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Received, November 4, 2021.
Accepted, April 12, 2022.
Published Online, July 6, 2022.

Quantitative Anatomic Comparison of Endoscopic Transnasal and Microsurgical Transcranial Approaches to the Anterior Cranial Fossa

BACKGROUND: Several microsurgical transcranial approaches (MTAs) and endoscopic transnasal approaches (EEAs) to the anterior cranial fossa (ACF) have been described.
OBJECTIVE: To provide a preclinical, quantitative, anatomic, comparative analysis of surgical approaches to the ACF.
METHODS: Five alcohol-fixed specimens underwent high-resolution computed tomography. The following approaches were performed on each specimen: EEAs (transcribriform, transtuberculum, and transplanum), anterior MTAs (transfrontal sinus interhemispheric, frontobasal interhemispheric, and subfrontal with unilateral and bilateral frontal craniotomy), and anterolateral MTAs (supraorbital, minipterional, pterional, and frontotemporal orbitozygomatic approach). An optic neuronavigation system and dedicated software (ApproachViewer, part of GTx-Eyes II—UHN) were used to quantify the working volume of each approach and extrapolate the exposure of different ACF regions. Mixed linear models with random intercepts were used for statistical analyses.
RESULTS: EEAs offer a large and direct route to the midline region of ACF, whose most anterior structures (ie, crista galli, cribriform plate, and ethmoidal roof) are also well exposed by anterior MTAs, whereas deeper ones (ie, planum sphenoidale and tuberculum sellae) are also well exposed by anterolateral MTAs. The orbital roof region is exposed by both anterolateral and lateral MTAs. The posterolateral region (ie, sphenoid wing and optic canal) is well exposed by anterolateral MTAs.
CONCLUSION: Anterior and anterolateral MTAs play a pivotal role in the exposure of most anterior and posterolateral ACF regions, respectively, whereas midline regions are well exposed by EEAs. Furthermore, certain anterolateral approaches may be most useful when involvement of the optic canal and nerves involvement are suspected.

KEY WORDS: Anterior cranial fossa, Endoscopy, Microsurgery, Comparative study, Quantitative study, Skull base surgery, Approaches, Quantitative comparison, Endoscopic transnasal, Microsurgical transcranial, Neuronavigation, Evidence-based

Operative Neurosurgery 23:E256–E266, 2022 https://doi.org/10.1227/ons.0000000000000312

The anterior cranial fossa (ACF) is the most anterior skull base region and accommodates the frontal, olfactory, and orbital neurovascular structures. It is bound anterolaterally by the inner surface of the frontal bone and posteriorly by the limbus and the lesser wings of the sphenoid bone and is divided into 1 midline and 2 symmetric lateral bone segments covering the nasoethmoidal complex and the orbits, respectively.[1-5]

ABBREVIATIONS: ACF, anterior cranial fossa; **CG,** crista galli; **CP,** cribriform plate; **EEAs,** endoscopic endonasal approaches; **ER,** ethmoidal roof; **ETC,** endoscopic endonasal transcribriform approach; **ETP,** endoscopic endonasal transtuberculum-transplanum approach; **ETT,** endoscopic endonasal transtuberculum approach; **FIA,** frontobasal interhemispheric approach; **FTOZ,** frontotemporal-orbitozygomatic approach; **MPT,** minipterional approach; **MTAs,** microsurgical transcranial approaches; **PPF,** posterior plate of frontal sinus; **PS,** planum sphenoidale; **PT,** pterional approach; **SBF,** subfrontal approach with bilateral frontal craniotomy; **SO,** supraorbital approach; **SUF,** subfrontal approach with unilateral frontal craniotomy; **TFI,** transfrontal sinus interhemispheric approach.; **TS,** tuberculum sellae.

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The morphostructural peculiarities and the pathological varieties of ACF, regarding both biological characteristics (eg, malignant tumors vs benign lesions) and location (eg, intracranial lesions vs nasoethmoidal and orbital pathologies with ACF invasion), have always made the choice of surgical access challenging.

In the past 2 decades, traditional microsurgical transcranial approaches (MTAs)[1,6-12] have been sometimes replaced by recently developed endoscopic transnasal (or endonasal) approaches (EEAs).[1,13-19] Nowadays, the endoscopic transnasal route for ACF tumor resection is increasingly appealing thanks to growing surgical expertise, advancement of technologies, and refinements of multimodal therapies.[20] On the other hand, there are many anterior skull base pathologies that remain suitable or best approached with open treatment, depending on their biology and location.[21] Different comparative studies on transcranial and endoscopic approaches are available, but they are mainly clinical, based on relatively small clinical series, and limited to specific areas of the ACF.[1,8-10,12,19,22-33]

Following the IDEAL recommendations for surgical research[22-24] and with the aid of a recently implemented neuronavigation-based research method,[25-35] this quantitative anatomic preclinical study was performed with the aim of providing an objective anatomic comparison of MTAs and EEAs to the ACF.

