Investigation of sexual dimorphism, morphology, and morphometry of the cribriform plate in the KwaZulu-Natal population: Osteological and radiological assessment

By

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A Thesis submitted to the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, University of KwaZulu-Natal, Durban, South Africa

In fulfilment of the requirement for Degree of Master of Medical Science (Clinical Anatomy)

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PREFACE

This research was carried out in the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, College of Health Sciences, University of KwaZulu-Natal, Durban, South Africa, from 2023 to 2024, under the supervision of Dr Edwin Naidu, Dr Samuel Olojede, Dr Camern Rennie and Prof Onyemaechi Azu for the award of Master of Medical Science degree (Clinical Anatomy).

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DECLARATION

I Ms. Nondumiso Ngiphiwe Hlatshwayo....................................... declare that:

(i) The research reported in this dissertation/thesis, except where otherwise indicated, is my original research.

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DEDICATION

This dissertation is dedicated to my beloved mother, Thandeka Radebe, whose unwavering love, guidance and sacrifices have been my constant source of inspiration in my academic journey. Your selfless devotion to our family and passion for excellence have instilled in me the seeds of hard work and dedication. May this humble achievement be a testament of the impact of your love and support, I am forever grateful. *"Ngiyimina nje, kungenxa yakho"*.

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Lastly, I extend my deepest gratitude to the God of my ancestors, whose divine guidance and blessings have made this achievement possible. *"Ukubonga kwami koba ngaye njalo"*.

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LIST OF ACRONYMS AND ABBREVIATIONS

AEA	anterior ethmoidal artery
BREC	Biomedical Research Ethics Committee
CT	computed tomography
CSF	cerebrospinal fluid
KZN	KwaZulu-Natal
LLCP	lateral lamella of the cribriform plate
mm	millimetres
n (%)	number of patients/people (their percentage)

ABSTRACT

Introduction**:** The cribriform plate is a fragile anatomical structure of the ethmoid bone. It is situated in the anterior cranial fossa between the brain and nasal cavity and serves as a channel for olfactory nerves to pass through to the brain. Despite its importance, there is a paucity of information in the literature on the morphology and sexual dimorphism of the cribriform plate, particularly in African populations. So, understanding the anatomical variations of the cribriform plate, particularly in relation to sex and laterality, is crucial as these differences may influence olfactory function, surgical approaches in the anterior cranial fossa, and the overall understanding of craniofacial anatomy in the selected KwaZulu-Natal (KZN) population. This study intended to observe and measure the shape, forms, and variations in the dimensions of the cribriform plate in relation to sex and laterality on both the bones and for computed tomography (CT) scans of a selected KZN population.

Materials and methods: Fifty-five (55) CT scans of the cribriform plate were assessed from the axial and coronal views and fifty-eight (58) dried skulls without the calvaria were investigated bilaterally in this study. Morphology of the cribriform plate was recorded based on the Kawahara method, morphometry and related structures of the cribriform plate were investigated to identify any sexual dimorphism in KZN population.

Result: In CT scans, the Type IV shape of the cribriform plate was the most prevalent in males, and the Type I cribriform plate shape was the most common in females. All morphometric parameters in comparison to sex were not statistically significant ($p > 0.05$) and they were observed to be slightly higher in males on both sides (males width on the right side was 4.78±1.30 mm and females width on the right side was 4.19±1.05 mm; males width on the left side was 4.33 mm (median) and females width on the left side was 4.18±0.97 mm; males length on the left side was 20.1±4.34 mm and females length on the left side was 20.0±3.84 mm; males depth on the left side was 5.15±1.65 mm and females depth on the left side was 4.94±1.40 mm) except for the length on the right side of females which was 20.6±3.73 mm. The teardrop type of the crista galli was the most common type with 53.3% on males and 64.0% on females. Keros classification type II was the most prevalent on sexes and Keros type III was the least identified within the population. On the right and left sides of the cribriform plate in both sexes, the anterior ethmoidal artery was commonly located below the skull base. Male Black South Africans had a right side of the cribriform plate that was longer (20.6 mm), whereas White South African males had a right side of the cribriform plate that was slightly smaller (19.7 mm). Compared to White females, Black South African females have a longer right side of the cribriform plate (20.7 mm). Cribriform plates' width and depth in Black South African females had lower means (width on the right side was 4.00±1.05 mm and on the left side it was 4.17±1.06 mm; depth on the right side was 4.74±1.56 mm and on the left side it was 4.81±1.26 mm) than White South African females on both sides.

