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An Anatomical Study of the Ethmoidal Foramina in the Medial Wall of the Human Orbits

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ABSTRACT

Introduction: adequate knowledge regarding the number and positioning of the ethmoidal foramina, in the medial orbital wall is important for the technological advancement of new, less invasive orbital procedures as well as for invasive surgical procedures to prevent damage to the medial orbital wall and/or ligation of neural and vascular structures. The use of navigational ratios, when approaching the fragile medial orbital wall, is an important tool for surgeons.

Traditionally, the “24-12-6 mm rule” that describes the distances, along the medial wall, from the anterior lacrimal crest to anterior ethmoidal foramina, anterior ethmoidal foramina to posterior ethmoidal foramina and posterior ethmoidal foramina to optic canal, respectively, has been used. This study was conducted to identify the number of ethmoidal foramina in the medial wall, describe the location of the ethmoidal foramina.

Methodology: seventy cadaveric orbits were examined in this study. No significant differences were found between sex, ancestry or side.

Results: it was found that the highest percentage (71.43%) of orbits contained two ethmoidal foramina and the second highest percentage (15.71%) of orbits contained three ethmoidal foramina.

Conclusion: the navigational ratio in the total sample was found to be 22-14-10 mm and general trends found in the results was that the foramina distances in females were slightly smaller than males. It is important for clinicians to take note of different variations of ethmoidal foramina positioning and numbers.

Keywords: Ethmoidal foramina; Medial orbital wall; Variations; Navigational ratios.

Introduction

The human orbit is of great clinical and surgical significance to several medical disciplines, such as neurosurgery, ophthalmology and maxillofacial surgery (Akdemir *et al*., 2004). Fractures to the medial orbital wall or pathologies such as tumours may require surgical intervention (Schlosser and Bolger, 2003; Piagkou *et al*., 2013). Knowledge of the anatomical landmarks found within the orbital cavity is imperative to avoid complications that could result, due to the delicate nature of intra-orbital surgery. Additionally, minor imbalance or injury, such as ligation of a blood vessel or nerve, could lead to major visual dysfunction (Piagkou *et al*., 2013). The medial orbital wall, being the thinnest portion of the human orbit is especially vulnerable during such surgeries, and highly prone to injury (Patnaik and Sanju, 2001; Akdemir *et al*., 2004; Piagkou *et al*., 2013).

There has been a move toward less invasive techniques and surgeries in an effort to prevent unnecessary damage and reduce the likelihood of intra-operative injury in the area of interest. Therefore, adequate knowledge of anatomical landmarks and their variations will ensure better orientation and visualisation of the orbit (Patnaik and Sanju, 2001; Schlosser and Bolger, 2003). Adequate knowledge, concerning medial wall-related surgeries, entails the precise description of the medial orbital wall osteology and the number of ethmoidal foramina (EF). The medial orbital wall is composed of four bones which are joined together by sutures. The medial orbital wall contains the EF, often found running along or near the frontoethmoidal suture line (FESL) (Patnaik *et al*., 2001; Piagkou *et al*., 2013; Wilkinson, 2018). These ethmoidal foramina, namely the anterior ethmoidal foramen (AEF), middle ethmoidal foramen (MEF) and posterior ethmoidal foramen (PEF), allows for the passage of blood vessels and associated nerves (Caliot *et al*., 1995; McQueen *et al*., 1995; Piagkou *et al*., 2013).

The EFs are important considering that they can be used as anatomical landmarks during surgery regarding the medial orbital wall (Piagkou *et al*., 2013). This is because:

1. The EF orbital openings mark the limits of the cribriform plate anteriorly and posteriorly. Endonasal approaches of the anterior cranial fossa are landmarked by the EF.
2. The floor of the anterior cranial fossa and the level of the roof of the ethmoidal labyrinth is marked by the EF.
3. The planum sphenoidale is situated posteriorly to the PEF and the frontal area of the anterior cranial

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fossa is located anteriorly to the AEF.

4. PEF is anterior to the area related to the apex of the orbit, the area found between the EF is related to the retrobulbar part and the area around the AEF is associated with the bulbar orbital part (Dutton *et al.*, 2006; Piagkou *et al.*, 2014).