METHODS

This work was performed according to the ethical standards of our Institutional Review Board. All human cadaveric studies have been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

Of note, the methods of this study were replicated from previous peer-reviewed anatomic studies both from our group and in the literature.[13,34-40]

Preparation of Specimens and Neuronavigation

A total of 5 alcohol-fixed specimens (10 sides) were dissected. Intracranial arteries were injected with red silicone rubber.[13,34-40]

A computed tomography scan was performed on each specimen and, subsequently, uploaded to the neuronavigation software (GTx-Eyes II, University Health Network—University of Toronto, Toronto, Ontario, Canada) in Digital Imaging and Communications in Medicine format.[34-43]

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Method of Dissection and Approaches Studied

Using standard microsurgical and endoscopic instrumentation (Karl Storz),[13] all dissections were performed at the Head and Neck & Forensic Dissection Research Center of Insubria University, Italy. To document the microsurgical and endoscopic anatomy visualized, a M320 Leica (Leica Microsystems Srl) surgical microscope and a 4K head-camera (Olympus) were used, respectively.[13]

Eleven surgical approaches were performed on each specimen. Anterolateral MTAs performed included the supraorbital approach (SO), according to Perneczky and Reisch,[44] the minipterional approach, as described by Figueiredo et al,[45] the pterional approach, as illustrated by Yasargil,[46] and the frontotemporal-orbitozygomatic (FTOZ) approach, in accordance with Van Furth et al.[22] These approaches were performed bilaterally and are shown in Figure 1. The anterior MTAs quantified included a transfrontal sinus interhemispheric approach (TFI), in accordance with Ducic and Coimbra[47] a subfrontal approach with unilateral frontal craniotomy (SUF), as described by Spektor,[48] a subfrontal approach with bilateral frontal craniotomy (SBF), in accordance with Nakamura et al,[49] and a frontobasal interhemispheric approach (FIA), according to Dehdashti and De Tribolet.[8] Of these approaches, only the SUF was performed bilaterally (Figure 2). The EEAs performed included the endoscopic endonasal transcribriform approach (ETC), according to Liu and Eloy,[16] the endoscopic endonasal transtuberculum approach (ETT), in accordance with Cook et al,[14] and the ETT-transplanum approach (ETP), as described by Liu and Eloy.[50] These are shown in Figure 3.

To maintain accurate exposures of each approach, the dissections were performed in a modular fashion that went from least invasive to most invasive, following the order in which they have been described above.

Quantification of Surgical Corridor and Areas Exposed

Following the methods of previous studies, quantification of the surgical corridor was performed in a "noncrossing" and "crossing" modality with the aid of an optical neuronavigation system (Polaris Vicra; NDI), coupled with GTx-Eyes II,[13,34-40] and data collection was repeated 3 times for each modality.

To standardize the measurements, the height of the surgical corridor was set at the level of the craniotomy for MTAs and of the nasal pyriform aperture for EEAs. Furthermore, during MTAs, frontal lobe retraction was kept constant to 15 mm with the aid of a Greenberg Retractor System.

The ACF is composed of the frontal bone, the ethmoid bone, and the anterior aspects of the body and lesser wings of the sphenoid (Figure 4).[5,6] ITK-SNAP software was used to demarcate the 21 predetermined surfaces of the ACF (Figure 4). These surfaces were grouped in 3 different macroregions: (1) the anterior midline region, composed of crista galli (CG), cribriform plate (CP), ethmoidal roof (ER), posterior plate of frontal sinus (PPF), planum sphenoidale (PS), and tuberculum sellae (TS); (2) the orbital roof region, divided into a medial and lateral part of the orbital plate of the frontal bone (orbital plate of frontal bone medial part and orbital plate of frontal bone lateral part, respectively); and (3) the posterolateral region, composed of the anterior clinoid, divided into medial and lateral part (anterior clinoid process medial part and anterior clinoid process lateral part, respectively), lesser wing, and roof of the optical canal.

Finally, Autodesk Meshmixer 3.5 and ApproachViewer (part of GTX-Eyes-II)[41] quantified the percentage of each of the 21 surfaces exposed by each surgical approach.

