mucosa under orbital floor and visible sphenoid sinus through the ostium. **E** Endoscopic perspective from inside the maxillary sinus after inferior meatal antrostomy, of the right ICA and clival region. **F** Direct view of contralateral petroclival region, with exposed medial wall of cavernous sinus, foramen lacerum, C3 and C4 segments of ICA, pituitary gland, and all the retro-clival area (BA, basilar artery)

can be exposed and reached by tailored surgical approaches, defined according to the time (simultaneous or multistage) and the modality (isolated or variously combined) of performing:

- The supero-medial and infero-medial areas, located medially to the paraclival ICA, accessed through an isolated EEEA (*single port strategy*).
- The supero-lateral area, located laterally to the paraclival ICA and superiorly to the petrous ICA, accessed through an EEEA combined with a TOA, simultaneously or multistage performed [26] (*two ports strategy*).
- The infero-lateral area, located laterally to the paraclival ICA and inferiorly to the petrous ICA, accessed through an EEEA combined with a CTM, simultaneously or multistage performed [39] (*two ports strategy*).
- Finally, for lesions arising from the posterior midline skull base (supero-medial and infero-medial areas), with secondary lateral extension beyond the paraclival and petrous segments of ICA (supero-lateral and infero-lateral areas), a multiportal combined multistage approach, resulting from the EEEA transclival combined with the TOA and CTM approaches, may be considered (*three ports strategy*).

## Discussion

Because of its deep position, the complex surrounding anatomical relationship, the great operative difficulties, and the high incidence of surgical complications, surgery for petroclival pathologies represents one of the most demanding and technically challenging procedures.

At first sight, it could be argued that the surgical complexity of the *pure endonasal route* raised as the target areas moves away from the midline with the increasing of the surgical path and the angle of attack, as confirmed by clinical studies in the pertinent literature [8, 15, 28, 36]. Indeed, the rate of cranial nerve palsy during the commonly utilized “paramedian” transpterygoid corridor has proven to be higher than the midline transclival approach [8, 22, 41]. This is likely the result of a purely anatomical reason as the

