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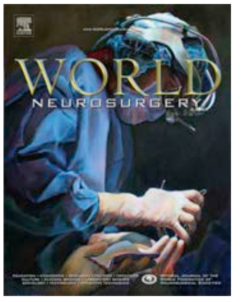

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SURGICAL FREEDOM EVALUATION DURING OPTIC NERVE DECOMPRESSION. LABORATORY INVESTIGATION.

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ABSTRACT

Background and aims. Various surgical routes have been used to decompress the intracanalicular optic nerve. Historically, a transcranial corridor was used, but more recently ventral approaches (endonasal and/or transorbital) have been proposed, individually or in combination. The present study aims to detail and quantify the amount of bony optic canal removal one may achieve via transcranial, transorbital and endonasal pathways. Additionally, the surgical freedom of each approach was analyzed.

Methods. In 10 cadaveric specimens (20 canals), optic canals were decompressed via pterional, endoscopic endonasal, and endoscopic superior eyelid transorbital corridors. The surgical freedom and circumferential optic canal decompression afforded by each approach was quantitatively analyzed. Statistical comparison was carried using a non-paired Student t-test.

Results. An open pterional transcranial approach allowed the greatest area of surgical freedom (transcranial: 10.9 ± 3.4 cm^2; transorbital 3.7 ± 0.5 cm^2; endonasal homolateral 1.1 ± 0.6 cm^2 and endonasal contralateral 1.1 ± 0.5 cm^2) with widest optic canal decompression when compared with the other two ventral routes (transcranial: 245.2°; transorbital: 177.9°; endona sal: 144.6°). These differences reached statistical significance for the transcranial approach.

Conclusions. This anatomical contribution provides a comprehensive evaluation of surgical access to the optic canal via three distinct, but complementary, approaches: transcranial, transorbital and endonasal. Our results show that, as expected, a transcranial approach achieved the widest degree of circumferential optic canal decompression and the greatest surgical freedom for manipulation of surgical instruments. Further surgical experience is necessary to determine the proper surgical indication for the transorbital approach to this pathology.

INTRODUCTION

Over the past few decades, several approaches have been proposed for decompression of the optic canal [1-18]. Historically, transcranial routes (i.e., pterional, supraorbital, and orbitozygomatic) were preferred for optic nerve decompression. In an effort to reduce morbidity, focus has shifted towards minimally invasive approaches, with endonasal and transorbital corridors gaining increasing support in the current literature [7, 19-22]. Recent anatomic contributions have eloquently quantified the extent of bony optic canal decompression one can obtain via ventral [19] and transcranial approaches, both individually and in combination. To date, the extent to which a surgeon may maneuver operating instruments using these approaches has not yet been analyzed. This concept is commonly described in the literature as “surgical freedom”; i.e. the maximum range of surgical instruments within the operative field [23]. Given the limited operative field and the abundance of critical neurovascular structures in the region, a detailed analysis of the exposure afforded by each of these routes is wanting, in order to refine the indications and support the choice of approach according to the pathology causing optic nerve compression.

A quantitative understanding of surgical freedom combined with recent anatomical data could provide significant insight when determining the best approach for optic canal decompression for various pathologies. This is the basis for the present laboratory investigation, in which we carried out a quantitative comparison of surgical freedom when approaching the optic canal via three different routes: transcranial, transorbital, and endonasal. In addition, we sought to provide a volumetric analysis of the bony removal afforded by each approach and a qualitative assessment of the effectiveness of each route, both alone and in combination. To our knowledge, this is the first contribution to the literature providing a comprehensive evaluation of surgical access to the optic canal via these three distinct, but complementary paths.

METHODS

Ten adult cadaveric specimens, without known intracerebral abnormality, were dissected. Anatomic dissections were performed at the Laboratory of

Neuroanatomy (Goodyear Laboratory) of the University of Cincinnati (OH, USA) and at the Laboratory of Surgical Neuroanatomy (LSNA) of the University of Barcelona (Spain). Cadavers were registered with the BrainLab Curve (Feldkirchen, Germany) for the acquisition of landmark points utilized in the calculation of operative exposure. A registration correlation tolerance of 2 mm was considered acceptable.

Dissections began macroscopically and then proceeded microscopically using a Leica operating microscope (Leica Microsystems, Inc., Buffalo Grove, IL). Endoscopy was performed using a rigid 4-mm-diameter endoscope, 14 cm in length, with 0° and 30° rod lenses (Stryker, Kalamazoo, Mic higan, USA). These were connected to a light source through a fiber optic cable and a video camera. Images were captured using a high-definition digital video system (Stryker, Kalamazoo, Michigan, USA). A high-speed drill and craniotome were used for bony removal. In five specimens, both transcranial and endonasal approaches were performed, while in the remaining five cadaveric heads both the transorbital and endonasal routes were evaluated.

Transcranial approach

Cadaveric heads were positioned supine, fixed in a Mayfield® Modified Skull Clamp (Integra, Plainsboro, NJ), rotated 5-10° to the contralateral side, and extended 10-15°. A curved incision was made immediately behind the hairline, extending from the zygoma to the midline. The temporalis muscle was then dissected subperiosteally and retracted in a single myocutaneous flap until the pterion was exposed. A standard pterional craniotomy (Figure 2A) and extradural anterior clinoidectomy were performed following our previously published technique [24] using a Budde® Halo Retractor System (Integra, Plainsboro, NJ) for exposure. Decompression proceeded with an operating microscope (Leica Microsystems, Inc., Buffalo Grove, IL) via a combination of a high-speed 3-mm drill and microdissectors. Bony decompression included the complete unroofing of the superolateral optic canal and optic strut, stopping prior to violation of the sphenoid sinus (Figure 2B). A C-shaped incision was then made in the dura and optic nerve decompression completed by sharply dividing the falciform ligament and optic nerve sheath (Figure 3). Thin-cut CT scans were then repeated to confirm circumferential decompression.

In four specimens, the transcranial approach preceded the endonasal procedure with CT imaging between stages to ensure accuracy of measurements.