Numbers of EF in the orbit range from one to six, according to studies conducted by Piagkou *et al.* (2013) and Abed *et al.* (2011). Due to anatomical variation, the presence of supernumerary EF has been reported according to the study conducted by Piagkou *et al.* (2013). Most relevant literature have established that the most frequent number of EF seen in orbits is two (AEF and PEF) and thereafter three which, includes the MEF (Kirchner *et al.*, 1961; Rontal *et al.*, 1979; Caliot *et al.*, 1995; McQueen *et al.*,1995; Takahashi, 2011; Abed *et al.*, 2014; Piagkou *et al.*, 2013; Vadgaonkar *et al.*, 2015; Mueller and Bleier, 2017). Numerous studies (Rontal *et al.*, 1979; Caliot *et al.*, 1995; McQueen *et al.*, 1995; Takahashi *et al.*, 2011; Abed *et al.*, 2011; Piagkou *et al.*, 2013; Mueller and Bleier, 2017) have looked at both the differences in number of EF and measurements between sexes and ancestry in order to understand the variations so that they may provide a clearer picture of the anatomy of the human orbit. In most studies that were analysed, it was noted that there are seemingly no significant differences with regard to the number of EF or distances between landmarks in the medial wall of the orbit (Rontal *et al.*, 1979; McQueen *et al.*, 1995; Takahashi *et al.*, 2011; Abed *et al.*, 2011; Piagkou *et al.*, 2013; Mueller and Bleier, 2017).

The use of navigational ratios, when approaching the fragile medial orbital wall, seems to have begun in the early 1990's and is an important tool for surgeons (Lander and Terry, 1992; McDermott *et al.*, 1995; Rootman *et al.*, 1995). Traditionally, clinicians have used the 24-12-6mm rule that describes the distances from the anterior lacrimal crest (ALC) to AEF, AEF to PEF and PEF to optic canal (OC), respectively, to navigate through the important structures found in the medial orbital wall (Rootman *et al.*, 1995; Piagkou *et al.*, 2013; Mehta and Perry, 2015). These are the most common measurements used to describe the location of the foramina in the medial orbital wall. There have been slight variations from this rule (McQueen *et al.*, 1995; Karakas *et al.*, 2003; Cheng *et al.*, 2008; Abed *et al.*, 2011; Piagkou *et al.*, 2013; Mehta and Perry, 2015). In this study, the navigational ratios were analysed to be able to describe and compare the distance measurements that have been recorded and to provide a clearer understanding of the variations between the different sexes, ancestries and orbital sides that were found.

The aim of this study was to assess the morphology and location of the AEF and PEF. This was achieved through identification of the number of EFs in the medial orbital wall, measurements between the AEF and PEF, ALC and AEF/PEF and the OC and AEF/PEF in the same manner that was done by McQueen *et al.*, 1995. The variations were also recorded in both orbits studied.

Clinically, this knowledge would provide necessary guidance to specialists and surgeons in the treatment of numerous pathologies and injuries which includes ethmoidal vessel haemorrhages or ethmoidal nerve syndrome and prevent intra-operative ligation of ethmoidal vessels. For example, some authors describe the posterior ethmoidal artery as an anatomical landmark that should not be crossed during surgery in order to prevent damage to the optic nerve (Mutalik *et al.*, 2011; Piagkou *et al.*, 2013; Celik *et al.*, 2014). From the literature it is evident that several studies have been done on the EF regarding their morphology and variation (Kirchner *et al.*, 1961; Rontal *et al.*, 1979; Caliot *et al.*, 1995; McQueen *et al.*,1995; Takahashi, 2011; Abed *et al.*, 2014; Piagkou *et al.*, 2013; Vadgaonkar *et al.*, 2015; Mueller and Bleier, 2017). It also however, indicates the lack of studies carried out in the Southern Hemisphere and particularly South Africa where the genetic distribution is highly diverse. This diversity leads to anatomical variation and therefore the knowledge of these variations is imperative for

clinicians and surgeons to understand in order to reduce the risk during surgery. Thus, more research on the morphology of the EF is extremely relevant with regards to the South African population.

Methodology

The study was carried out using methods adapted from previous studies by few authors (Rontal *et al.*, 1979; McQueen *et al.*, 1995; Cheng *et al.*, 2008; Abed *et al.*, 2011 Mehta and Perry, 2015). Eighty-six human orbits (43 right and 43 left orbits) of were examined. The age range of the sample was between 24 and 100 years and the mean age at death was 59,8 ± 21,7 years. Seventy orbits (35 right and 35 left) were included in the study.