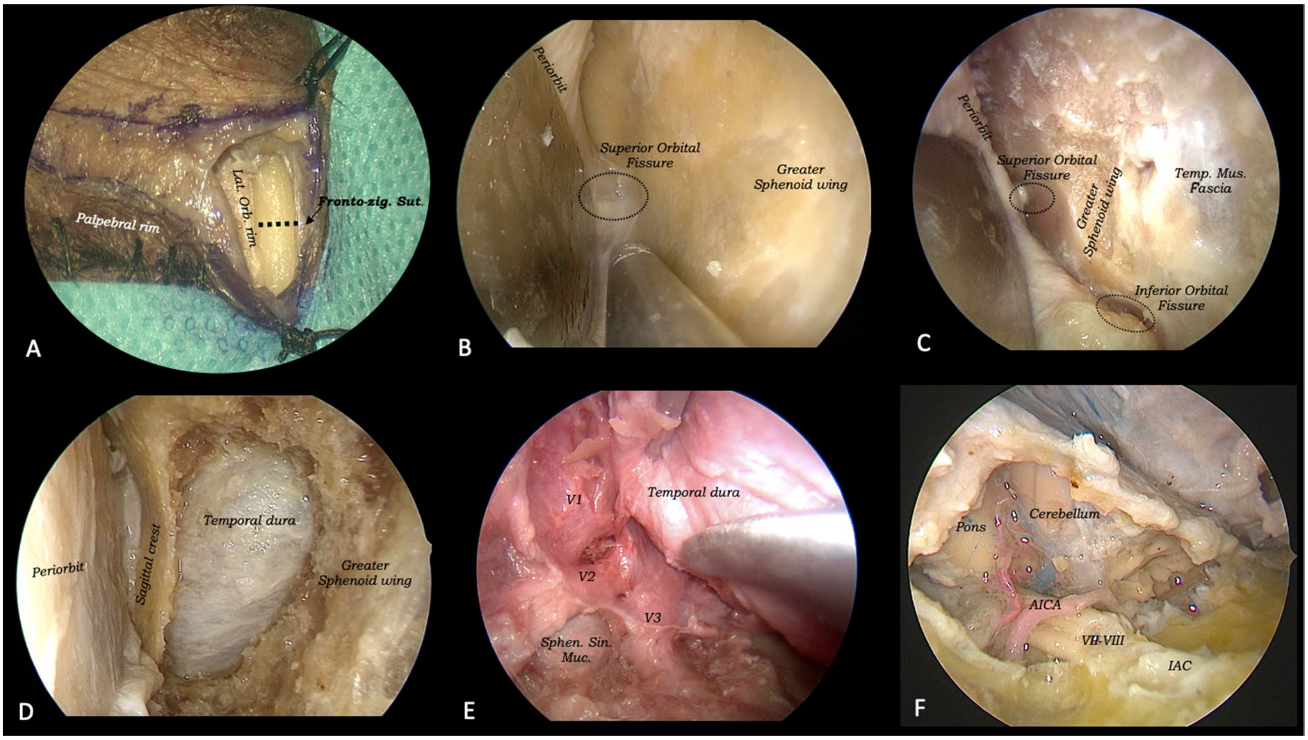


**Fig. 3** Transorbital exoscopic-endoscopic approach (TOA). **A** Superior eyelid access under exoscopic visualization; identification of fronto-zygomatic suture. **B** Identification with endoscopic assistance of the intra-orbital anatomic landmarks (periorbita, superior orbital fissure, great sphenoid wing). **C** Drilling of the orbit lateral wall. **D** Exposition of the sagittal crest and temporal pole dura mater. **E** Interdural dissection via meningo-orbital band of the cavernous sinus lateral wall, V1–V2–V3 branches of the trigeminal nerve and the Gasserian Ganglion. **F** Drilling of the petrous apex in the area that can be exposed laterally to the third branch (V3) of the trigeminal nerve allowed to disclose the internal acoustic canal content (VII–VIII cranial nerves) and posterior fossa neurovascular structures

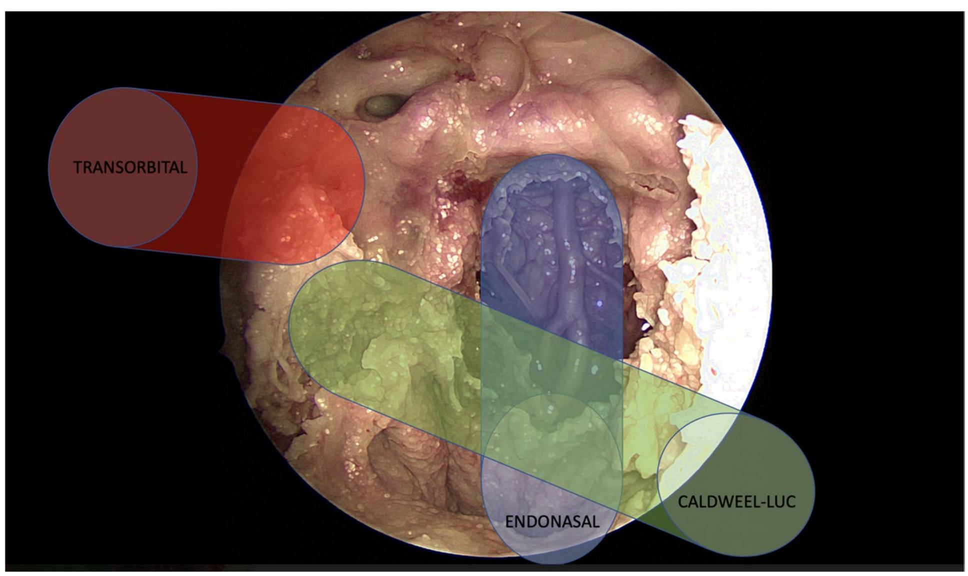


**Fig. 4** Didactic illustration showing the cones of visibility provided by endoscopic transorbital, endonasal transclival, and contralateral transmaxillary routes to the petroclival region

cranial nerves, except the abducens, emerge from a paramedian position over the brainstem.

