https://doi.org/10.46351/jas.v32i2pp66-77

JAS Journal of Anatomical Sciences (U.P. Chapter of Anatomical Society of India)

Original Article

Morphometric analysis of dried skulls for optimization of transorbital approaches to middle cranial fossa: Anatomic insights for surgical planning

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ABSTRACT

Introduction: The structures in the middle cranial fossa are challenging to assess due to complex placement and relations. Recent advances like transorbital approach offers a direct route to cranial targets via the orbit, reducing manipulation of neurovascular structures and improving postoperative outcomes. However, there is limited data on distances between orbital rim landmarks and key cranial structures. This study aims to provide critical quantitative data to support precise intracranial navigation.

Materials and Methods: The study analyzed 43 human skulls of unknown age and sex. Linear distances from the superolateral angle and supraorbital notch of the orbital rim to key landmarks in the middle cranial fossa were measured using ImageJ software. Linear distance of important landmarks pertaining to transorbital approach from lateral orbital rim were recorded. Data was statistical analyzed using GraphPad Prima 8.0.2.

Results: All the linear distances obtained between the key landmarks in middle cranial fossa like trigeminal fossa, foramen ovale, spinosum and rotundum; carotid sulcus upto supraorbital notch were less then those obtained from frontozygomatic suture. Bilaterally structures showed consistency (Student's t-test, $p = 0.6624$).

Conclusions: This study provides precise, reproducible measurements that can guide surgeons in locating critical middle cranial landmarks for safe navigation into the orbital and cranial cavity during transorbital neuroendoscopic surgeries. These findings will be valuable for both anatomical education and neurosurgical practice.

Keywords: Trigeminal fossa, Carotid sulcus, Foramen ovale, Foramen spinosum, Foramen rotundum, ImageJ

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Date of Receiving: 27 Aug 2024
Date of Acceptance: 29 Sep 2024

INTRODUCTION

The middle cranial fossa is a complex space which houses several important neurovascular structures which are placed in intricate relation to each other [1]. These neurovascular structures may get susceptible to pathologies, tumours and congenital anomalies making this area clinically significant. However complex placement of these structures, makes it challenging for the neurosurgeons and interventional radiologists to navigate towards their target through this cavity [1, 2]. Following popularization of endoscopic approach, several routes (transnasal, supraorbital and transorbital) have been defined to assess structures present over central skull base. Endoscopic transorbital approach offers a direct and minimally invasive approach to targets in orbit and middle cranial fossa. It was first defined by Mois in 2010 and has recently gained notoriety amongst neurosurgeons [3].

Anatomically, middle cranial fossa is divided into sellar and parasellar portions. Sellar region contains pituitary gland resting on sella turcica [1]. The parasellar region comprises of critical neurovascular structures like cavernous sinus, internal carotid artery, cranial nerves, meckle's cave with Gasserian ganglion along with V1, V2, V3 branches and middle meningeal artery. Endoscopic transorbital approach offers a narrow and safe corridor to address small lesions in parasellar and lateral part of middle cranial fossa [4].

The cavernous venous sinus is highly vulnerable space. Several cranial nerves (oculomotor, trochlear, ophthalmic, abducent) and internal carotid artery are contained in the wall and cavity of cavernous sinus. Tumor, congenital anomaly, infection and vascular pathology like carotidocavernous fistula and carotid aneursym may involve one or more compartments of cavernous sinus. Endoscopic transorbital route offers a promising approach to expose all the regions (Dolenc's/Clinoid triangle, supratrochlear triangle, Parkinson's/infratrochlear triangle, Mullan's /anteromedial triangle, anterolateral triangle) defined except Hakuba/oculomotor triangle which needs transnasal approach. Also, transorbital corridor provides a safer route to assess carotid aneurysm in the paraclinoid part of internal carotid artery for surgical clipping [2]. When transvenous endovascular embolisation via facial vein or inferior petrosal sinus is challenging then transorbital endoscopic approach provides an alternate surgical approach to obliterate these carotidocavernous fistula [5].