Endoscopic transorbital approach

Specimens were positioned supine, pinned, and fixed with a Mayfield head holder, rotated 5° laterally to the contralateral side. Skin incision was placed in the superior eyelid in a supratarsal skin crease, as previously described [25]. The orbicularis oculis muscle was divided parallel to its fibers and the frontal process of the zygoma was exposed laterally. The periosteum covering the zygoma was cut and dissected sharply toward the orbit, where it continued with the periorbita. This layer was followed to the orbital septum and then into the orbit using a no.1 Penfield dissector. Dissection proceeded in this plane until the inferior and superior orbital fissures were reached. At this point, a 0° endoscope was introduced into the upper portion of the surgical window to monitor the subsequent steps. A malleable retractor was placed to deflect the orbital contents inferomedially and to create space for further dissection, as the optic canal is medial to the superior orbital fissure. Bony decompression of the optic canal was achieved by removing portions of the greater and lesser wings of the sphenoid, which form the lateral portion of the optic canal. Finally, in some specimens, anterior clinoidectomy was required for adequate optic decompression from this approach.

Endoscopic endonasal approach

Through a binostril approach, a middle turbinectomy, posterior ethmoidectomy, wide sphenoidotomy, and posterior nasal septectomy were performed. Removal of the uncinate process and medial antrostomy allowed for access to the inferior and medial orbital walls. The medial orbital wall, namely the thin lamina papyracea, was removed to expose the proximal optic nerve as it exits the annulus of Zinn and enters the canal. Unroofing of the medial optic canal was performed in a proximal to distal fashion to the lateral edge of tuberculum sellae via a blunt dissector and gentle drilling, uncovering the intracanalicular portion of the optic nerve. The optic sheath was then opened using a sickle blade, taking care to avoid injury to the annulus of Zinn. The sheath was opened superiorly to avoid injuring the ophthalmic artery, which courses inferior to the nerve.

Data acquisition and statistical analysis

Osirix MD software (OsiriX; Osirix Foundation, Geneva, Switzerland) was used to quantitatively analyze the degree of bony optic canal decompression. Then, the surgical freedom was calculated as described by de Notaris and Prats-Galino [23, 26] using the midpoint of the intracanalicular optic nerve as the base for the stereotactic pointer.

For each approach, points for calculating surgical freedom were acquired as follows: p_1, the point of maximal cranial extension in the direction of the nasion; p_2, the point of maximal caudal extension in the cephalad direction to the vertex; p_3, the point of maximal lateral extension toward the external acoustic meatus; and p_4, the point of maximal medial extension toward the nasal septum. Cartesian coordinates of each point were then obtained from the BrainLAB working station, which yielded three vectors that were used to delineate two juxtaposed triangles. Surgical freedom was then calculated as the sum of the area of these two triangles. The horizontal angle of attack was retrieved by merging p_1 and p_2 with the optic nerve point while the vertical angle of attack was measured by connecting p_3 and p_4 with this target.

The virtual 3D model of the surgical freedom related to each routes was created using Amira Visage Imaging (Amira Visage Imaging Inc., San Diego, California, USA). Bony structures were segmented and surgical freedom areas were then represented using advanced instruments for measurement and quantification provided by the Amira workstation.

All data were uploaded into Microsoft Excel, and the non-paired Student t-test function was used to calculate statistical differences among approaches.

RESULTS

Anatomic observations

A pterional craniotomy combined with extradural clinoidectomy allowed for extensive decompression of the superolateral optic canal. After drilling down the lesser sphenoid wing, the lateral limit of the superior orbital fissure was identified for anatomic orientation to the optic canal. Along with unroofing of the superior canal, the anterior clinoid process and optic strut were removed in an extradural fashion. Next, the falciform ligament was incised, thus achieving a wide superolateral decompression of the intracanalicular optic nerve with relative ease and safety.

Alternatively, the transorbital pathway permitted access to the most lateral aspect of the optic canal from a ventrolateral vantage point. The optic canal was exposed by following the lesser sphenoid wing and retracting the orbital contents inferomedially. From this window, borders of the optic canal could be appreciated, namely the superior orbital fissure laterally and the posterior ethmoidal artery running in its foramen medially. The optic canal was then decompressed laterally and the optic nerve could be followed intracranially to the optic chiasm.

Lastly, the endonasal approach provided access to the inferomedial optic canal that protrudes into the sphenoid sinus. Decompression of this border of the optic canal proceeded after removal of the lamina papyracea as described above. The exposure of the intracanalicular portion of the optic nerve, surrounded by the optic sheath, was followed to the orbital apex, where the nerve passes through the annulus of Zinn at the proximal limit of the canal. After bony decompression, the intracanalicular dura was opened to the level of the tuberculum sellae, exposing the intracranial part of the optic nerve, as well as the ophthalmic artery as it branches off the supraclinoidal internal carotid artery and courses most commonly in the inferomedial canal (Figure 1).

Decompression analysis

Quantitative analysis of the degree of optic canal decompression obtained through each of the three operative routes revealed significant differences between three corridors. The pterional approach with anterior clinoidectomy provided the largest circumferential decompression with a mean of 245.2° (range 211.0° - 277.5°). Conversely, the transorbital endoscopic pathway afforded an average of 177.9° of circumferential decompression (range: 171.8°- 273.5°), whereas the endoscopic endonasal route averaged 144.6° (range 109.8°- 180. 2°) circumferential decompression (Figure 2).

When considering the total circumference of the optic canal (360°), the transcranial pathway allowed for decompression of the superolateral 68.1% circumference of the optic canal; the transorbital route provided removal of the most lateral 49.9% of the optic canal; and the endonasal approach afforded a 40.2% decompression of the most inferomedial aspect of the canal. Only the difference between the transcranial and endonasal approaches was found to be statistically significant ($p < 0.01$) (Graph 1, Table 1).

Surgical freedom and angle of attack

The transcranial approach provided the greatest surgical freedom (10.9 ± 3.4 cm^2), followed by the transorbital approach (3.7 ± 0.5 cm^2), and lastly, the ipsilateral (1.1 ± 0.6 cm^2) and contralateral (1.1 ± 0.5 cm^2) endonasal corridors, respectively (figure 3). The increased maneuverability of the transcranial route was statistically significant when compared to all other routes, whereas the surgical freedom of the transorbital approach was significantly greater than that of the endonasal route (Figures 3 and 4, Table 2).