The eyeball along with the soft tissue within the orbits of the cadavers were removed carefully along with the medial wall fascia (if the medial wall was not too fragile) using forceps and a scalpel. The medial wall of the orbits was cleaned out to expose the bone from the OC to the ALC, for observation of the foramina, distance measurement recordings and photographic analysis. If the medial wall proved to be too fragile, the fascia was left in place and was observed and measured as it was. The medial wall of each orbit was examined for additional foramina and trauma/damage. The number of EF was identified, and distances were measured from the ALC to the AEF and PEF, from the medial edge of the OC to the AEF and PEF and between the AEF and PEF. A string, marker and a millimetre scale ruler was used (Figure 1).

The IBM® SPSS® 25 Software for Macintosh was used for statistical analysis. The side, sex and differences in the number of EF were analysed using the chi-squared test. The side, sex and differences in the measured distances between anatomical features was analysed using the paired samples t-test, independent-sample t-test and one-way ANOVA respectively. Values of $p < 0.05$ were regarded as statistically significant. No ethical approval was required as the bodies used in the study are covered in accordance with the South African National Health Act and human donation programme of the University of Cape Town's cadaver collection.

Results

In Figure 2 are images taken during data collection showing different numbers of ethmoidal foramina found in the medial orbital wall in the left orbits of four individuals.

Number of ethmoidal foramina

The number of EF is given in Table 1. of the 70 orbits, 15 (21.42%) had accessory foramina – more than two EF. Of all the orbits, four orbits (5.71%) contained only

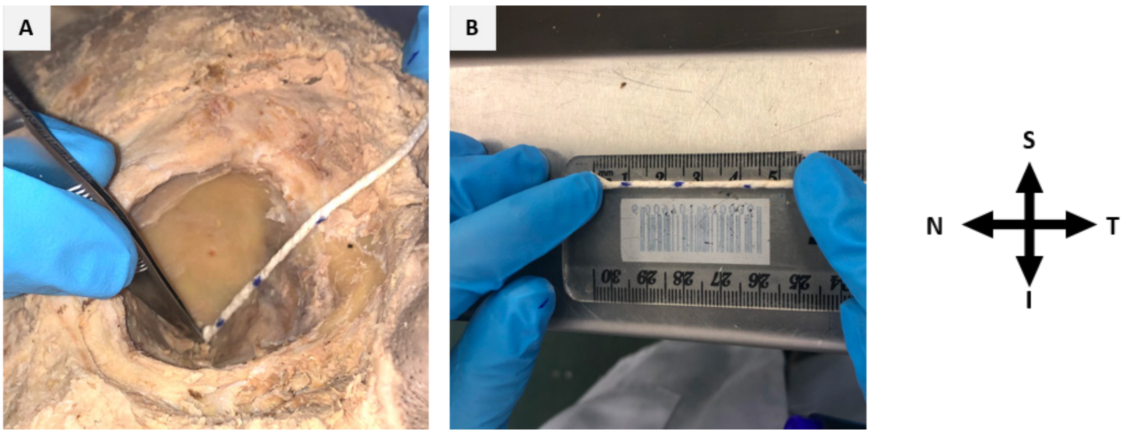

Figure 1: Measurement of the orbital foramina distance. (A) String end was placed at the medial edge of the OC and stretched along the medial wall until the medial orbital rim. A marker was then used to mark the AEF, PEF and ALC on the string. (B) The string was placed against the ruler and the respective distances were measured. S- superior, I- inferior, N- nasal, T- temporal.