In past few decades, transorbital neuroendoscopic surgical (TONES) approach has gained popularity. It has opened a safe and minimally invasive corridor to expose structures present in anterolateral aspect of middle cranial fossa i.e. parasellar and lateral aspect of cranial cavity up to petrous temporal bone which cannot be reached by endonasal approach [6]. In transorbital approach, upper eyelid crease curvilinear skin incision is placed to identify orbital septum and to create surgical plane deep to orbicularis oculi.

On reaching orbital rim, periorbita is elevated to navigate antero-posteriorly inside the orbital cavity. During endoscopic approach the lateral wall of orbital cavity displays two important anatomical landmarks. One is consistently seen in all skulls- frontosphenoid suture, the key landmark to decide the site of bone drilling beyond which dissection continues in a plane deep to periorbita till the lateral margin of superior orbital fissure (SOF) & inferior orbital fissure (IOF) is identified [7]. Second landmark is meningo-orbital foramen [8]. Several names attributed to meningo-orbital foramen are- craniorbital foramen, lacrimal foramen, foramen of Hyrtl, sphenofrontal foramen, sinus canal foramen and anastomotic foramen [9].

The meningo-orbital/ orbito-lacrimal artery may be the orbital branch of middle meningeal artery or anastomosis between the orbital branch of middle meningeal artery and lacrimal artery [10]. This foramen is an inconstant but important landmark for SOF & IOF. The meningo-orbital vessels are potential source of significant haemorrhage hence mandates careful dissection of lateral orbital wall. This reflects the significance of knowing prevalence and anatomical details of this foramen [8]. Intraorbital part of greater wing of sphenoid is drilled to expose temporal dura. Interperiosteal dural dissection via meningo-orbital band to reach lateral wall of cavernous sinus and Gasserian ganglion is done. Middle meningeal artery supplying duramater is cut to prevent the intraoperative haemorrhage.

Despite the plethora of work done to describe different ways to transorbitally approach middle cranial fossa, there is a paucity of reports providing quantitative data to be used to carefully navigate through orbit to reach targets in middle cranial fossa. Hence the aim of current study was to provide quantitative anatomical data from orbital rim to paramedian and lateral structures in middle cranial fossa. The study also provides data of important landmarks in lateral wall of orbital cavity. Any anatomical variation in the route may create dilemma during surgery, hence awareness about the possible bony and vascular variations is important.

MATERIAL AND METHODS

A cross-sectional survey was conducted on 43 dry human skulls (without calvaria or cranium) of unknown age and sex, sourced from the Department of Anatomy, Maulana Azad Medical College (MAMC), New Delhi.

Sample size was calculated using the equation $n = (Z_{1-\alpha/2}^{2}\ p(1-p))/ d^{2}$

where n is the estimated sample size, $Z_{1-\alpha/2}$ is the standard normal variate (at a 5% type I error ($P < 0.05$), it's value 1.96), p represents the expected population proportion from previous or pilot studies, and d is the absolute error or precision (set at 20%, i.e., d=0.2) [11]. As the study is novel and lacks prior data on morphometric dry skull measurements of the middle cranial cavity landmarks relative to the orbit, p was set to 0.5 to yield the largest sample size for a given d [12]. This calculation determined a minimum sample size of 24 skulls, and thus 43 intact skulls were included. Skulls with damage or deformation at the skull base or orbital cavity were excluded from analysis.