The paraclival and parasellar ICA segments represent other "natural anatomic barriers" which limit the possibility of lateral extension during EEEA to address lesions crossing vascular structures or located in the far lateral paramedian areas [20]. Although some authors demonstrate the possibility of extending the midline transclival route

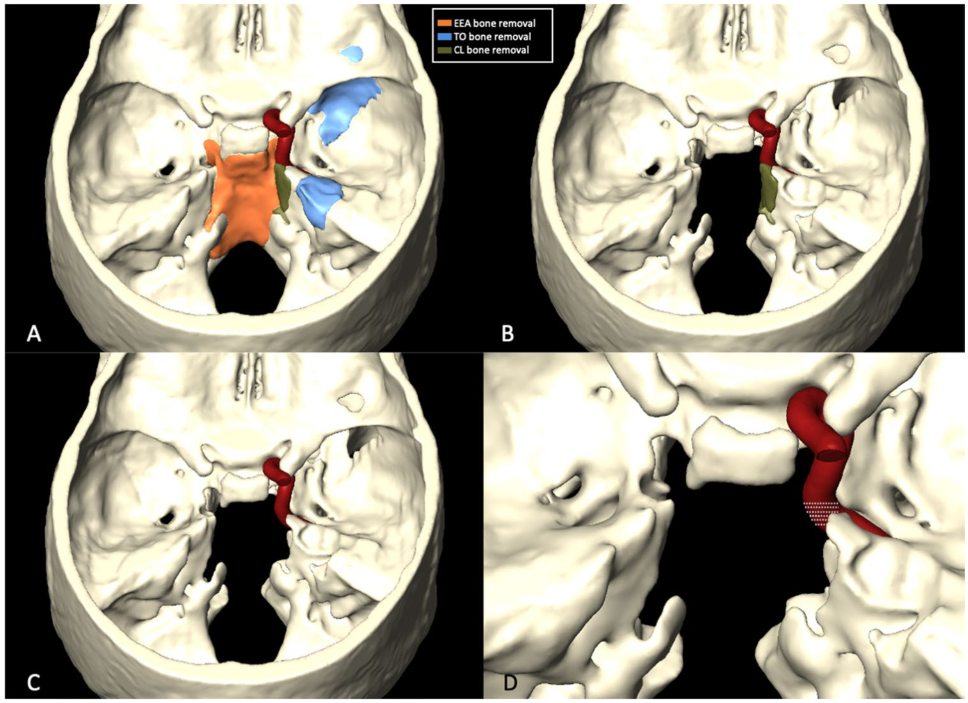


**Fig. 5** Bone removal. Quantitative analysis. The virtual overall 3D model of bone removal was created using Amira Visage Imaging (Amira Visage Imaging Inc., San Diego, CA, USA). The 3D reconstruction of the right ICA was also performed. **A** In this axial view of the 3D reconstruction, the bone removal via the EEEA, CL, and TOA is highlighted in orange, green, and blue, respectively. **B** The drilled bone via EEEA and TOA is removed, preserving only that reached by CTM (green). **C**–**D** Removing the bone drilled via CTM, it is possible to expose the lacerum segment of the ICA (white stripped lines). ICA, internal carotid artery; EEEA, extended endoscopic endonasal approach; CL, Caldwell-Luc; TOA, transorbital approach