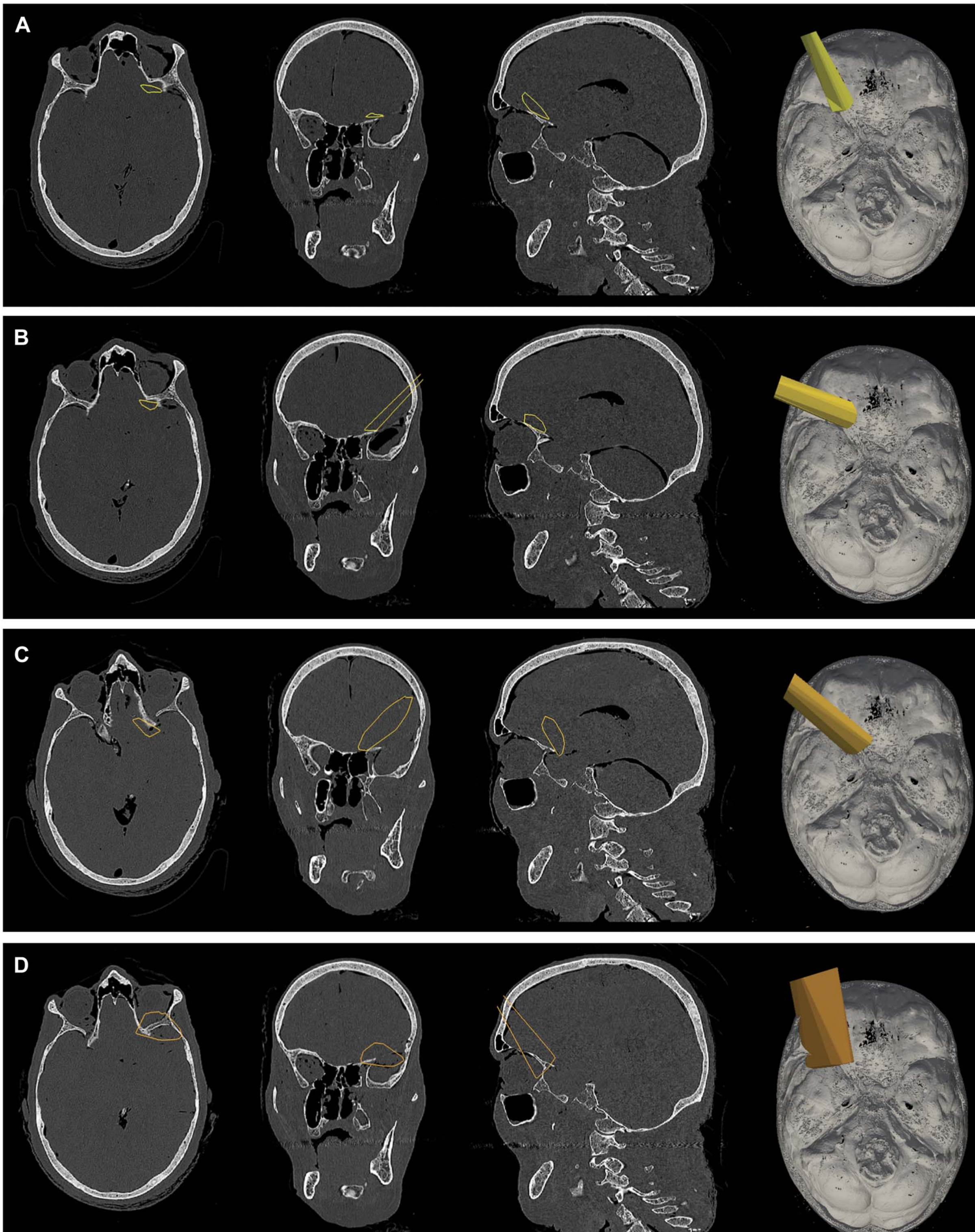

FIGURE 1. *Screenshots from ApproachViewer in axial, coronal, and sagittal planes and 3-dimensional volume rendering of quantified noncrossing anterolateral microsurgical transcranial approaches:* **A**, *supraorbital approach;* **B**, *minipterional approach;* **C**, *pterional approach; and* **D**, *frontotemporal-orbitozygomatic approach.*

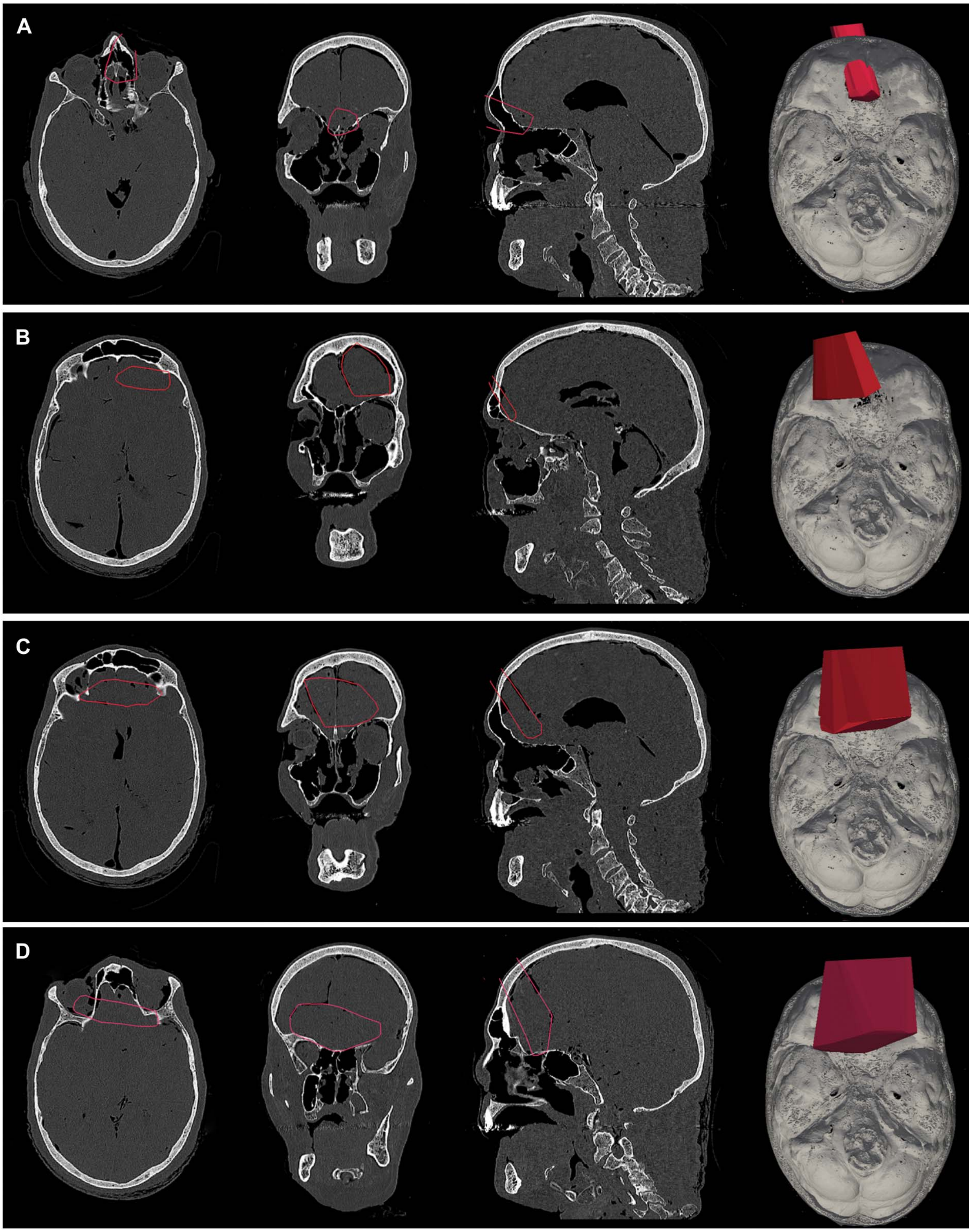

FIGURE 2. *Screenshots from ApproachViewer in axial, coronal, and sagittal planes and 3-dimensional volume rendering of quantified noncrossing anterior microsurgical transcranial approaches:* **A**, *transfrontal sinus interhemispheric approach;* **B**, *subfrontal approach with unilateral frontal craniotomy;* **C**, *subfrontal approach with bilateral frontal craniotomy; and* **D**, *frontobasal interhemispheric approach.*