Each skull was numbered, and key landmarks relative to the orbital rim-supraorbital notch and frontozygomatic suture were identified and marked. Vertical lines were traced onto the cranium's outer table with chalk to map these landmarks in the norma verticalis cranii plane. Skulls were aligned in Frankfurt's plane and photographed from a superior (norma verticalis) view, with the camera positioned at a fixed distance and a 90° angle to the skull base. Using NIH ImageJ software, digital linear measurements were taken for distances between the two external landmarks- supraorbital notch and frontozygomatic suture and key anatomical points, which included (Fig. 1):

A. Carotidoclinoid notch
B. Medial end of trigeminal fossa
C. Lateral end of trigeminal fossa
D. Anterior borders of foramina ovale
E. Anterior borders of Foramen rotundum
F. Anterior borders of Foramen spinosum
G. Apex of the petrous part of the temporal bone
H. Posterior clinoid process
I. Midpoint of the carotid sulcus

Additionally, variations in orbital morphology relevant to the TONES approach, such as meningo-orbital foramina was also documented. Specifically, the prevalence, number, and location of the meningo-orbital foramen were recorded. Considering the surgical importance of the frontosphenoid suture and meningo-orbital artery, their distances from the superolateral orbital rim margin were measured using a divider and ruler [13-15]. To minimize intraobserver variability, all measurements were taken independently by two co-authors, with mean values used for analysis.

Intra-rater Reliability Test: To assess operator reliability, measurements were repeated on a randomly selected skull three times across seven sessions, and the coefficient of variance was calculated.

Statistical Analysis: Data were analyzed using GraphPad Prism 8.0.2. Descriptive statistics (mean, range, standard deviation) were calculated. The Kolmogorov-Smirnov test was used to test the normality assumption. The two-tailed independent sample t-test was performed to compare means between

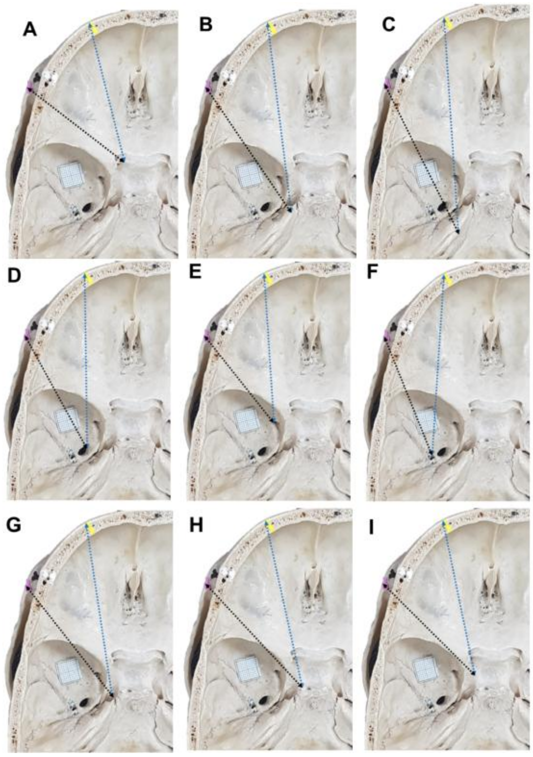

Fig. 1. Photograph of superior view of cranial cavity showing, linear distance between external orbital landmarks – Supraorbital foramen and Frontozygomatic suture (marked with yellow and pink chalk, respectively) and intracranial key targets- (A) carotidoclinoid notch, (B) medial and (C) lateral trigeminal fossa margins, (D) anterior borders of foramina ovale, (E) rotundum and (F) spinosum, (G) apex of petrous part of temporal bone, (H) posterior clinoid process, and (I) midpoint of carotid sulcus measured from supraorbital foramen (marked with blue-colored arrow) and frontozygomatic suture (marked with black-colored arrow), respectively.

groups. $P < 0.05$ was considered to be statistically significant.

RESULTS

The range, mean, and standard deviation of each middle cranial cavity anatomical point evaluated from supraorbital foramen and frontozygomatic suture, respectively on the right and left sides are summarized in Table 1. We found no significant differences in laterality in any of the measurements ($P < 0.05$).

The average of the measurements of the middle cranial cavity landmarks from the frontozygomatic suture were significantly shorter than those from the supraorbital foramen, indicating a more direct approach route to cranial cavity structures (Fig. 2).