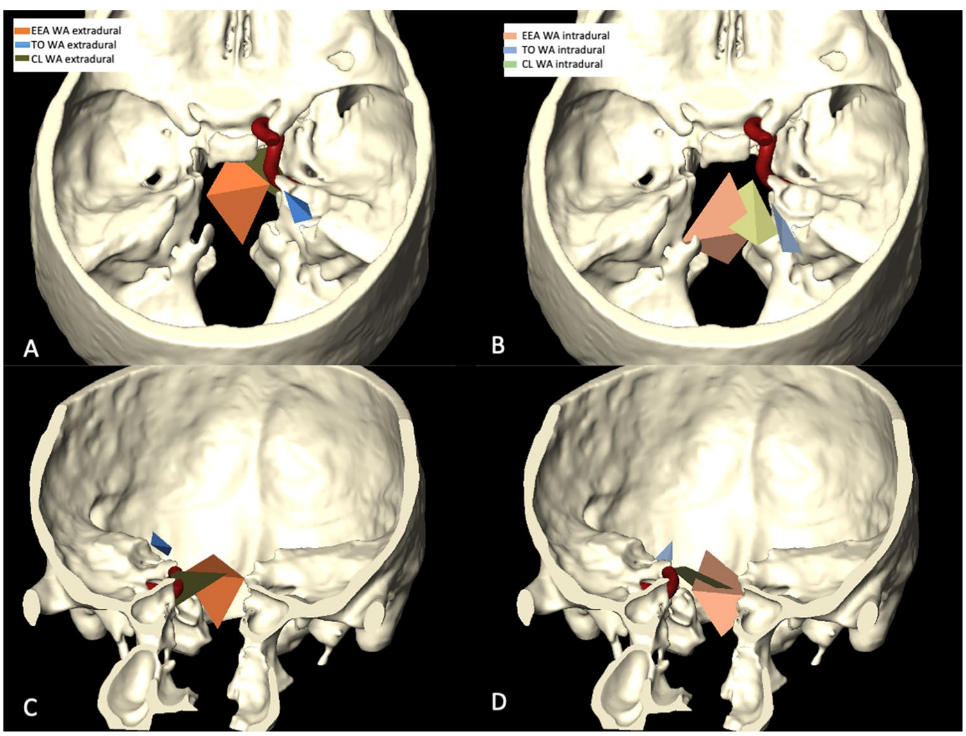


**Fig. 6** Working area. Quantitative analysis. The virtual overall 3D reconstruction of working area using Amira Visage Imaging (Amira Visage Imaging Inc, San Diego, California, USA). The 3D reconstruction of the right ICA was also performed. The working area is represented by the widest two-dimensional planar area. The extradural working areas achieved with the EEEA, TOA, and CTM are represented in orange, blue, and green, respectively; they are reconstructed in an axial (**A**) and a in coronal view (**C**). The intradural working area is represented in the same colors, with a lighter shade, in an axial (**B**) and in a coronal plane (**D**). The overall amount of working area is particularly convenient and permits to working almost at 360° around the ICA. ICA, internal carotid artery; EEEA, extended endoscopic endonasal approach; CL, Caldwell-Luc approach; TOA, transorbital approach

**Table 1** Summarized data of exposure intra- and extradural area according to the extended endoscopic endonasal transclival (EE), contralateral transmaxillary, and transorbital (TO) approaches

| Approach | Side | Exposure area (mm$^2$) | |
|---|---|---|---|
| | | Extradural (mean) | Intradural (mean) |
| EE | Median | 468.41 (468.41) | 583.27 (583.27) |
| CTM | L-R | 298.15 | 327.89 |
| | R-L | 332.34 | 497.96 |
| | | (315.25) | (412.93) |
| TO | R | 88.84 | 146.51 |
| | L | 99.64 | 93.00 |
| | | (94.24) | (119.75) |

*EE*, endoscopic endonasal; *CTM*, contralateral transmaxillary; *TO*, transorbital; *L*, left; *R*, right

to the paramedian petroclival synchondrosis through the skeletonization of the carotid canal [12, 22], we discarded this hypothesis because of our dissection methodology to reach wider working areas through progressive osteotomies. Indeed, the rate of cranial nerve palsy during the commonly used "paramedian" transpterygoid corridor (which provides wide exposure of the petrous apex, middle cranial fossa, cavernous sinus, and Meckel cave) was higher than the midline transclival approach [8, 41]. Another well-known limitation of EEA is represented by a limited possibility of lateral extension to address lesions crossing vascular structures or located in the far lateral paramedian areas, due to the restricted surgical freedom provided by the pyriform aperture and to the difficulty in crossing the plane of major vessel