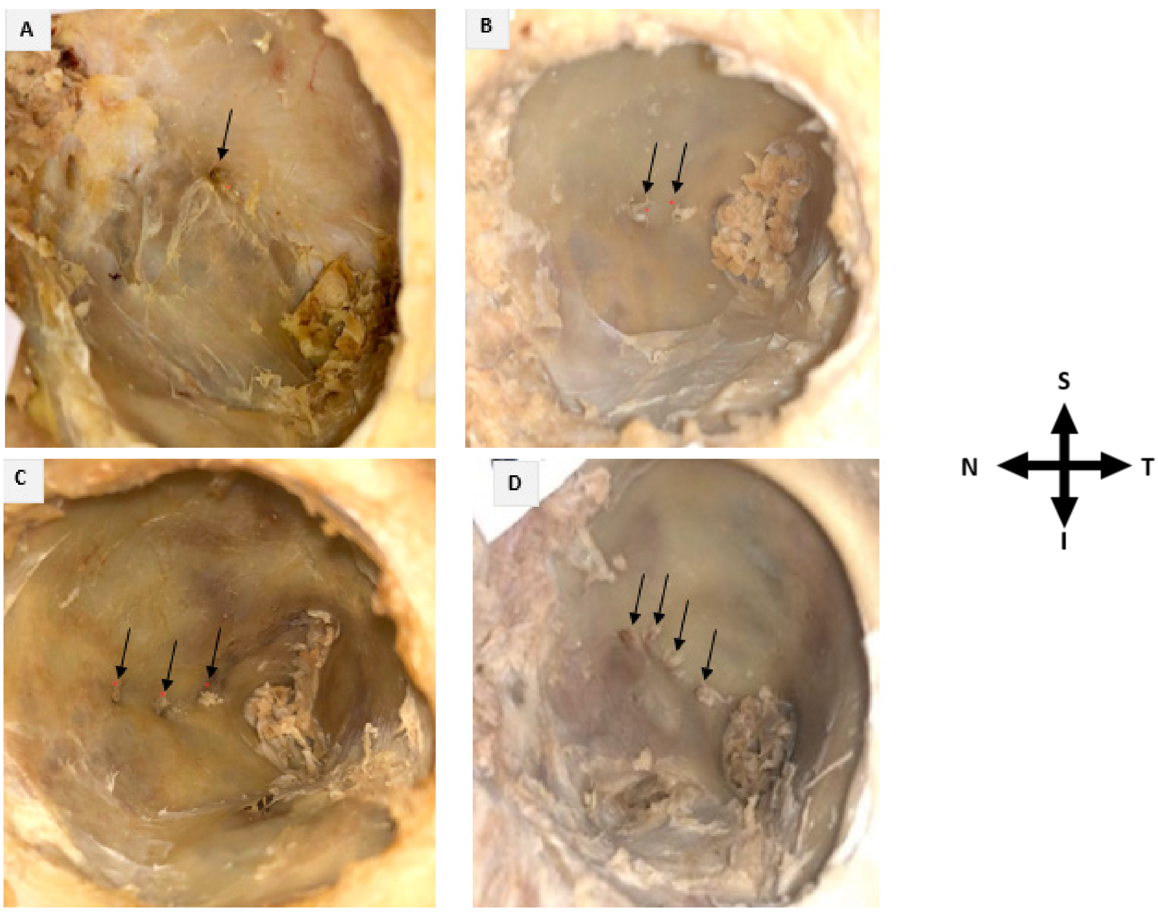

Figure 2: The medial orbital wall showing different numbers of ethmoidal foramina (red dots and black arrows) (A) one ethmoidal foramen, (B) two ethmoidal foramina, (C) three ethmoidal foramina, (D) four ethmoidal foramina.
S- superior, I- inferior, N- nasal, T- temporal.

a single ethmoidal foramen. All of these orbits were of males, two of them were right and the other two were left.

There were no statistically significant differences found between sex (p=0.534) with regard to the number of EF found in each orbit however, there was a statistically significant difference found between sides (p=0.007).

The number of EF in the right and left orbits of males and females are presented in Table 2. In males, it was found that three right orbits (15.79%) and five left orbits (26.32%) had accessory foramina. Only two left male orbits and three right male orbits had less than two EFs. In females, the number of EF ranged only from two to three in right orbits where three orbits (18.75%) had three EF and the number of EF in left orbits ranged from two to four. Only one left orbit (6.25%) in the female sample contained four EF.

There were no statistically significant differences found between sides in both the male sample (p= 0.060) and female sample (p= 0.710).

Distances between anatomical features

The distances from the AEF to the PEF and from both the AEF and PEF to the ALC and OC are displayed in Table 3 according to sex and side. The mean distances from the ALC to the AEF, AEF to PEF and from the PEF to OC (Table 3) in all orbits were 22.48mm (±2.52), 13.76mm (±2.16) and 10.05mm (±2.12) respectively. The mean distances from the ALC to the AEF, AEF to PEF

Table 1. Number of ethmoidal foramina in both the left and right orbits.