Distance of Frontosphenoid suture from Frontozygomatic suture:

The frontosphenoid suture on the lateral orbital wall, along with the meningo-orbital foramina, serves as critical landmarks for surgeons during the TONES approach. Descriptive statistics for frontosphenoid suture location relative to the frontozygomatic suture are presented in Table 2, showing no significant side-to-side difference.

Meningo-orbital foramen:

The meningo-orbital foramen was present in 55% of skulls (24 out of 43), with approximately 60% located in the frontal bone and the remaining 40% in the sphenoid bone. Among these 24 skulls, 15 exhibited a bilateral presentation, while 9 showed a unilateral presence of the foramen within the orbit. A small subset (~5%) displayed duplication of the foramen. Table 3 presents descriptive statistics of the frontosphenoid suture in relation to the frontozygomatic suture, showing no significant variation between sides.

DISCUSSION

The data obtained in this study provides a comprehensive analysis of the landmarks pertaining to the transorbital endoscopic approach to orbit and middle cranial fossa. There is paucity of information in literature which led authors to undertake this study. To discuss how the findings of present study relate to previous studies, presents a problem, as after thorough review of literature authors could not find a study to compare all the data obtained. We have thereafter compared the results with those of orbital studies.

The literature review unfolded previous anatomical morphometric analysis done in axial plane using CT-Scan, to measure the angular distance between the vectors extending from frontozygomatic suture and four target points- tip of anterior clinoid process, foramen ovale, foramen rotundum and lateral margin of trigmenial fossa [16].

Other studies have measured the area of anterolateral triangles on central skull base to expose vivian canal and its contents [17]. Despite the growing importance of transorbital endoscopic approach to paramedian and lateral structures in middle cranial fossa, there is lack of work done to measure the linear distance between orbital rim and key structures in middle cranial fossa. Present study provides data pertaining to the distance of external landmark to intracranial bony target. No difference was found on comparing data of both sides. However, all the distances measured from supraorbital notch located medially were higher than frontozygomatic suture located laterally. This suggests the lateral orbital wall provides shorter route for navigation.

Frontosphenoid suture and Meningo-orbital foramen

The frontosphenoid suture and meningo-orbital artery are essential landmarks in the TONES approach, helping surgeons safely navigate the lateral orbital wall. Measurements of their distances from the superolateral orbital rim margin provide reliable markers, guiding precise positioning within the orbit to avoid damage to critical structures.

Table 1. Key middle cranial cavity anatomical landmarks measurements from supraorbital foramen and frontozygomatic suture, respectively

Distance from		SUPRAORBITAL FORAMEN			FRONTOZYGOMATIC SUTURE		
Cranial cavity landmarks	Side	Range (cm)	Mean ± SD (cm)	p-value	Range (cm)	Mean ± SD (cm)	p-value
Carotidoclinoid notch	Right	6.69-8.94	7.45± 0.55	0.73	4.60-6.52	5.91± 0.39	0.98
	Left	6.26-8.65	7.41± 0.60		5.23-6.66	5.92± 0.33	
Medial margin of Trigeminal fossa	Right	8.65-11.49	9.76± 0.66	0.76	6.47-8.46	7.37± 0.44	0.82
	Left	8.63-11.11	9.71± 0.68		6.36-8.46	7.35± 0.41	
Lateral margin of Trigeminal fossa	Right	9.16-12.02	10.39± 0.69	0.5462	6.81-8.71	7.65± 0.45	0.32
	Left	9.07-12.01	10.30± 0.71		6.36-8.87	7.55± 0.48	
Anterior border of foramen ovale	Right	7.58-10.32	8.81± 0.68	0.59	5.33-6.99	5.95± 0.38	0.75
	Left	7.68-10.21	8.73± 0.68		5.12-7.01	5.98± 0.39	
Anterior border of foramen rotundum	Right	6.35-8.99	7.54± 0.65	0.80	4.10-5.87	4.99± 0.38	0.17
	Left	6.13-8.88	7.50± 0.66		3.92-5.83	5.11± 0.38	
Anterior border of foramen spinosum	Right	8.08-11.07	9.39± 0.72	0.45	5.79-7.29	6.15± 0.45	0.99
	Left	8.14-10.78	9.27± 0.70		5.21-7.58	6.15± 0.44	
Apex of petrous part of temporal bone	Right	8.45-11.21	9.44± 0.65	0.67	6.43-8.06	7.24± 0.39	0.88
	Left	8.15-10.86	9.37± 0.67		6.39-8.19	7.25± 0.36	
Posterior clenoid process	Right	8.08-10.18	8.99± 0.57	0.89	6.34-7.94	7.18± 0.40	0.41
	Left	7.91-10.39	8.97± 0.62		6.41-8.46	7.25± 0.39	
Midpoint of carotid sulcus	Right	7.61-9.79	8.39± 0.59	0.92	5.84-7.52	6.65± 0.36	0.41
	Left	7.44-9.68	8.41± 0.59		5.92-7.46	6.71± 0.37	