For the skulls, Type IV of the cribriform plate was the most prevalent shape in males (35.5%). In females, both type I and IV were detected constituting 22.2% and were the most common types. On the right and left sides of both males and females, the length, width, and depth parameters were slightly higher in males except for the width on the left side, which was higher in females. The number of olfactory foramina was higher in females compared to males. The ossified shape (41.9%) and teardrop shape (51.9%) were the most common types in males and females, respectively. Keros classification type II was the most determined type on both sides of the olfactory fossa between the two sexes. The width of the cribriform plate on the left side of male Black South Africans (5.18±1.51 mm) and White South Africans (3.93±1.18 mm) was the only parameter that was statistically significant, ($p \leq 0.019$).

Conclusion**:** The findings of this study reveal no statistical significance on the morphology and morphometry in most of the dimensions within the KZN population. However, the slightly noticeable variations observed, may impact surgical planning in procedures involving the anterior cranial fossa and can also be used in clinical practice for this population-specific medical assessments to reduce the risks associated with the cribriform plate.

Keywords: Cribriform plate, Sexual dimorphism, Morphology, Morphometry, Ethmoid bone

CHAPTER ONE

1.1 Introduction

Maxillofacial fractures which include fractures of the nasal bone, mandible, cheekbones, palate, and skull remain the cause of functional impairment, lasting deformity, and disability globally (Jullien, 2021, Kanala *et al.,* 2021). The ethmoid bone is not classified as a maxillofacial bone. While it is located in the facial region of the skull, it is considered a cranial bone rather than a facial bone (ADMIŞ, 2024). The ethmoid bone forms part of the cranial base and contributes to the structure of the nasal cavity, the orbit (eye socket), and the nasal septum (Yu and Wang, 2019). The ethmoid bone is one of the bones of the skull, which has various features such as crista galli, olfactory foramina, olfactory fossa, perpendicular plate of ethmoid, foramen caecum and cribriform plate (Mureșan *et al.,* 2022).

The cribriform plate is a sieve-like partition on the ethmoid bone located at the base of the skull on the anterior cranial fossa between the olfactory bulb and nasal cavity (White and Folkens, 2005, Yohannan *et al.,* 2021). The cribriform plate is part of the ethmoidal notch of the frontal bone which forms the roof of the nasal cavity, supports the olfactory bulb, and is perforated by olfactory foramina for the passage of the olfactory nerves to the roof of the nasal cavity to channel smell to the brain (López-Elizalde *et al.,* 2018, Gomez and Pickup, 2023). The foramina at the medial part of the groove allow the passage of the olfactory nerves to the upper part of the nasal septum while the foramina at the lateral part transmit the olfactory nerves to the superior nasal concha. The olfactory fossae are separated by the crista galli that arises from the superior surface of the ethmoid bone (Boulton *et al.,* 2023).

All the midface structures that make up the ethmoid bone consist of 5 - 15% of facial structures. On these bones, males are three times more likely than females to suffer a fracture (Gomez and Pickup, 2023). These rates are influenced by socioeconomic and cultural factors, highest incidences occur between the ages of 21 and 30 (Septa *et al.,* 2014). The pinnacle frequency is found in ages 21 to 30 years, social and financial contrasts impact these rates (Kühnel and Reichert, 2015).

Previous studies have investigated and reported changes in the morphology and morphometry of the cribriform plate with regards to related structures (Ganjaei *et al.,* 2019, Jabaz and Abedtwfeq, 2022). However, there is a paucity of information on sexual dimorphism concerning the cribriform plate among the KwaZulu-Natal's (KZN) diverse populations. Thus, this study is designed to investigate the shape, forms, and variations in dimensions of the cribriform plate with regards to sex on both cadaveric or dried bones and computed tomography (CT) scans of a selected KZN population. To achieve this, the study will investigate the following research questions:

- Differences in morphology and morphometry: What are the possible differences in the morphology and morphometry of the cribriform plate between various KZN population groups?
- Sex-related changes: What are the changes in morphology and morphometry of the cribriform plate of various KZN population groups regarding sex?
- Influence of nearby structures: How do the nearby structures affect the morphology of the cribriform plate of various KZN population groups?

1.2 Literature Review

1.2.1 Gross Anatomy

The ethmoid bone is an unpaired, midline cranial bone that forms a crucial part of the superior nasal cavity and nasal septum (Yu and Wang, 2019). This bone also plays a key role in forming the medial wall of the orbit, providing a delicate boundary between the ocular and nasal cavities (Shumway *et al.,* 2018). It consists of the cribriform plate, ethmoidal labyrinths, and perpendicular plate. The paper-thin cribriform plate represents the nasal cavity roof (Gunbey *et al.,* 2018) and the olfactory fossa floor, which is bounded medially by the crista galli and laterally by the lateral lamella of the cribriform plate (LLCP) (Sasmal *et al.,* 2022).