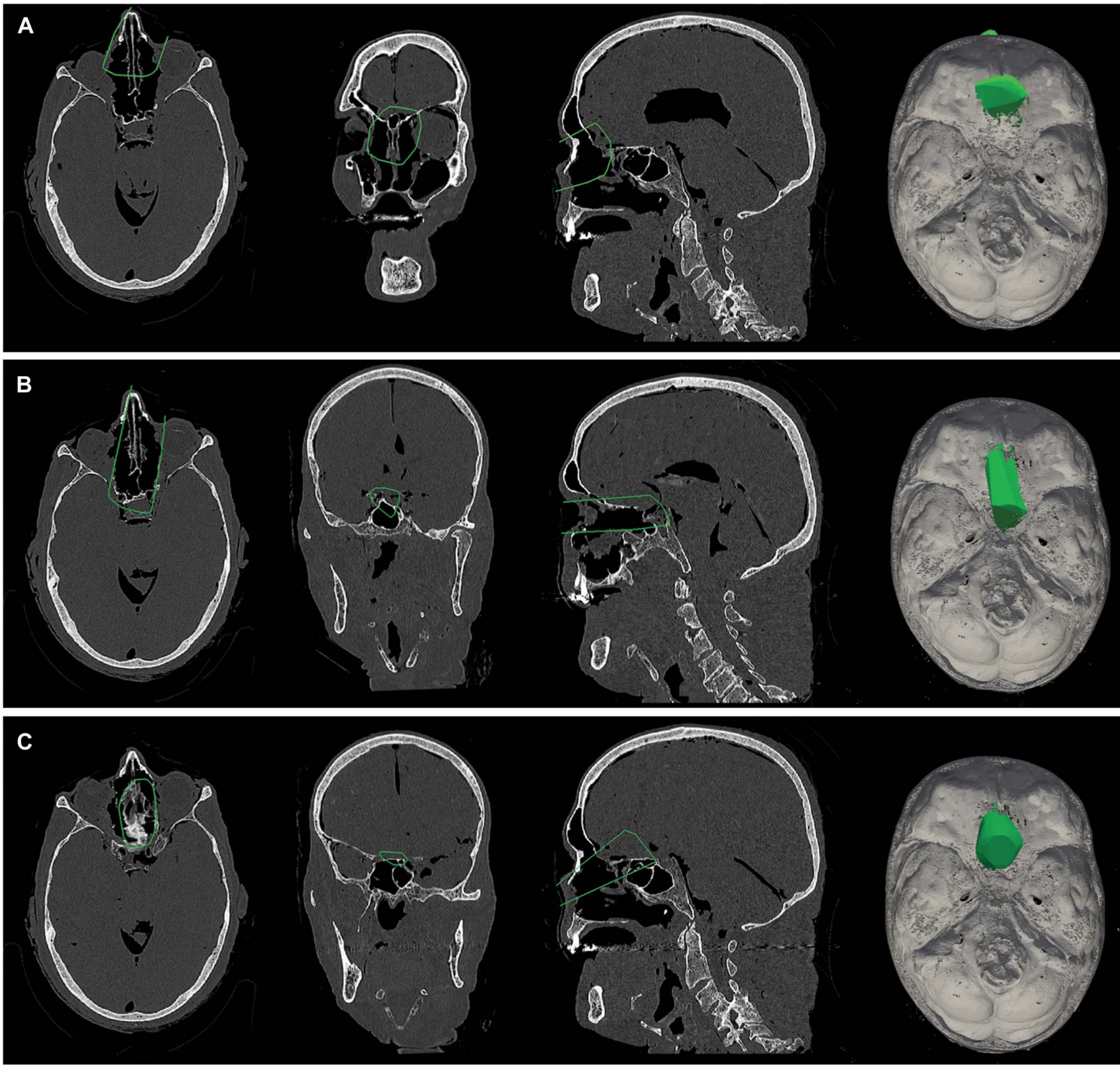

FIGURE 3. *Screenshots from ApproachViewer in axial, coronal, and sagittal planes and 3-dimensional volume rendering of quantified noncrossing endoscopic endonasal approaches:* **A**, *endoscopic endonasal transcribriform approach;* **B**, *endoscopic endonasal transtuberculum approach; and* **C**, *endoscopic endonasal transtuberculum-transplanum approach.*

Statistical Analysis

STATA software (StataCorp LLC) was used to perform all statistical analyses. To compare the areas exposed by each specimen, linear mixed models with random intercepts were used. The β coefficients communicated the final estimates of the area exposed. The 1000-fold replication bootstrap resampling method calculated the 95% CI. A $P < .05$ was considered for statistical significance.

RESULTS

The mean percentages of exposed ACF areas by each surgical approach are reported in detail in the **Supplemental Digital Content**, http://links.lww.com/ONS/A758, and graphically summarized in Figures 5-7.