Further analysis revealed that the angle of attack to the optic nerve in the horizontal plane was greatest for the transcranial route (73.632 ± 8.57 degrees), followed by the transorbital approach (27.40 ± 3.38 degrees), and lastly the endonasal ipsilateral (14.12 ± 2.62 degrees) and contralateral (13.54 ± 3.38 degrees) corridors, respectively. These differences also reached statistical significance (Table 3).

The angle of approach to the optic nerve attained in the vertical plane was greater for the transcranial versus the transorbital approach, although this did not reach statistical significance. However, the, both ipsi- and contralateral endonasal pathways, provided a statistically significantly lower vertical angle of attack to the optic nerve than both transcranial and transorbital routes (Table 3).

DISCUSSION

The results of this study have shown that the transcranial approach affords the greatest surgical freedom and degree of optic canal decompression when compared to the alternative minimally invasive corridors to this region.

Several pathologies, both extra- and intracranial, may cause compressive optic neuropathy [27-29]. Anterior skull base meningiomas (i.e, suprasellar and parasellar region, optic nerve sheath, or olfactory groove) represent the most common oncologic source of compression of the optic nerve in its canal. Tumors typically result in visual loss secondary to intracranial and/or intracanalicular compression of the optic nerve [30, 31]. An additional "strangling" effect may occur at the level of the optic canal as it transitions from its bony, rigid optic canal into the suprasellar region, where the optic nerve(s) and chiasm, denuded of any circumferential fixating structures may be displaced and angulated at the level of the optic foramen.

Historically, transcranial approaches have been the preferred method for optic canal decompression. More recently, reports in the literature have gravitated towards endonasal and minimally invasive microscopic approaches in an effort to reduce morbidity and decrease hospitalization. Optic nerve decompression has also been reported using those techniques [7].

In the present study, we performed a quantitative analysis of three different pathways that may be used to reach the optic canal: transcranial, transorbital and endonasal. A pterional craniotomy allowed for wide decompression of the optic nerve However, with such route, it was difficult to access the inferomedial aspect of the ipsilateral optic canal. Recent literature has identified the trans- and supra-orbital corridors as viable options for access to the anterior and middle skull base [1-11]. Call et al [32] were the first to describe optic nerve decompression through a transorbital approach in a series of eight patients. Since that time, the explosion of endoscopic skull base surgery for the management of a wide range of pathology has propelled both the development of new techniques and the refinement of established procedures, e.g. the transorbital approach. Accordingly, this ventromedial trajectory, with the aid of the endoscope, may be a valuable option for accessing the superolateral optic canal in addition to other anterior and middle cranial fossa pathology in select situations. At this juncture, transorbital neuroendoscopic surgery (TONES) has been advocated for a variety of indications, with or without removal of the orbital rim and/or frontal bone [16]. In a recent publication, Dallan et al. [10] adopted the superior eyelid approach to access the lateral and superolateral walls of the orbit in addition to anterior and middle cranial fossa lesions, for tumors such as spheno-orbital meningiomas. Combined with endoscopic visualization, this could be extrapolated to minimally invasive optic canal decompression. Although this approach addresses a similar region of the canal as a the orbito-pterional or fronto-orbitozygomatic approaches, it requires a minimal skin incision, shorter surgical time, necessitates zero brain retraction, and potentially decreases idiopathic trauma to orbital structures, and allows for faster recovery.

The other ventral pathway that we analyzed in our study was the transnasal endoscopic route. Initially reserved for the management of paranasal sinus disease, this route has become widely accepted as a minimally invasive approach for a variety of locations of the skull base. This includes endoscopic endonasal decompression of the orbit and optic nerve, which has become a valid treatment for thyroid-related orbitopathy and select cases of traumatic optic neuropathy [1, 3].

From a surgical standpoint, the location of optic canal compression should dictate the choice of surgical approach between endoscopic and open surgical approaches, especially in the case of tumor resection. Thus, comprehensive preoperative assessment of the location and degree of optic canal invasion is critical for selecting the optimal approach. As a matter of fact, compression of the optic nerve in the superior part of its canal may mandate a transcranial approach whereas a more infero-medial pahotlogy may suggest to use a ventral route like the endonasal one. The specific indications for the transorbital pathway have not been yet clarified in proper surgical series, and further surgical experience on this approach and associated repair techniques are wanting.

In conclusion, we have shown that a transcranial approach allows for the greatest surgical freedom and degree of optic canal decompression when compared to other plausible minimally-invasive corridors to this region. These approaches, which should be considered complementary, offer the skull base surgeon an array of options for treating pathology in this area. A thorough, thoughtful evaluation of the offending pathology causing optic nerve compression is mandatory to decide the best strategy and application of this full complement of approaches to the optic canal.

Limitations

Cadaveric specimens are useful models to investigate surgical approaches, but they do not fully replicate the clinical environment. Particularly concerning the endoscopic transorbital approach, one must consider the amount of orbital content retraction that may be tolerated in the operative versus laboratory setting. To this point, orbital retraction has been well tolerated without any significant reported complications. Intraoperative globe tonometry might be a useful adjunct to determine the maximal safe degree of globe retraction. Alternatively, intermittent relief from retraction (dynamic retraction) could be useful to protect the globe from undue pressure.

Additionally, it is important to stress that our quantitative measurements must be interpreted as rough values and cannot be analyzed with strict statistical methods. These data represent the arithmetic mean of each parameter, and therefore can be used primarily for surgical orientation and instruction and not as absolute reference values for all clinical scenarios, as individual anatomy can be widely variable. Further experience and thorough scrutiny of intraoperative observations must be undertaken to better determine the utility of the transorbital approach to this location. Surgeon experience and preference should be weighed in the context when selecting the most appropriate surgical approach.