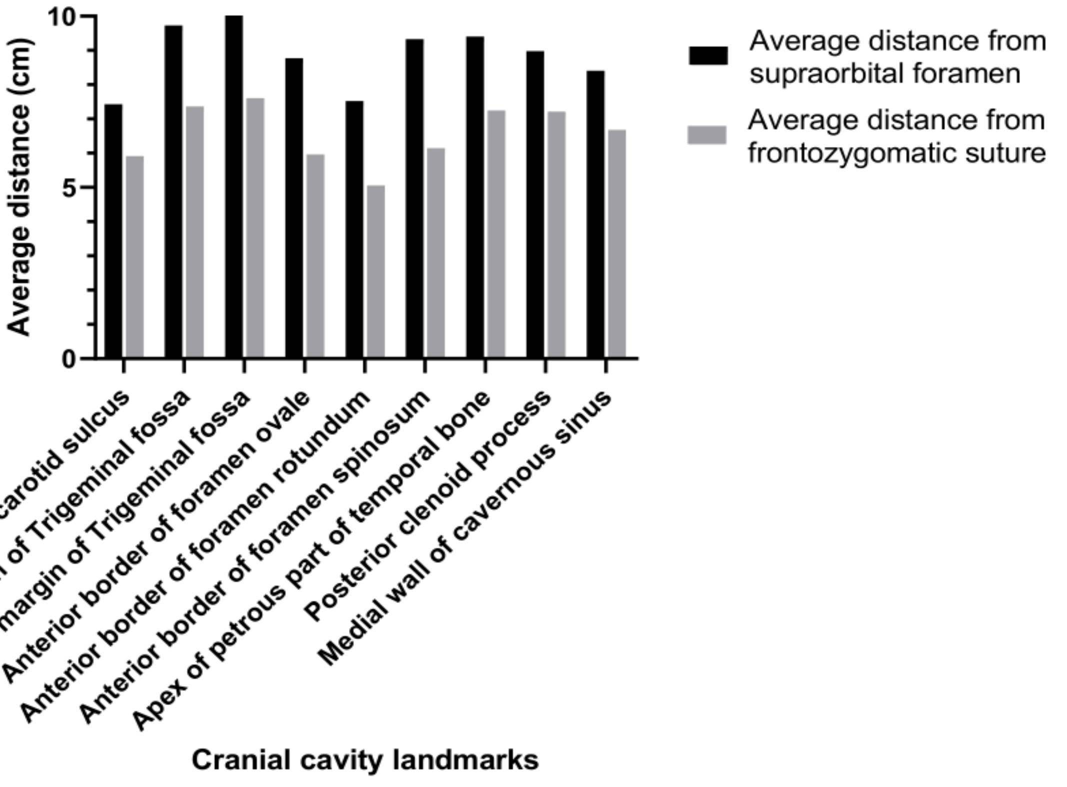

Fig. 2. Comparison of the average distances from the supraorbital foramen and frontozygomatic suture to the middle cranial cavity landmarks.