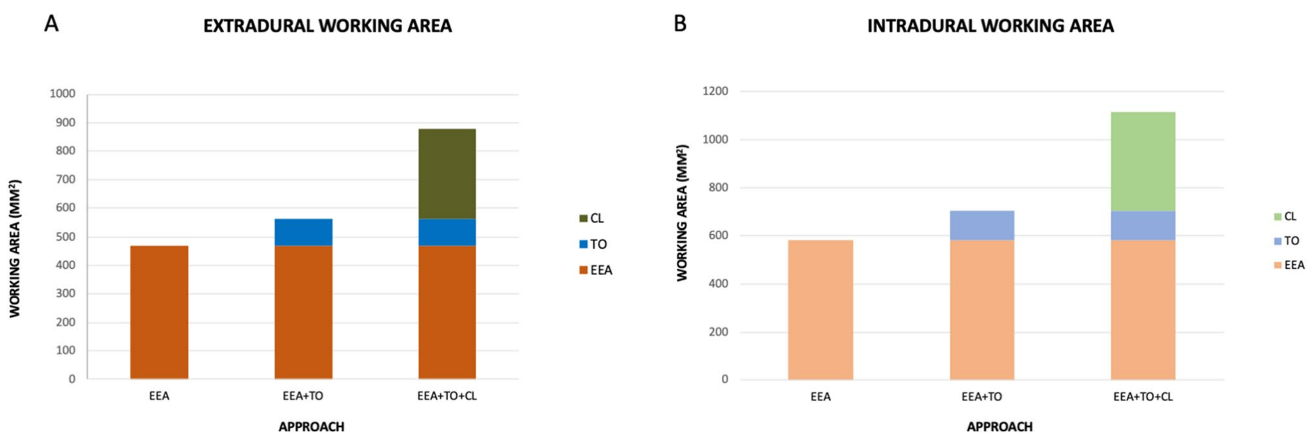


**Fig. 7** Quantitative analysis. The average amounts of the extradural (**A**) and intradural (**B**) working areas are resumed in these histograms. The values of extradural working area achieved with EEEA, TOA, and CTM approaches are colored in orange, blue, and green, respectively (**A**). The same colors, but in a lighter shade, have been used to represent the values of the intradural working area (**B**). EEEA, extended endoscopic endonasal approach; CL, Caldwell-Luc approach; TOA, transorbital approach

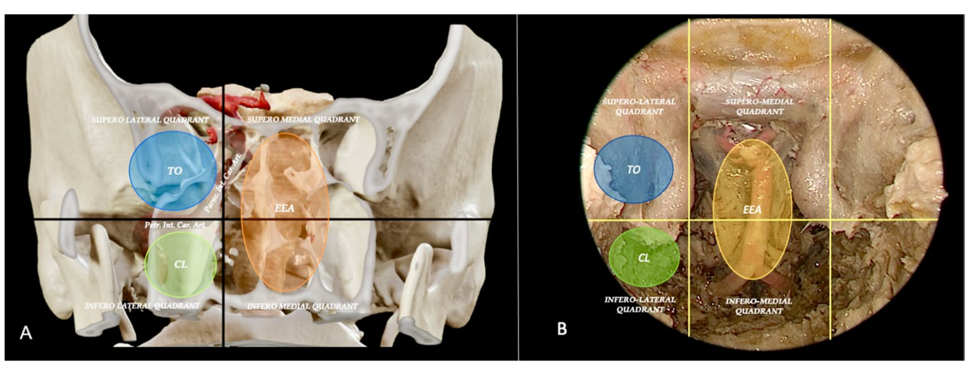


**Fig. 8** Schematic illustration of surgical target areas and related tailored approaches in **A** 3D reconstruction and **B** cadaver specimen. The petroclival region may be divided in four areas by two virtual perpendicular planes: one passing along the major axis of the paraclival ICA and the other one passing along the major axis of the horizontal segment petrous ICA. The resulting target areas are the supero- and infero-medial quadrants, medially to the paraclival ICA, accessed via EEA; the supero-lateral quadrant, laterally to the paraclival ICA and superiorly to the petrous ICA, accessed via TOA; the infero-lateral quadrant, laterally to the paraclival ICA and inferiorly to the petrous ICA, accessed via CTM; and finally, for lesions involving all four quadrants, a combined multiportal approach via EEA + TO + CL may be considered. EEA, endoscopic endonasal approach; TOA, transorbital approach; CL, Caldwell-Luc