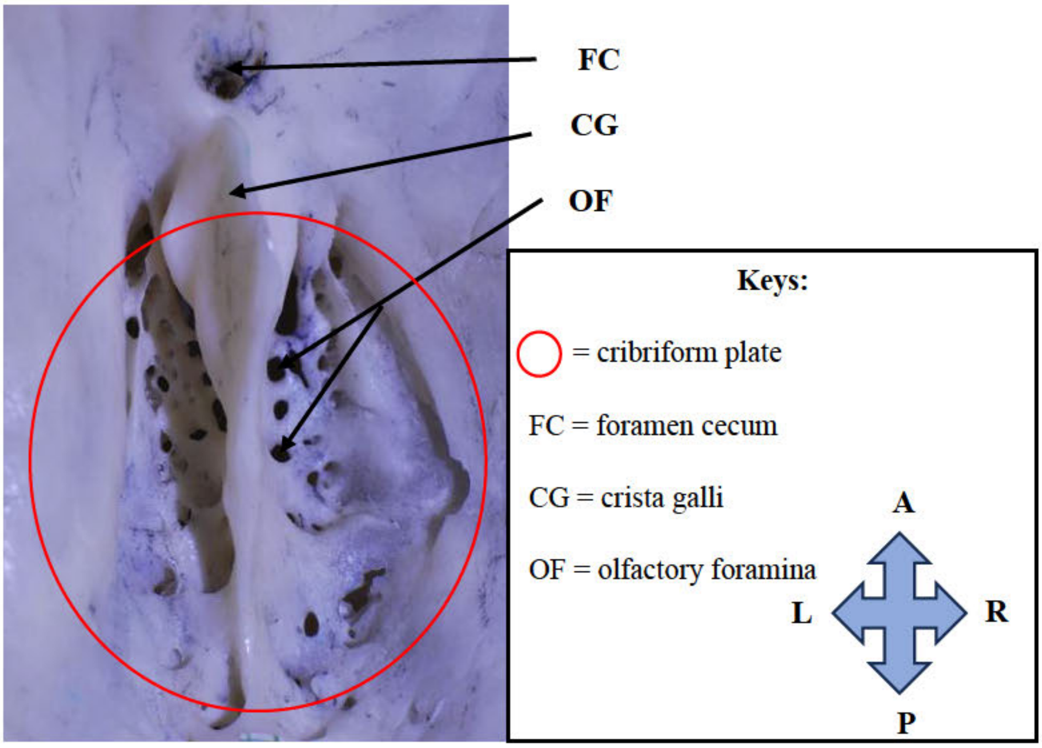

Figure 1: Image showing the anatomy of the middle of the anterior cranial fossa in axial view. Adapted from (Coelho *et al.,* 2018).

The cribriform plate is spongy or trabecular bone and has low thickness with profound notches supporting the olfactory bulb (White *et al.,* 2005) (Figure 1). It has a short, thick front edge that joins the frontal bone. The foramen cecum is completed by its two small, projecting alae, or wings, which are received into corresponding depressions in the frontal bone (Bird, 2017). Due to the presence of a small air sinus inside, its sides are smooth and occasionally bulging (Cappello *et al.,* 2018).

The crista galli projects upwards from the centre line of the cribriform plate (Figure 1). The falx cerebri attaches to the long, thin posterior border of the crista galli (Okumuş, 2022). The narrow and deeply grooved cribriform plate can be found on either side of the crista galli. Furthermore, a process of dura mater occupies a small fissure at the front of the cribriform plate, on either side of the crista galli. A foramen, or notch, that carries the nasociliary nerve is located lateral to this fissure and a groove leads backward to the anterior ethmoidal foramen from this notch (Zacharek *et al.,* 2005).

1.2.2 Embryology of the cribriform plate

The cribriform plate is an essential component of the human skull that is crucial to the anatomy of the nasal cavity and the olfactory system (Vasvári et al., 2005b). Understanding its embryology and development involves several aspects. The chondrocranial and membranous components of the cranial base play a complex role in the development of the cribriform plate and ethmoid bone. The cartilaginous nasal capsule which aids in the early development of the skull base, is where the ethmoid bone first forms (McBratney-Owen *et al.*, 2008).