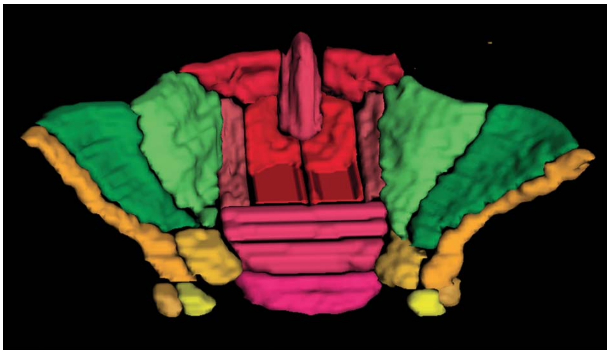

FIGURE 4. *Three-dimensional volume rendering of the spheno-orbital surfaces drawn bilaterally, shown with an intracranial perspective. The anterior cranial fossa has been divided into 21 target areas, drawn on each computed tomography and grouped into 3 macroregions. (1) Anterior midline region: 1. crista galli: triangular bone projection that rises vertically from the midline of the cribriform plate; 2. cribriform plate: horizontal plate of the ethmoid bone that extends from the frontoethmoidal suture to the anterior margin of the planum sphenoidal, bound laterally by the medial part of the orbital roofs; 3. ethmoidal roof: medial extension of the orbital plate of the frontal bone that forms the fossa ethmoidalis; 4. planum sphenoidale: anterior portion of the sphenoid bone extended from the ethmoidal arteries to the posterior margin of the chiasmatic sulcus (limbus sphenoidale) and bound laterally by the medial part of the orbital roofs; 5. posterior plate of frontal sinus: posterior bony wall of the frontal sinus; 6. tuberculum sellae: bony elevation ridge that extends from the limbus sphenoidale to the superior margin of the sellae turcica. (2) Orbital roof region: 1. orbital plate of frontal bone lateral part: lateral portion of the bony plate extended from the lateral limit of the midline structures up to the point of origin of the cranial vault and bound posteriorly by the lesser wing; 2. orbital plate of frontal bone medial part: medial portion of the bony structure just defined. (3) Posterolateral region: 1. anterior clinoid process lateral part: lateral portion of bone projection directed medioposteriorly in continuity with the medial end of the lesser wing of the sphenoid bone anteriorly and with the body of the sphenoid bone medially; 2. anterior clinoid process medial part: medial portion of the structure just described; 3. lesser wing: bony structure that continues laterally from the anterior clinoid process up to the sphenosquamosal suture, delimited anteriorly by the frontosphenoidal suture and posteriorly by the sphenoid ridge; 4. optical canal: roof of the optic (ie, cylindrical canal running obliquely through the lesser wing of sphenoid bone that transmits the optic nerve and ophthalmic artery).*

Areas of Exposure

Anterior Midline Region

The anterior midline region is exposed by EEAs and anterior MTAs. In detail, among MTAs, CG is exposed mostly by the FIA (81%), with a statistically significant gain of 34% compared with SUF. Consider that EEAs, CG, PPF, CP, and ER are exposed by the ETC (66%, 65%, 86%, and 75%, respectively); PS is exposed by the ETP (87%); TS is exposed by the ETP (90%) and ETT (85%). The largest exposure of PPF is provided by the FIA (80%), with a significant gain of 18% compared with SUF. CP and ER are better accessed by the TFI (90% and 81%, respectively), with a significant exposure increase of 4% and 6% compared with ETP and 12% and 16% compared with FIA. TFI and FIA permit limited exposure of PS (12% and 8%), with a significant exposure decrease of 75% and 79% compared with the ETP.

Orbital Roof Region

The orbital roof region is primarily reached by MTAs, with maximum exposure offered by the SUF, SBF, and FTOZ. The orbital plate of frontal bone medial part is better exposed by the SUF and SBF (59% and 57%, respectively), with an exposure gain of 16% and 14% compared with FTOZ, and a significant exposure gain of 56% and 55% compared with TFI. The orbital plate of frontal bone lateral part is better exposed by the FTOZ (72%), with a significant exposure gain of 43% compared with SO.

Posterolateral Region

The posterolateral region is exposed by the mainly anterolateral MTAs. FTOZ guarantees the maximum exposure for all posterolateral surfaces, whereas the SO the lowest, with a statistically significant difference.

Approach Volumes

EEAs have a mean distance from the target of 11 cm and similar working volumes (ETC: 88 cm^3, ETT: 86 cm^3, and ETP: 105 cm^3), which are larger than MTAs (Figure 8). The working volume of MTAs increased in relation to invasiveness of the approach, with different distances from the target (9 cm for SUF and SBF; 10 cm for FIA, TFI, and anterolateral MTAs) (Figure 8; **Supplement Digital Content**, http://links.lww.com/ONS/A758).

DISCUSSION

This study provides a systematic, preclinical, anatomic quantitative comparison of the most common surgical approaches to the ACF, both microsurgical transcranial and endoscopic transnasal, through a quantitative research method. Both the exposed areas and the “surgical” volume provided by each approach were quantified. The experimental findings can be summarized in 3 main results: (1) anterior MTAs provide good exposure of anterior ACF structures (Figure 7; **Supplement Digital Content**, http://links.lww.com/ONS/A758), whereas posterolateral regions are only partially exposed (Figure 6; **Supplement Digital Content**, http://links.lww.com/ONS/A758); (2) anterolateral MTAs ensure significant exposure of the posterolateral region (Figure 6; **Supplement Digital Content**, http://links.lww.com/ONS/A758), whereas more medial and anterior targets are only partially exposed (Figures 5 and 7; **Supplement Digital Content**, http://links.lww.com/ONS/A758); and (3) EEAs provide a large and effective exposure of midline and paramedian ACF regions (Figure 5; **Supplement Digital Content**, http://links.lww.com/ONS/A758).