Table 2. Position of the frontosphenoid suture with respect to the frontozygomatic suture

Side	Range (cm)	Mean ± SD (cm)	p-value
Right	0.95- 2.10	1.458 ± 0.3	0.1213
Left	0.60- 2.0	1.356 ± 0.3	

Table 3. Position of the meningo-orbital foramen with respect to the frontozygomatic suture

Side	Range (cm)	Mean ± SD (cm)	p-value
Right	2.00- 3.07	2.885 ± 0.6	0.1332
Left	2.00- 2.92	2.622 ± 0.3	

Table 4. Prevalence and location of meningo-orbital foramen in the orbits of dry skulls

Authors	Year	Ethnicity	Sample size	Unilateral/ Bilateral	Prevalence	Location	Distance from fronto-zygomatic suture
Mahajan M et al [18]	2020	Asian (India)	223 skulls	Bilateral= 46.63% Unilateral= 53.37%	69.05%	-	24.9 ± 3.4mm
Macchi V et al [19]	2015	Siena	920 skulls	Bilateral= Nil Unilateral= 42.21%	42.21%	Frontal bone=58.26% Greater wing of sphenoid= 17.19% F-S suture=24.55%	-
Agarwal C et al [20]	2015	Asian (India)	42 skulls	Bilateral= Nil Unilateral= 42.24%	45.24%	-	-
Celik S et al [21]	2014	Europe (Turkey)	150 orbits of skulls	Bilateral= 52.4% Unilateral= 32.5%	84%		26.3 ± 3.9mm
O'Brien & McDonald [10]	2007	Europe (UK)			73%	Fronto-sphenoid suture	
Present study	2024	Asian (India)	43 skulls	Bilateral=62.5% Unilateral= 37.5%	45%	Frontal bone=60% Sphenoid bone=40%	27.52 ± 45

The mean distances from the frontozygomatic suture to the frontosphenoid suture on the right and left sides (1.458 ± 0.3 cm and 1.356 ± 0.3 cm, respectively) showed no statistically significant side-to-side variation. This symmetry is advantageous for surgical planning, as it allows surgeons to use a consistent reference point when approaching either side of the skull. These findings, detailed in Table 2, highlight the frontosphenoid suture as a dependable landmark, with a relatively narrow range that facilitates accurate, side-independent orientation during TONES.

The meningo-orbital foramen is inconstant landmark during TONES but mandates careful navigation to avoid rupture followed by inevitable hemorrhage and blurring of surgical field. Previous studies have reported variable number and location of meningo-orbital foramen (Table 4).

The minimally invasive TONES approach provides an anterolateral entry to the middle cranial fossa through the lateral orbital wall, necessitating a thorough understanding of the prevalence and distribution of sutural bones, or wormian bones, in this region. Awareness of these sutural bones is crucial, as their displacement during surgery could result in damage to surrounding structures [22]. The lateral wall of the orbit, the thickest of all orbital walls, has a triangular shape and is formed by the orbital surface of the greater wing of the sphenoid posteriorly and the orbital surface of the frontal process of the zygomatic bone anteriorly. This wall is intersected horizontally near the roof by the frontal-sphenoid and frontal-zygomatic sutures, and vertically by the sphenoid-zygomatic suture [23].

CONCLUSION

This study provides valuable morphometric data essential for optimizing the transorbital endoscopic approach to the middle cranial fossa. By mapping precise distances from key orbital rim landmarks to significant cranial structures, these findings enable more accurate surgical navigation, thereby reducing intraoperative risks to critical neurovascular structures.

The presence of wormian bones in the lateral orbital wall and variations in meningo-orbital foramen prevalence highlight the need for individualized surgical planning to anticipate anatomical variations. This quantitative insight enhances anatomical education and surgical planning, supporting safer, minimally invasive approaches to the middle cranial fossa, especially in cases requiring access to parasellar and lateral skull base regions. Further studies correlating these findings with clinical outcomes could solidify the transorbital approach as a preferred method for specific neurovascular interventions.

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