such as the ICA [20]. Since the possibility to displace soft tissue (i.e., the paraclival carotid artery) and to work posteriorly to the carotid canal could not be easily reproduced in a postoperative computer-based CT scan model, it was considered a major source of bias.

As a result, the aim of the present anatomical and quantitative study was to verify the feasibility of a multiportal approach to the petroclival region through optimal angles of attack, minimizing the distance to the target and obtaining the maximal safe resection. The key concept is to "strengthen" and "complement" the role of the midline endonasal approach to reach far away paramedian anatomical regions with poor working angles and areas.

For this purpose, we selected three different complementary routes — the EEEA, the CTM, and the TOA — each one offering, when combined, the possibility to deal with pathologies involving the petroclival region and crossing over the paraclival and parasellar segments of the ICA. They may be performed as isolated or in a variously combined manner, in single or multiple stages, based on target area, the nature of the pathology, the aim of the surgery, and the patient features.

The EEEA allows the exposure of the superior and inferior portions of the middle third of the clivus and retro-clival area. As a natural midline corridor, it is properly indicated for lesions involving the median intra-/extradural posterior skull base, medially to the paraclival ICA — *supero-medial* and *infero-medial areas* (*single port strategy*) (Fig. 8) — like clivus chordomas, chondrosarcomas, meningiomas, epidermoid cysts; nevertheless, its main drawbacks are represented by the prohibition to cross the plane of cranial nerves and the ICAs as well as difficulty in mobilizing or dissecting these vulnerable structures. While a commonly used approach, it is not without potential complications. The most critical neurovascular structures are the brainstem, CNs II–XII, the paraclival ICA, and the entire posterior circulation; consequently, possible morbidities include CSF leak, structural, neurological, infectious, and medical complications [18].

The CTM route to the petroclival region allows to reach the lateral aspect of the petrous apex without the need of skeletonization of the carotid canal or manipulation of the paraclival ICA [30]. Indeed, the addition of a CTM approach allows the increasing of the extradural (from 4.68 to 7.83 $cm^2$) and intradural (from 5.83 to 9.95 $cm.^2$) working area (Fig. 7). If from one side, the EEEA allows to work medially to the petrous and lacerum segments of ICA [30], from the other side, the CTM, through a wider angle of attack relative to the paraclival ICA, along a parallel corridor to the horizontal petrous ICA, improves the capability of the surgeon to work inferiorly, posteriorly, and laterally to these ICA segments, without the need for a complete exposition and mobilization of the ICA or sacrifice of the vidian nerve [30]. So, this surgical corridor in combination with the EEA one (*two ports strategy*, *single or multistage*) is useful to reach lesions involving the *infero-lateral area* (Fig. 8) — laterally to the paraclival and inferiorly to the petrous ICA — like the caudal portion of the lesions extending laterally to the contralateral paraclival ICA, such as large clival chordoma and chondrosarcomas, meningiomas, and metastases, with extreme lateral extension to the middle and lower third of the clivus beyond the petroclival synchondrosis [25, 30, 34], as witnessed by the most common site of residual chordoma after EEEA represented by the inferior and lateral aspect of the petrous apex [30]. This approach does not add significant morbidity: the main risks are transient infraorbital nerve hypoesthesia (for injury of maxillary branch of the trigeminal nerve), CSF leak, oral-antral fistula, facial swelling, and nasolacrimal duct dysfunction [27, 34].