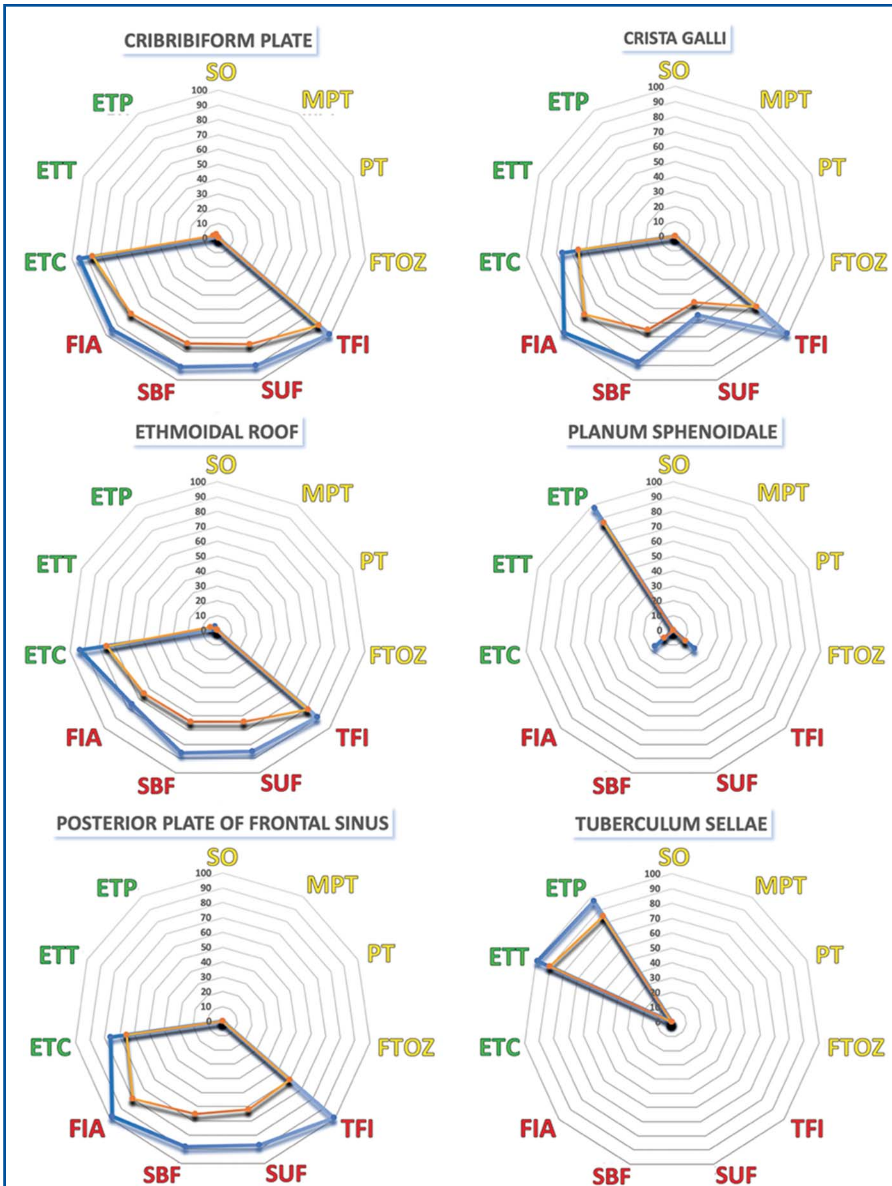

FIGURE 5. *Exposure of the anterior midline region offered by all studied approaches. The radar diagrams show the percentage value of exposed area obtained by each approach for each surface, as measured in noncrossing (orange) and crossing (blue) modalities. Approaches are sorted clockwise in alphabetical order and grouped into anterolateral MTAs (yellow), anterior MTAs (red), and EEAs (green). EEAs, endoscopic endonasal approaches; ETC, endoscopic endonasal transcribriform approach; ETP, endoscopic endonasal transtuberculum-transplanum approach; ETT, endoscopic endonasal transtuberculum approach; FIA, frontobasal interhemispheric approach; FTOZ, frontotemporal-orbitozygomatic approach; MPT, minipterional approach; MTAs, microsurgical transcranial approaches; PT, pterional approach; SBF, subfrontal approach with bilateral frontal craniotomy; SO, supraorbital approach; SUF, subfrontal approach with unilateral frontal craniotomy; TFI, transfrontal sinus interhemispheric approach.*

Anterior MTAs offer significant exposure of anterior targets, such as the CG, PPF, CP, and ER; for these regions, FIA and TFI provide a wider exposure than EEAs (Figure 5; **Supplement Digital Content**, http://links.lww.com/ONS/A758).

The orbital roof region is significantly exposed by both anterior and anterolateral MTAs (Figure 6; **Supplement Digital Content**, http://links.lww.com/ONS/A758). Endoscopic endonasal access to these more lateral regions of the ACF is prevented by the intrinsic