Orbit Type	Total	Nº of ethmoidal foramina in orbit				
		0	1	2	3	4
All	70	1 (1,143%)	4 (5,71%)	50 (71,43%)	11 (15,71%)	4 (5,71%)
Male	38	1 (2,63%)	4 (10,53%)	25 (65,79%)	5 (13,16%)	3 (7,89%)
Femele	32	-	-	25 (78,13%)	6 (18,75%)	1 (3,13%)
Right	35	1 (2,86%)	2 (5,71%)	26 (74,29%)	5 (14,29%)	1 (2,86%)
Left	35	-	2 (5,71%)	24 (68,57%)	6 (17,14%)	3 (18,57)

Table 2. Number of ethmoidal foramina in the right and left orbits in both the males and female sexes.

Sex	N	Orbit Side	Nº of ethmoidal foramina in orbit				
			0	1	2	3	4
Male	16	Right	1 (5,26%)	2 (10,53%)	13 (68,42%)	2 (10,53%)	1 (5,26%)
		Left	0	2 (10,53%)	12 (63,16%)	3 (15,79%)	2(10,53%)
Femele	19	Right	0	0	13 (81,25%)	3 (18,75%)	0
		Left	0	0	12 (75%)	3 (18,75%)	1 (6,25%)

Table 3. Distances between the ethmoidal foramina, anterior lacrimal crest and optic canal in orbits according to sex and sides

Anatomical Measurement Points	Mean distance (range) (M) and Standard deviation (SD) (mm)											
	All		Sex					Side				
			Male		Femele		p†	Right		Left		p‡
	M	SD	M	SD	M	SD		M	SD	M	SD	
AEF to PEF*	13,76 (9-19,5)	± 2,16	14,28 (11-19,3)	± 2,31	13,24 (9,6-16)	± 1,76	0,155	13,77 (10-19,5)	± 1,99	13,76 (9-19)	± 2,70	0,337
AEF to ALC*	22,48 (17,2-29,2)	±2,52	22,58 (18,8-26)	± 1,98	2,28 (18-27,2)	± 2,42	0,709	22,11 (17,2-26,3)	± 2,31	22,84 (18,8-29,2)	±2,70	0,073
AEF to OC	23,19 (16-30	± 2,76	23,52 (18,1-27)	± 2,14	22,93 (17,6-29,8)	± 2,79	0,494	23,38 (18,5-30	± 2.35	23 (16- 29,5)	± 3,13	0,293
PEF to ALC	35,26 (19-41,3)	± 3,19	35,22 (28-39,3)	± 2,97	35,09 (30,1-39,6)	± 2,13	0,882	34,54 (19-41,25	± 3,79	36,01 (31,3-40)	±2.22	0,060
PEF to OC*	10,05 (6,5-20)	±2,12	10,02 (7-13,8)	± 1,58	10,10 (8,3-14,1)	± 1,62	0,888	10,28 (6,5-20)	± 2,33	9,83 (7,3-13,8)	± 1,87	0,417

† Nº statistical significance using Independent-samples t-test
‡ Nº statistical significance using Paired-samples t-test

and from the PEF to OC in male orbits were 22.56mm (±1.98), 14.28mm (±2.31) and 10.02 (±1.58) respectively and in female orbits, 22.28mm (±2.42), 13.24mm (±1.76) and 10.10 (±1.62) respectively. The mean distances from the ALC to the AEF, AEF to PEF and from the PEF to OC in right orbits were 22.11mm (±2.31), 13.77mm (±1.99) and 10.26mm (±2.33) respectively and in left orbits, 22.84mm (±2.70), 13.76mm (±2.70) and 9.83mm (±1.87) respectively.

There were no statistically significant differences in the distances between sexes, the most significant difference being in the AEF to PEF distance (p=0.155), nor were there any statistically significant differences between sides, with the most variation being found in the distance from PEF to ALC (p=0.060).

The Pearson correlation test was done to determine whether inter-observer distance measurements correlated with actual results. The Pearson correlation coefficient (r2) percentage for the AEF to PEF measurement was 78.15%, AEF to ALC measurement was 43.82%, AEF to OC measurement was 41.86%, PEF to ALC measurement was 64.96% and the PEF to OC measurement was 70.39%.