Finally, another ventral endoscopic route to the petroclival region is the TOA: this upper paramedian port, avoiding the parasellar and paraclival segments of the ICA, allows to reach through a small petrous apex drilling in a safe "entry zone" medial to the internal acoustic meatus and its content [10] and without brain retraction or cranial nerve manipulation, the cavernous sinus, middle tentorial incisura, and ventral lateral brainstem [10], furthermore improving the cranial exposure of the petroclival region up to 8.77 $cm^2$ extradurally and 11.14 $cm^2$, intradurally (Fig. 7). The combination of this port with the EEEA one (*two ports strategy*, *single or multistage*) is indicated for the treatment of lesions involving the *supero-lateral area* (Fig. 8) — laterally to the paraclival and superiorly to the petrous ICA — like meningiomas/chordomas of the upper third of the clivus with paramedian extension beyond the petroclival synchondrosis [11]. The main complications related to the endoscopic transorbital approaches include CSF leak, postoperative vision loss, abducent nerve paresis, and facial numbness; the majority of them are transient [6, 38].

A multiportal and multistage approach (*three ports strategy*), combining the EEEA transclival with the TOA and CTM approaches, may be considered for lesions arising from the posterior midline skull base (*supero-medial* and *infero-medial areas* — Fig. 8), with secondary lateral extension beyond the paraclival and petrous segments of ICA (*supero-lateral* and *infero-lateral areas* Fig. 8).

These ports can be easily interchangeable, and the endoscope and surgical instruments can be alternated as needed, changing the perspective from "extensive uniportal" to "tailored multiportal routes."

We consider that a multiportal, combined, modular approach could overcome the limits of a single route in terms of visualization, size of working area, and maximal safe resection, taking advantage of benefits offered by each single approach; TOA and CTM would allow to reach petroclival lesions with far lateral extension not accessible via EEEA alone.

Multiportal approach can access the target area from different angles of attack, avoiding the manipulation of neurovascular structures which could represent an obstacle. Multiportal non-coaxial vectors allow for non-parallel movement of surgical instruments with the endoscope, thus allowing surgeons to constantly "see behind" the structures in the surgical field. Furthermore, the use of multiple "operative working angles" obviates the need for augmented "operative spaces" avoiding the aggressive handling of the normal surrounding structures, extensive inner sinonasal disruption, minimizing the related comorbidities. We are aware that these three corridors could constitute three potential sources of CSF leak: therefore, we consider to prevent or decrease the rate of this occurrence; the reconstruction of the osteodural defect resulting from EEEA and CL [30] can be accomplished by the 3F technique according to Cavallo et al. [4] consisting of autologous fat graft from periumbilical region used as "cork" stopper across the osteodural defect, covered with a thin layer of fibrin glue and with a pedicled vascularized nasoseptal flap described by Hadad et al. [17] and popularized by Kassam et al. [23]. Concerning the transorbital route, when the defect is extended beyond the limits of the orbit, a watertight closure should be achieved following the same principles of endosnasal endoscopic skull base multilayer reconstruction [38], and the current results of the literature show a slightly lesser rate of CSF leak during SETOA than during EEA [38].

### Study limitations

The small sample size of specimens adopted during the dissections represents a limitation of this anatomical study. As any anatomical laboratory study, the anatomical variability must be considered: variability in size of the maxillary and sphenoid sinuses, the trajectory and tortuosity of the internal carotid artery, the angle described from the petroclival junction, and so on. Nevertheless, the quantitative analysis adds to a pure anatomical quantitative description the potential to partially solve the clinical reproducibility in a systematic way by considering access to a specific anatomical region as a complex 3-dimensional issue. Therefore, we feel these findings may prove useful for surgeons performing advance skull base procedures in the petroclival region.

## Conclusion

The present research provides evidence from a strong quantitative perspective that it is possible to attack the petroclival region by different trajectories avoiding the cranial nerves pathway and respecting the course of ICA without brain manipulation.

The use of such pathways can be combined in a new modular multiportal approach to further refine the surgeon's ability to access the paramedian skull base.

**Author contribution** All authors contributed equally to the work.

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**Data availability** Data of the current original research are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The authors declare no competing interests.

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