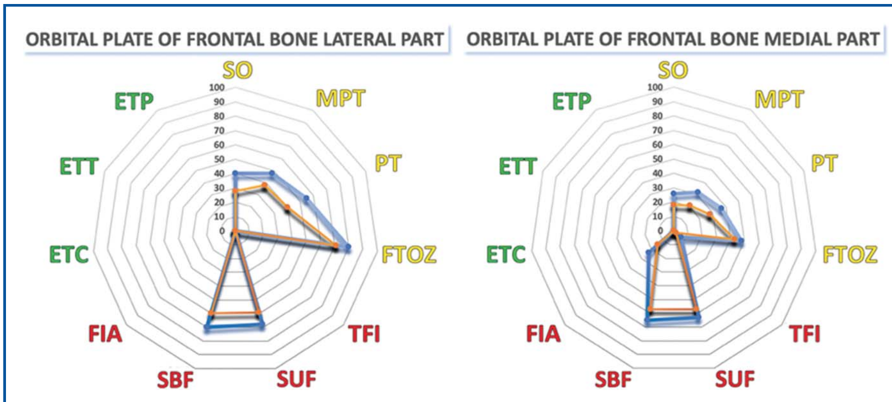

FIGURE 6. *Exposure of the orbital roof region offered by all studied approaches. The radar diagrams show the percentage value of the exposed area obtained by each approach for each surface, as measured in noncrossing (orange) and crossing (blue) modalities. Approaches are sorted clockwise in alphabetical order and grouped into anterolateral MTAs (yellow), anterior MTAs (red), and EEAs (green). EEAs, endoscopic endonasal approaches; ETC, endoscopic endonasal transcribriform approach; ETP, endoscopic endonasal transtuberculum-transplanum approach; ETT, endoscopic endonasal transtuberculum approach; FIA, frontobasal interhemispheric approach; FTOZ, frontotemporal-orbitozygomatic approach; MPT, minipterional approach; MTAs, microsurgical transcranial approaches; PT, pterional approach; SBF, subfrontal approach with bilateral frontal craniotomy; SO, supraorbital approach; SUF, subfrontal approach with unilateral frontal craniotomy; TFI, transfrontal sinus interhemispheric approach.*

limit of lateral extension of the EEAs.[13] On the other hand, the more the regions are lateral and anterior, the greater the exposure offered by the MTAs with the same retraction of the frontal lobes.[51]

EEAs offer a straight corridor to the anterior midline skull base structures. Exposure of the deeper posterior midline regions, such as the PS and the TS, offered by anterior MTAs is partially limited by the frontal lobes and olfactory routes. However, these regions can be reached with a maximal exposal rate by the corresponding EEAs (ETP and ETT) (Figure 5; **Supplement Digital Content**, http://links.lww.com/ONS/A758).[27-29,33]

Although the surgical corridor of the MTAs is limited by intracranial neurovascular structures, in the case of the EEAs, the limits of the approach are determined by the walls of the nasal cavities, reducing the risk of frontal lobe retraction-related damage with associated comorbidities. Despite the advantages in exposure of median and medial surgical targets offered by EEAs, the risk of cerebrospinal fluid leak still remains a problem to be addressed.[17,52,53] Thanks to the improvement of reconstructive surgery techniques,[53-55] this rate is being progressively reduced, thus limiting the major postoperative comorbidities of EEAs.[54-56]

A major consideration of ACF surgery is the possible invasion of the optic canals and encasement of the optic nerves. To safely operate and effectively remove lesions that are involved in this anatomy, a key step is exposing, and sometimes removing through drilling of its lateral limits, the anterior clinoid process. Our study elucidates an FTOZ or pterional approach that is best suited for this because they provide significantly more exposure to the posterolateral structures than the SO. Between these 2 approaches, we suggest using the FTOZ only when lesions extend superiorly, thus requiring removal of the zygoma and lateral orbital rim.

In clinical practice, to ensure gross total resection of the lesion, a purely endoscopic approach is not always possible although a combined cranioendoscopic approach (eg, massive frontal sinus involvement, dura, and brain infiltration) or a craniofacial resection (eg, intraorbital invasion and involvement of the anterolateral maxillary wall and hard palate) might be necessary.[53,57,58] Therefore, the choice of the best approach for the individual patient depends not only on the objective data of the exposure offered by a specific approach but also on the characteristics of the target lesion and the patient's performance status and comorbidities.

Limitations

This is a preclinical study, and possible distortions of intracranial anatomy in a clinical setting, such as mass effect or cerebrospinal fluid diversion, were not considered. Furthermore, fixation makes tissues stiffer and less elastic; this could lead to a reduction in the area of exposure offered by the single approach, both transnasal and transcranial.

Moreover, even the division between microsurgical and endoscopic approaches is somewhat artificial because the advantages of wide visualization can be exploited even with classic microsurgical approaches, using endoscope-assisted microsurgery or, in selected cases, pure endoscopic transcranial approaches.

CONCLUSION

This study highlights an anatomic basis for the emerging role of the EEAs in surgical treatment of ACF lesions, despite the limited