Discussion

Number of ethmoidal foramina

Of the 70 orbits, the EF followed a classic pattern – two EFs - in 50 (71.43%) of them (Table1). This finding is corroborated by most studies including one carried out by Caliot *et al*. (1995) in which, two EFs were found 80% of the time as well as one, more recently carried out, by Abed *et al*. (2011) where two EFs were found in 56% of orbits. Twenty (28.57%) of the 70 orbits in this study demonstrated anatomical variation from the classical pattern. Single EF variations were identified in the study by Caliot *et al*. (1995) where 2% of orbits had only a single EF and studies by Piagkou *et al*. (2013) and Abed *et al*. (2011) found similar a trend. The results in our study show that 5.71% of all orbits contained only one EF in the medial orbital wall – however, the higher percentage of single EF could be due to our small sample size. Our study found that the number of EF in a single orbit ranged from zero to four. Numbers of EFs found ranged from one to six in studies conducted by Piagkou *et al*. (2013) and Abed *et al*. (2011), however, extra EF (EF other than AEF, PEF and MEF) could likely have been foramina without neurovascular bundles which, were not classified as EF in this research project. More recently, a study by Mpolokeng and Louw, (2019) found one EF which provided exit for the neurovascular bundle.

There was statistically significant value (P=0.007) found between sides which, was not in accordance with other studies as most of the studies related seemed to have no significant difference between left and right orbits with regard to number EF in the medial wall (Caliot *et al*., 1995; Takahashi *et al*., 2011; Abed *et al*., 2011). Twenty-six (74.29%) right orbits and 24 (68.57%) left orbits had 2 EFs which, does not seem much different however, it was discovered that the number of EF found in the right orbit was negatively skewed, meaning that the mean number of EF was less than the median, whereas the number of EF found in the left orbit was positively skewed which, means the opposite.

Within the male sample, the most variation between the left and right orbits were found, with a p-value of 0.060. The number of EF in right male orbits ranged from zero to four whereas, in left male orbits, it ranged from one to four (Table 2) however this range differed by a only single orbit. More supernumerary EF were found in left male orbits as opposed to right male orbits. However, the number of orbits that contained two EF only differed by a single orbit between the left and right sides which, shows that there is not a great deal of variation. Within the female sample (Table 2), the number of EF between left and right orbits ranged from two to three in the right orbits and two to four in the left orbits; the ranges differing by only a single orbit (p= 0.710). Therefore, male orbits presented a greater degree of variation between the number of EF in left and right orbits than female orbits (although not significant).

Although the analysis of the total sample yielded a statistically significant value for the difference between left and right orbits, there were no statistically significant differences found in the detailed analysis done between left and right orbits within each sex. This may be as a consequence of the small and unequal sample sizes and therefore no solid conclusions can be drawn.

Distances between anatomical features and navigational ratios

The classical 24-12-6 rule, describes the distances in millimetres between the medial wall foramina. There have been minor variations of these measurements that have been found (Table 4), such as, in the study using 54 cadaveric orbits, by McQueen *et al*. (1995), that reported a ratio of “22-12-9mm” and in a study using 62 dry orbits, by Karakas *et al*. (2003), that reported a ratio of “24-10-7mm” (McQueen *et al*., 1995; Piagkou *et al*., 2013).

The current study found the navigational ratio in the total sample to be 22-14-10mm (Table 2). The navigational ratio in females it was 22-13-10mm and in males it was 23-14-10mm. In right orbits the navigational ratio was 22-14-10mm and in left orbits it was 23-14-10mm. From the navigational ratio’s it is clear that there was no significant difference between sexes, as reflected by the statistical analysis of each distance measured, except for the female ALC-AEF and AEF-PEF distances being slightly smaller than the male distances. Between right and left orbits, by looking at the navigational ratios, there was no significant difference between the distances measured, except that the ALC-AEF distance was very slightly larger in left orbits.

Table 4. Studies showing distances of the medial orbital wall.