CONCLUSION

This study provides a comprehensive quantitative analysis of surgical access to the optic canal via three distinct but complementary pathways: transcranial, transorbital and endonasal. Our results show that a transcranial approach achieved the widest degree of circumferential optic canal decompression and the greatest area of surgical freedom of instruments. Further surgical experience is needed to determine the proper indications for each procedure. However, it has to be stressed that the present contribution is merely a quantitative anatomic study of optic canal decompression via different neurosurgical routes. Our hope is to contribute to the understanding of the anatomy and the capabilities of various surgical approaches to the optic nerve, including a relatively novel avenue in the superior eyelid transorbital endoscopic approach. The limits of clinical applications should be considered as a separate issue that will deserve additional study which are currently ongoing.

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LEGENDS FOR FIGURES & GRAPHS

Figure 1: Anatomic cadaveric pictures showing optic nerve decompressed via pterional (a), endoscopic transorbital (b), endoscopic endonasal (c) paths. The relationships with the surrounding structures are highlighted. ON, optic nerve; PS: planum sphenoidale; Or, orbital roof; Ch, optic chiasm; O, orbit; PEA: posterior ethmoidal artery; AEA: anterior ethmoidal artery; CP, cribriform plate; S: sella; ICA: internal carotid artery.

Figure 2: Three-dimensional representation obtained with Osirix MD software (OsiriX; Osirix Foundation, Geneva, Switzerland) of the optic nerve decompression via different surgical routes (a). The degree of optic canal removal is shown in coronal section (b). Green, transcranial pterional; red, transorbital; yellow, endonasal.

Figure 3: Three-dimensional representation in a ventral perspective of the surgical freedom areas calculated after different approach to the optic nerve. Green (transcranial pterional), red (transorbital), yellow (endonasal homolateral) and orange (endonasal contralateral). The 3D reconstruction has been obtained in an example specimen using Amira Visage Imaging.

Figure 4: Representation of the surgical freedom with a 3D reconstruction oriented in the axial plane and showing the different surgical freedom areas to the optic nerve. Green (transcranial pterional), red (transorbital), yellow (endonasal homolateral) and orange (endonasal contralateral). The 3D reconstruction has been obtained in an example specimen using Amira Visage Imaging.

Graphic 1: Degree of optic canal removal obtained via the different surgical approaches (transcranial in green; transorbital in red; endonasal in yellow). The difference between transcranial and endonasal optic canal removal was found to be strongly statistically significant (**, $p < 0.01$). On the other hand, the transcranial optic nerve decompression achieved a higher and statistically significant degree of bone removal if compared with the transorbital approach (*, $p < 0.05$).

Graphic 2: Surgical freedom evaluation during transcranial pterional, transorbital and endonasal homolateral and contralateral approaches to the optic canal. The increased maneuverability of the transcranial route was statistically significant when compared to all other routes (*, $p < 0.01$). Further, the surgical freedom obtained with the transorbital approach was significantly greater than endonasal ones (*, $p < 0.01$).

Graphic 3: Horizontal angle of attack to the optic canal via the different routes used in the study. This angle of attack to the optic nerve in the horizontal plane was greatest for the transcranial route when compared with all the other approaches (*, $p < 0.01$). The transorbital horizontal angle of attack was found to be greater when compared to the one obtained with the endonasal pathways (*, $p < 0.01$).

Graphic 4: Vertical angle of attack to the optic canal. This angle of attack was greater for the transcranial versus the transorbital approach but this difference did not reach statistical significance. On the contrary, both transcranial and transorbital paths reserved greater vertical angles of attack if compared with the endonasal routes (*, $p < 0.01$).

	Transcranial (TC)	Transorbital (TO)	Endonasal (E)	*p-value*		
				TC vs. TO	TO vs. E	TC vs. E
Angle of decompression	245.20 ± 18.8 (68.11%)	177.90 ± 65.61 (49.93%)	144.61 ± 26.87 (40.22%)	p=0.0311	p=0.0891	p<0.01

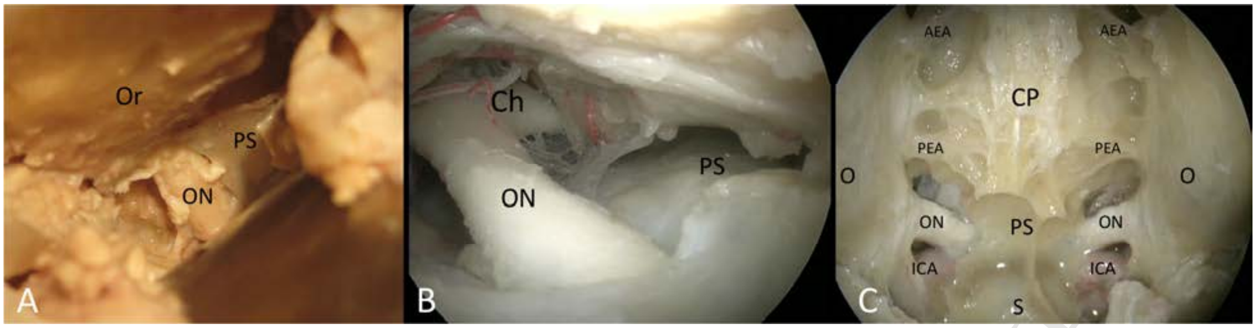
Table 1. Quantitative analysis of optic nerve decompression via pterional transcranial (TC), endoscopic superior eyelid transorbital (TO) and endoscopic endonasal (E) approaches. p-value, non-paired Student t-test; percentages are refereed to the total volume of the optic canal (100%).

	Transcranial (TC)	Transorbital (TO)	Endonasal contralateral (EC)	Endonasal omolateral (EO)	*p-value*					
					TC vs. TO	TO vs. EC	TO vs. EO	TC vs. EC	TC vs. EO	EC vs. EO
Surgical Freedom	10939.09 ± 3361.46	3717.91 ± 493.30	1114 .52 ± 555.72	1091.03 ± 518.29	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p=0.931

Table 2. Surgical freedom analysis during pterional transcranial (TC), endoscopic superior eyelid transorbital (TO) and endoscopic endonasal contralateral (EC) and homolateral (EO) approaches for optic nerve decompression. p-value, non-paired Student t-test.