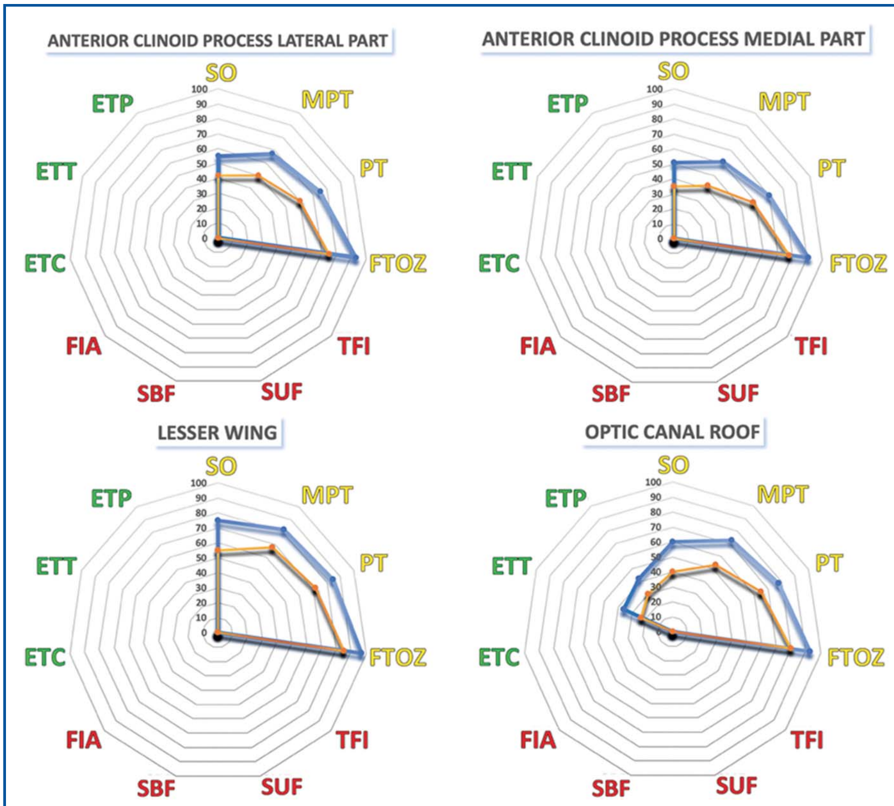

FIGURE 7. *Exposure of the posterolateral region offered by all studied approaches. The radar diagrams show the percentage value of the exposed area obtained by each approach for each surface, as measured in noncrossing (orange) and crossing (blue) modalities. Approaches are sorted clockwise in alphabetical order and grouped into anterolateral MTAs (yellow), anterior MTAs (red), and EEAs (green). EEAs, endoscopic endonasal approaches; ETC, endoscopic endonasal transcribriform approach; ETP, endoscopic endonasal transtuberculum-transplanum approach; ETT, endoscopic endonasal transtuberculum approach; FIA, frontobasal interhemispheric approach; FTOZ, frontotemporal-orbitozygomatic approach; MPT, minipterional approach; MTAs, microsurgical transcranial approaches; PT, pterional approach; SBF, subfrontal approach with bilateral frontal craniotomy; SO, supraorbital approach; SUF, subfrontal approach with unilateral frontal craniotomy; TFI, transfrontal sinus interhemispheric approach.*

lateral exposure offered. Anterior and anterolateral MTAs play a pivotal role in exposing the most anterior and posterolateral ACF regions, respectively. Furthermore, certain anterolateral approaches may be most useful when involvement of the optic canal and nerves is suspected. We believe that, even if limited to a preclinical setting, these findings can provide a valuable contribution to everyday neurosurgical practice and aid in the selection of the most accurate surgical approach.

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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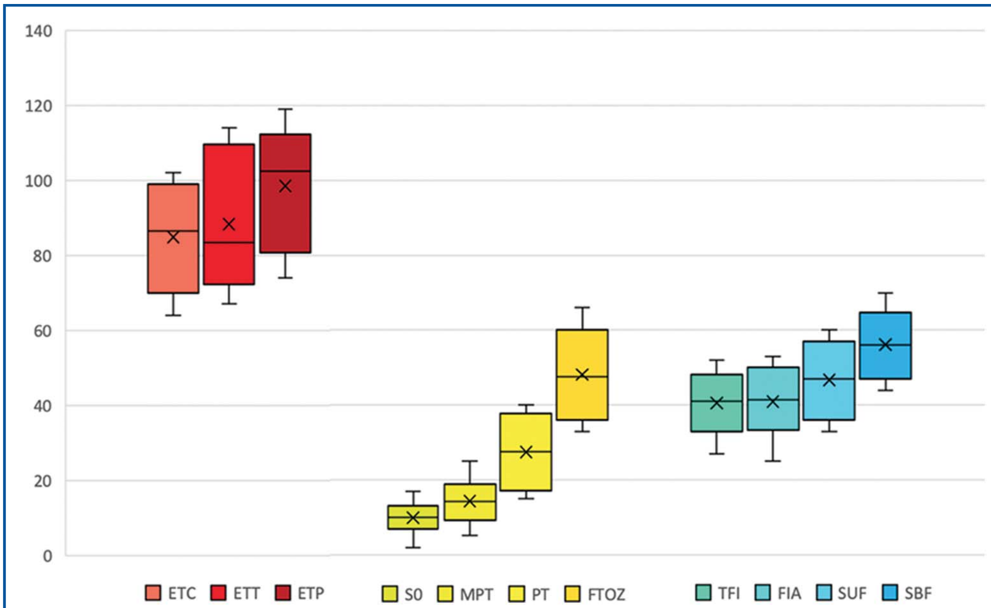

FIGURE 8. *Boxplots, graphical illustrations of surgical volumes. Red scale boxplots synthesize the data of the EEAs volumes, whereas anterolateral and anterior MTAs volumes are summarized in yellow and blue scales. EEAs, endoscopic endonasal approaches; ETC, endoscopic endonasal transcribriform approach; ETP, endoscopic endonasal transtuberculum-transplanum approach; ETT, endoscopic endonasal transtuberculum approach; FIA, frontobasal interhemispheric approach; FTOZ, frontotemporal-orbitozygomatic approach; MPT, minipterional approach; MTAs, microsurgical transcranial approaches; PT, pterional approach; SBF, subfrontal approach with bilateral frontal craniotomy; SO, supraorbital approach; SUF, subfrontal approach with unilateral frontal craniotomy; TFI, transfrontal sinus interhemispheric approach.*

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Acknowledgments

We would like to offer special thanks to Professor Luigi Fabrizio Rodella, who, although no longer with us, continues to inspire us by his dedication to the anatomical studies he performed over the course of his career.We thank Professor Manfred Tschabitscher, MD, PhD, for his guidance and support in the production of anatomical iconography.The authors acknowledge MedCure's provision of anatomical specimens.

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