Author (year)	Study Type	ALC-AEF	AEF-PEF	PEF-OC
Convention	-	24	12	6
McQueen *et al.* (1995)	54 cadaveric orbits (Diverse ancestry)	21.96 (±3.13)	12.35 (±3.19)	9.15 (±2.24)
Karakas *et al.* (2003)	62 dry skulls (Caucasian)	23.9 (±3.3)	9.8 (±2.9)	6.8 (±2.2)
Cheng *et al.* (2008)	194 dry skulls (Chinese)	24.87 (±1.91)	11.45 (±2.41)	5.71 (±2.04)
Abed *et al.* (2011)	48 cadaveric orbits (Caucasian)	25.61 (±2.25)	16.60 (±2.19)	7.25 (±2.59)
Piagkou *et al.* (2013)	249 dry skulls (Greek)	23.21 (±3.18)	9.78 (±3.14)	4.30 (±1.71)
Mehta and Perry (2015)	57 dry skulls (Caucasian)	24.85 (±1.79)	13.82 (±2.14)	5.44 (±1.46)
	70 dry skulls (African American)	25.16 (±2.13)	13.42 (±2.02)	5.47 (±1.31)
Current study	16 cadaveric orbits (Caucasian)	22.73 (±2.06)	13.54 (±2.35)	9.63 (±1.13)
	7 cadaveric orbits (African)	22.05 (±1.93)	14.34 (±1.42)	10.45 (±2.23)
	11 cadaveric orbits (Mixed ancestry)	22.22 (±2.58)	13.79 (±2.20)	10.44 (±2.23)

The navigational ratio of the total sample (22-14-10mm) from this study varies slightly from the classical 24-12-6mm rule and the navigational ratios found in other studies that have been published (Rontal *et al.*, 1979; Lander and Terry, 1992; McDermott *et al.*, 1995; McQueen *et al.*, 1995; Rootman *et al.*, 1995; Karakas *et al.*, 2003; Cheng *et al.*, 2008; Abed *et al.*, 2011; Piagkou *et al.*, 2013; Mehta and Perry, 2015). The ALC-AEF distance is slightly smaller (with the exception of McQueen *et al.* (1995) and Karakas *et al.* (2003)), while the AEF-PEF (with the exception of Abed *et al.* (2011) and PEF-OC distances are slightly larger in our study as compared to most other studies (Rontal *et al.*, 1979; Lander and Terry, 1992; McDermott *et al.*, 1995; McQueen *et al.*, 1995; Rootman *et al.*, 1995; Karakas *et al.*, 2003; Cheng *et al.*, 2008; Abed *et al.*, 2011; Piagkou *et al.*, 2013; Mehta and Perry, 2015). These variations between the results of different studies is likely due to a combination of different sample sizes, differences between cadaveric and dry orbits, genetic variation in different geographical populations well as differences in measuring points.

Conclusion

Adequate knowledge regarding the number, positioning and distances of the anatomical features, particularly the EF, in the medial orbital wall is important for the technological advancement of new, less invasive orbital procedures as well as for invasive surgical procedures to prevent damage to the medial orbital wall and/or ligation of neural and vascular structures. Although many studies before have conducted research regarding the EF, there exists variations in different geographic populations and there have not been any studies found, that have been done in South Africa.

In this study, we set out to identify the number of EF in the medial orbital wall, to describe the location of the EF precisely in cadavers by measuring distances between certain anatomical feature points, to compare the variation between the orbit sides and sexes.

We were able to show that in the total sample, the highest percentage of orbits contained two EFs (71.43%) and the second highest percentage of orbits contained three EFs (15.71%).

The only statistically significant difference that was yielded, was the number of EFs between right and left orbits of the total sample. No statistically significant differences were found in the detailed analysis done between left and right orbits within each sex. This may be as a consequence of the small sample sizes. It can however, be noted that male orbits overall, exhibited a greater degree of variation between the number of EFs in left and right orbits than female orbits.

The current study found the navigational ratio in the total sample to be 22-14-10mm which, varies slightly from the classical 24-12-6mm rule and the navigational ratios found in other studies that have been published (Rontal *et al.*, 1979; Lander and Terry, 1992; McDermott *et al.*, 1995; McQueen *et al.*, 1995; Rootman *et al.*, 1995; Karakas *et al.*, 2003; Cheng *et al.*, 2008; Abed *et al.*, 2011; Piagkou *et al.*, 2013; Mehta and Perry, 2015). There were no statistically significant differences between orbital side and sex. General trends that can be mentioned was that female distances were slightly smaller than males.

It is important for clinicians to take note of the variations in the location and number of EF in different sexes and sides before conducting any intra-orbital procedure.

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