	Transcranial (TC)	Transorbital (TO)	Endonasal contralateral (EC)	Endonasal homolateral (EO)	*p-value*					
					TC vs. TO	TO vs. EC	TO vs. EO	TC vs. EC	TC vs. EO	EC vs. EO
Horizontal angle	73.632 ± 8.57	27.40 ± 3.38	14.12 ± 2.62	13.54 ± 3.38	p<0.01	p<0.01	p<0.01	p<0.01	p<0.01	p=0.7097
Vertical angle	32.91 ± 7.42	28.08 ± 4.25	16.02 ± 4.50	16.22 ± 2.59	p=0.1324	p<0.01	p<0.01	p<0.01	p<0.01	p=0.9125

Table 3. Angle of attack during pterional transcranial (TC), endoscopic superior eyelid transorbital (TO) and endoscopic endonasal contralateral (EC) and homolateral (EO) approaches for optic nerve decompression. p-value, non-paired Student t-test.


Or
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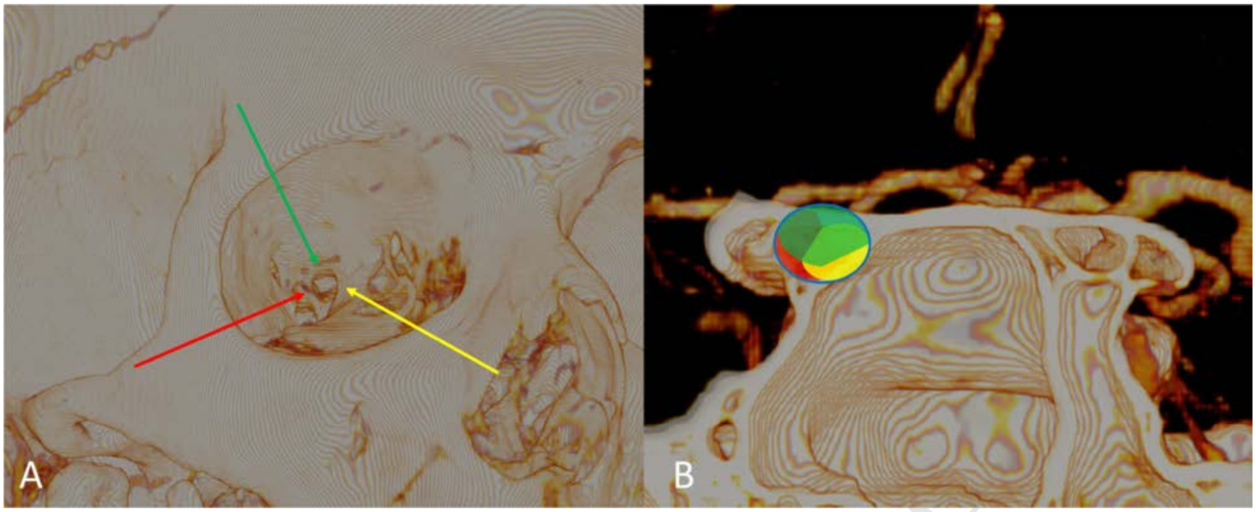
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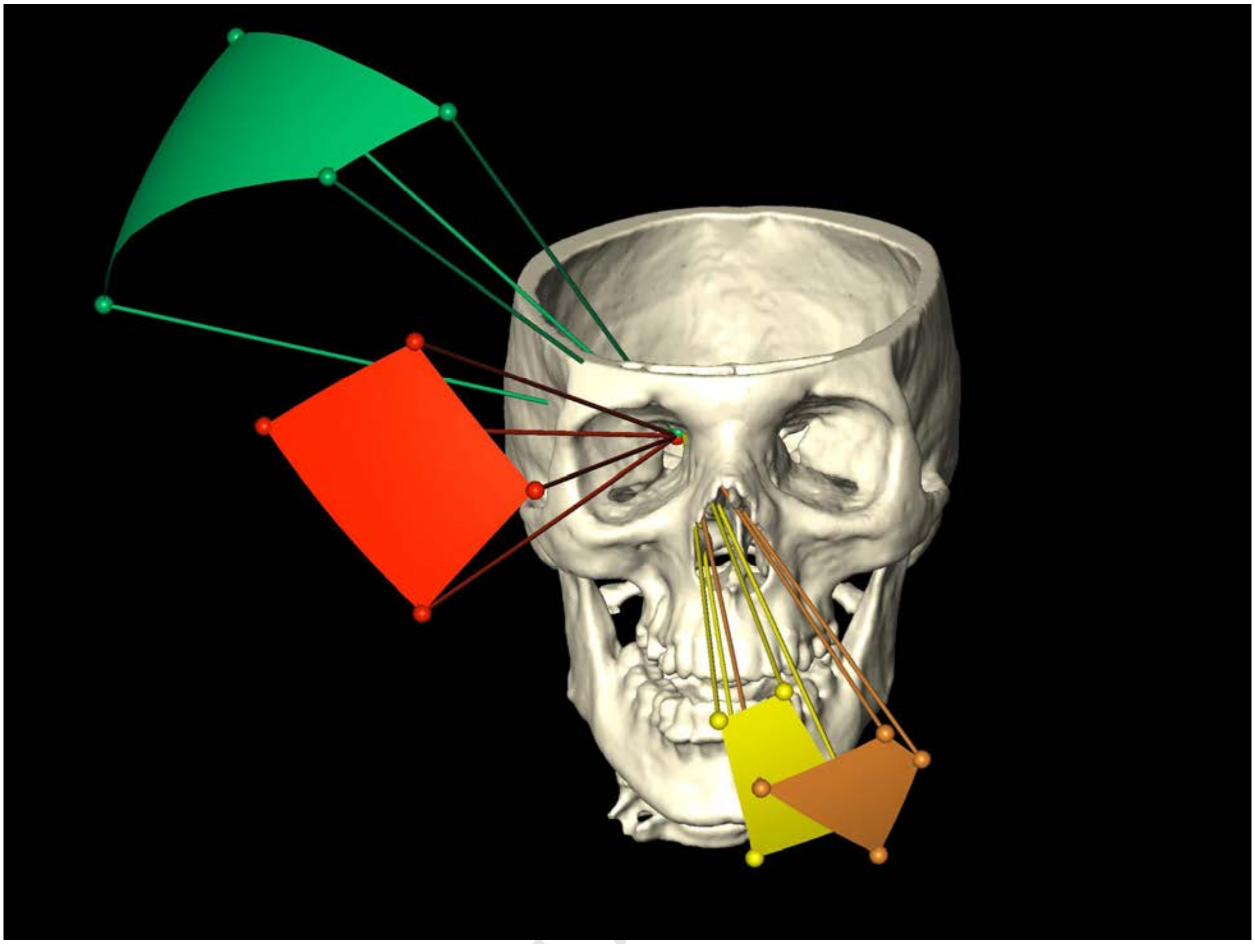
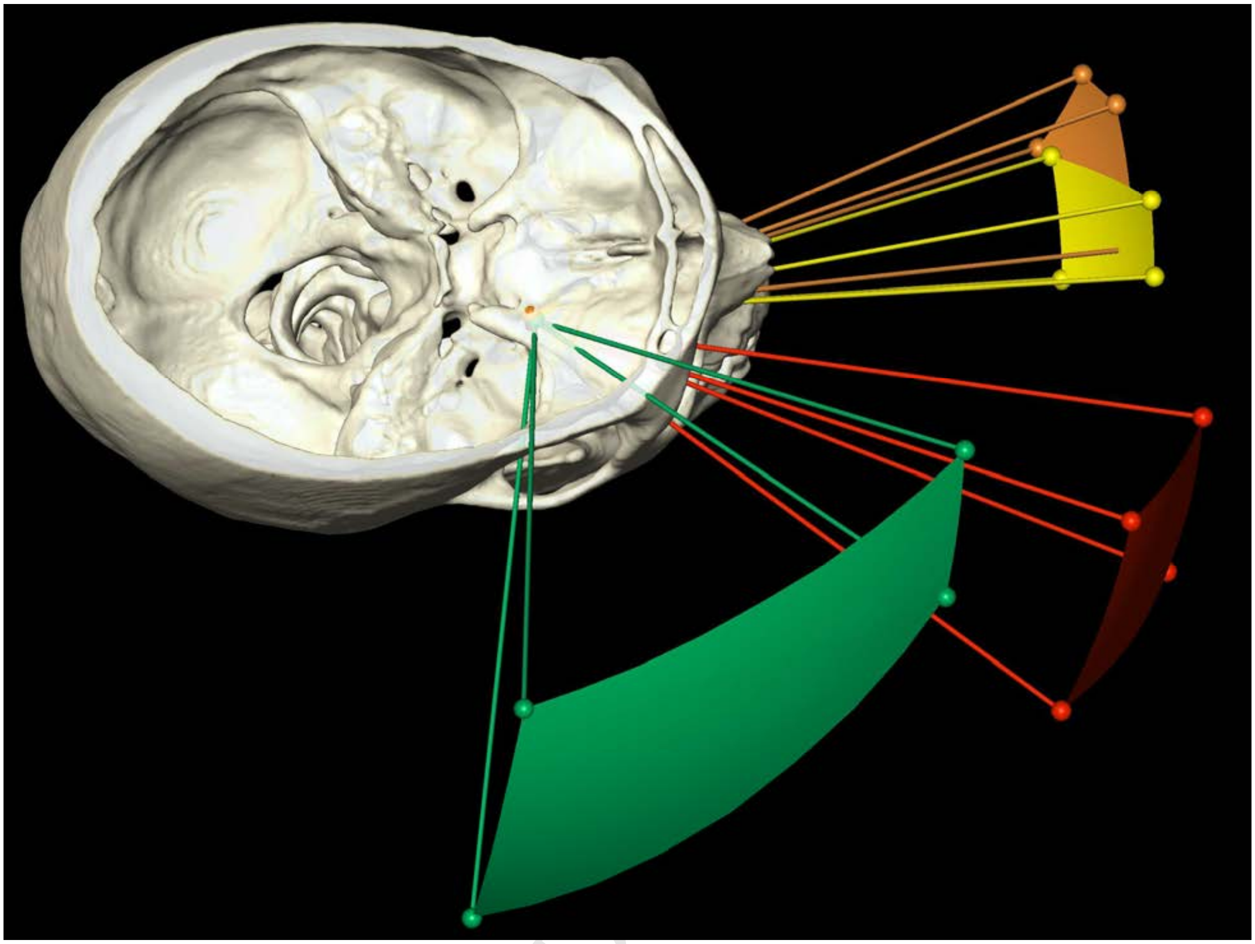
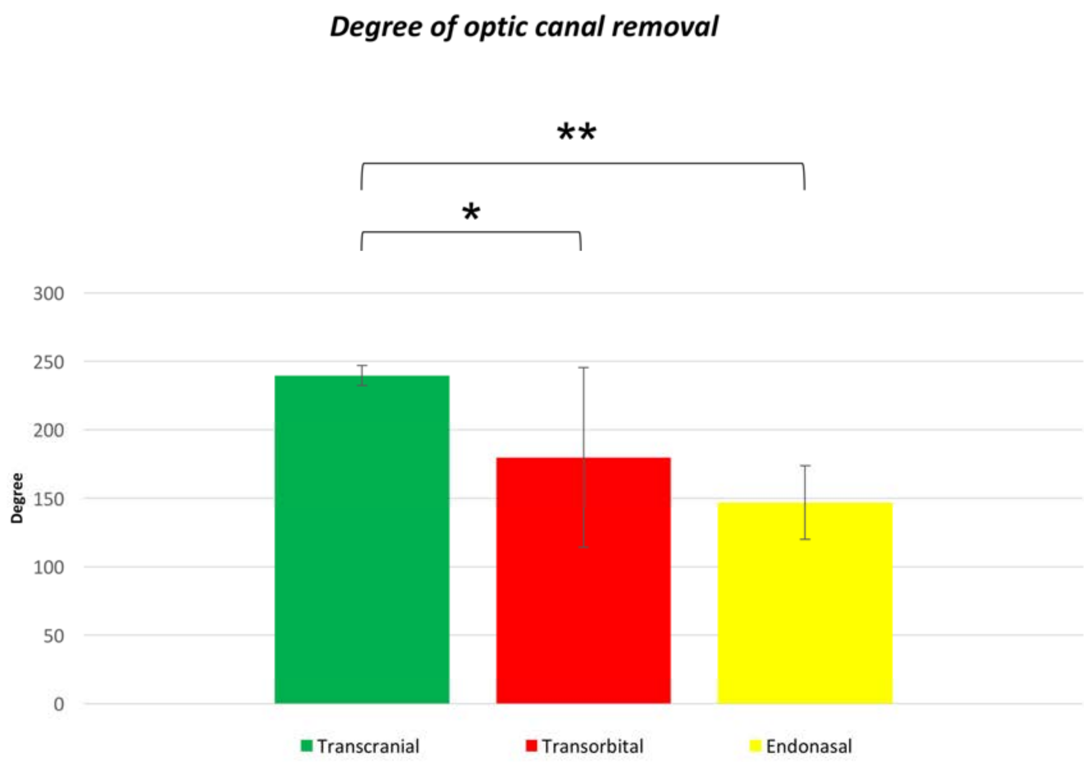
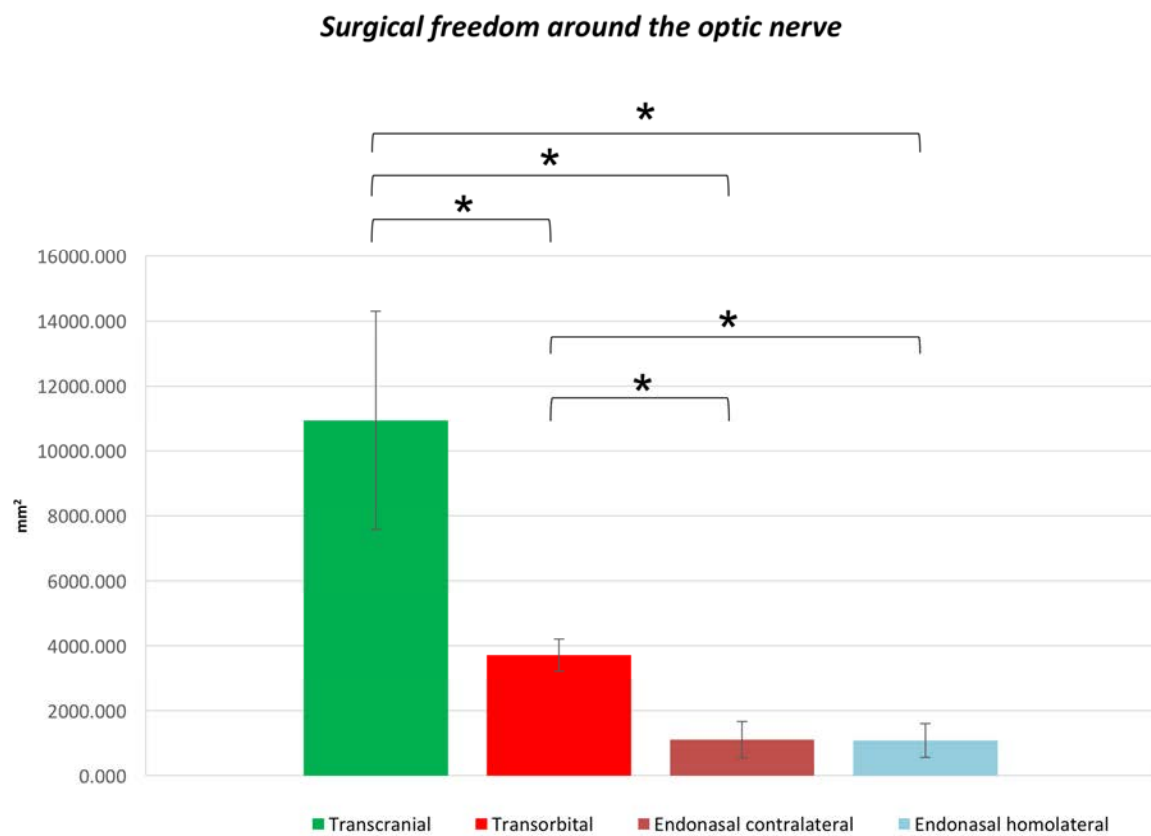
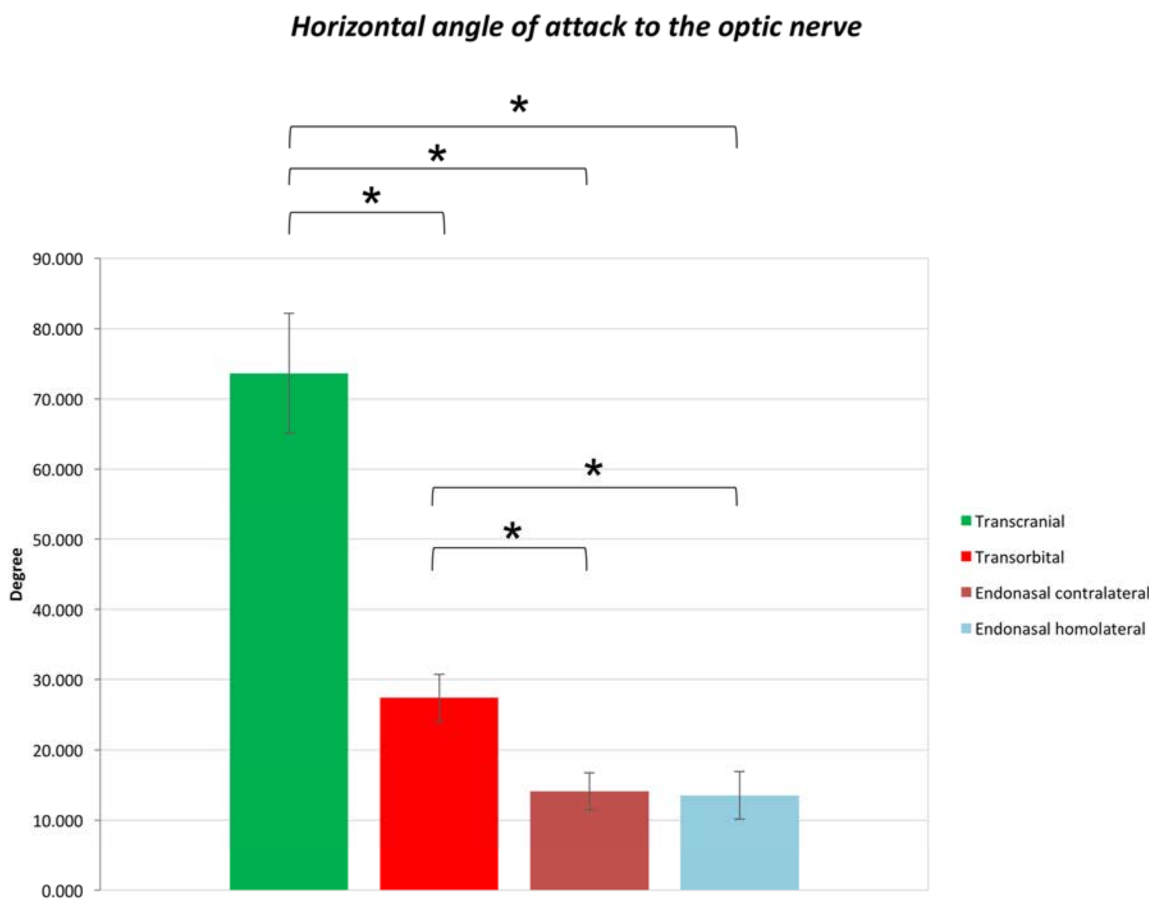
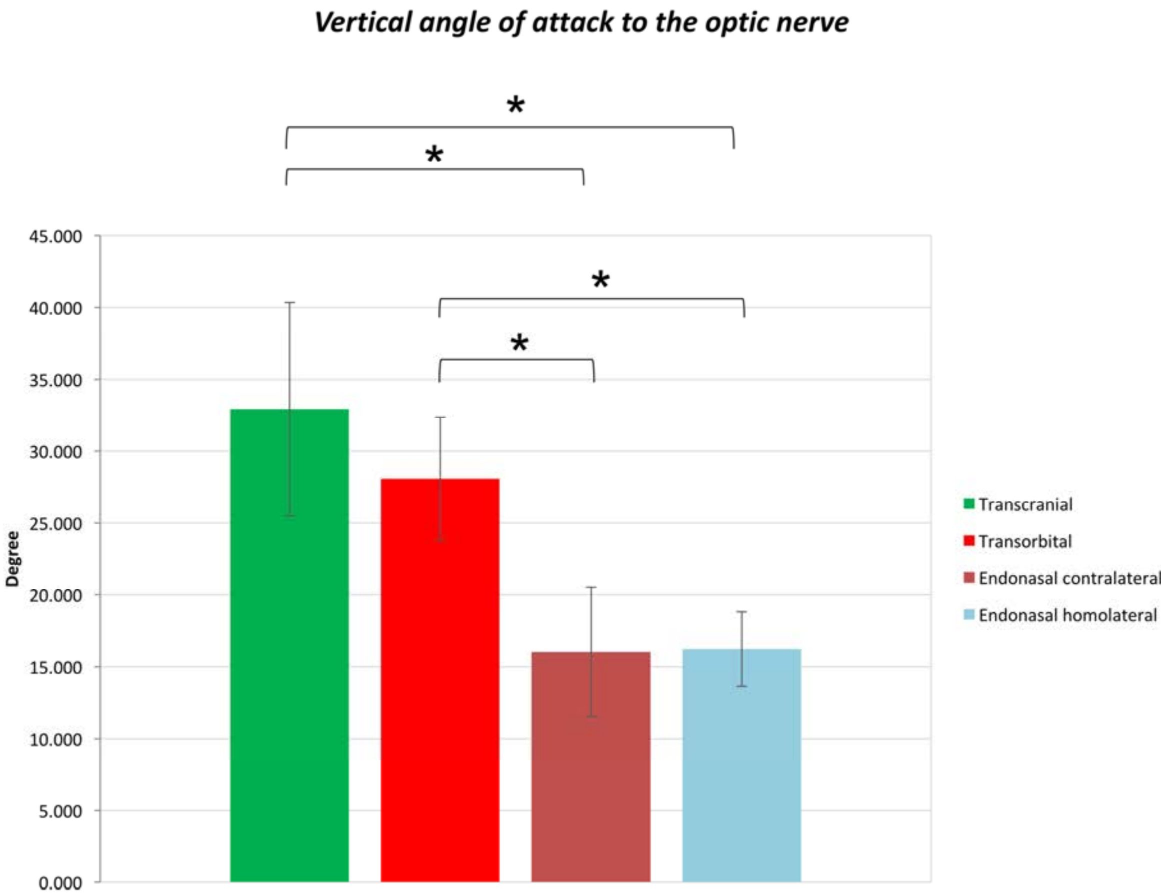





Degree of optic canal removal
**
*
300
250
200
150
100
50
0
Degree
Transcranial
Transorbital
Endonasal


Surgical freedom around the optic nerve
*
*
*
*
*
16000.000
14000.000
12000.000
10000.000
8000.000
6000.000
4000.000
2000.000
0.000
mm²
Transcranial
Transorbital
Endonasal contralateral
Endonasal homolateral


Horizontal angle of attack to the optic nerve
*
*
*
*
*
90.000
80.000
70.000
60.000
50.000
40.000
30.000
20.000
10.000
0.000
Degree
Transcranial
Transorbital
Endonasal contralateral
Endonasal homolateral


Vertical angle of attack to the optic nerve
*
*
*
*
45.000
40.000
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
Degree
Transcranial
Transorbital
Endonasal contralateral
Endonasal homolateral

- ✓ This paper provides a comprehensive evaluation of surgical access to the optic canal;
- ✓ Three distinct, but complementary, approaches have been tested: transcranial, transorbital and endonasal;
- ✓ Angle of optic canal decompression and surgical freedom analysis has been calculated;
- ✓ The transcranial approach achieved the widest degree of circumferential optic canal decompression and the greatest area of surgical freedom.