In the developmental stages, the cartilaginous ethmoid starts to ossify during week eight to week nine intrauterine. Both the perpendicular plate and the labyrinthine portions form the cribriform plate (Hiyama *et al.,* 2013). By the age of three years, the cribriform plates have ossified, causing the ethmoid bodies to unite with the perpendicular plate to form a single ethmoid bone. Additionally, this procedure stabilizes the nearby facial features like the upper nasal and interorbital areas (Som and Naidich, 2014).

Ethmoidal growth and pneumatization occur on different sinus drainage channels that are separated by the basal lamellae, which gives rise to the air cells (ethmoid labyrinth) of the ethmoid bone, these cells continue to grow until late foetal development and childhood (Jankowski *et al.,* 2022). Variations in the ethmoidal air cell system contribute to morphological diversity, whereas pneumatization of the ethmoid bone affects neighbouring anatomical features such as the orbital walls and nasal cavity (Hui *et al.,* 2022).

The nasal septal cartilage, which contributes to the forward growth of the midface, is one example of the surrounding tissues that affect the growth of the ethmoid bone (Baddam *et al.,* 2022). Throughout development and adolescence, this dynamic remodelling takes place alongside modifications of the craniofacial skeleton (Baddam *et al.,* 2022).

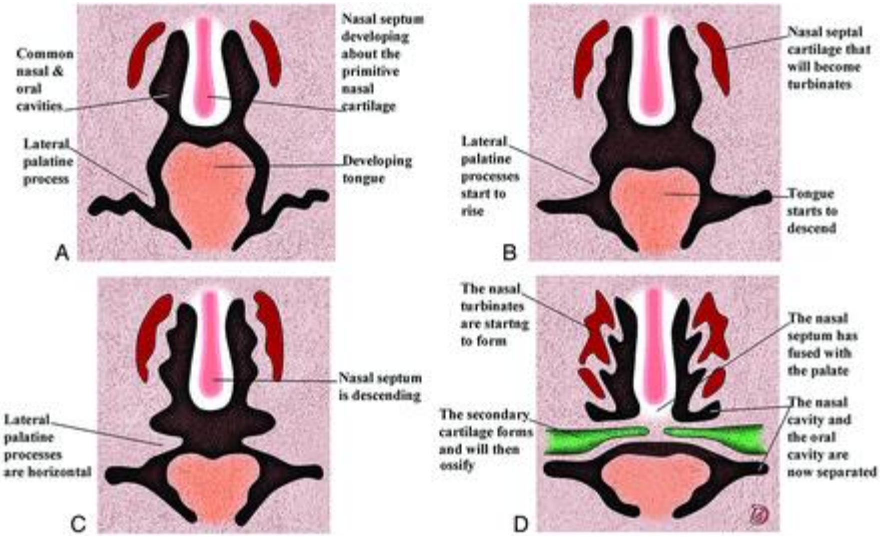

Figure 2: Sequential diagrams (A-D) from roughly 6-10 foetal weeks shown only back to the intermaxillary portion represent the ever-evolving improvement of the secondary palate and its combination with the nasal septum. Adapted from (Som and Naidich, 2014).

1.2.3 Structures associated with Cribriform plate

(i) Nasal Cavity

The cribriform plate may be affected in several ways by the asymmetry of the nasal cavity. The bony structure that separates the nasal cavity into two halves is called the nasal septum (Anderson *et al.,* 2008) (Figure 3). A common condition known as deviation of the nasal septum can result in asymmetry in the nasal cavity. The nasal cavity's airflow patterns may shift as a result of this asymmetry, which may have an impact on the cribriform plate (Teixeira *et al.,* 2016).

For instance, if the nasal septum is deviated to one side, the airflow inside the nose may change, resulting in more turbulence and shear stress on the side of the septum that is deviated (Davis *et al.,* 2003). The increased stress on one side of the cribriform plate may increase the likelihood of that side being damaged or injured (Raza *et al.,* 2013).

The distribution of pressure within the nasal cavity can also be affected by nasal asymmetry (Serifoglu *et al.*, 2017). The pressure difference between the nasal cavity and the anterior cranial fossa of the brain, which is separated from the nasal cavity by the cribriform plate, may be affected by this pressure distribution (Aziz *et al.,* 2014). There is a possibility that cerebrospinal fluid could leak from the brain into the nasal cavity if this pressure differential changes (Chaaban *et al*., 2014).

Although the precise mechanisms by which nasal cavity asymmetry affects the cribriform plate are not completely understood, it is evident that these two structures may be related (Serifoglu *et al.,* 2017).

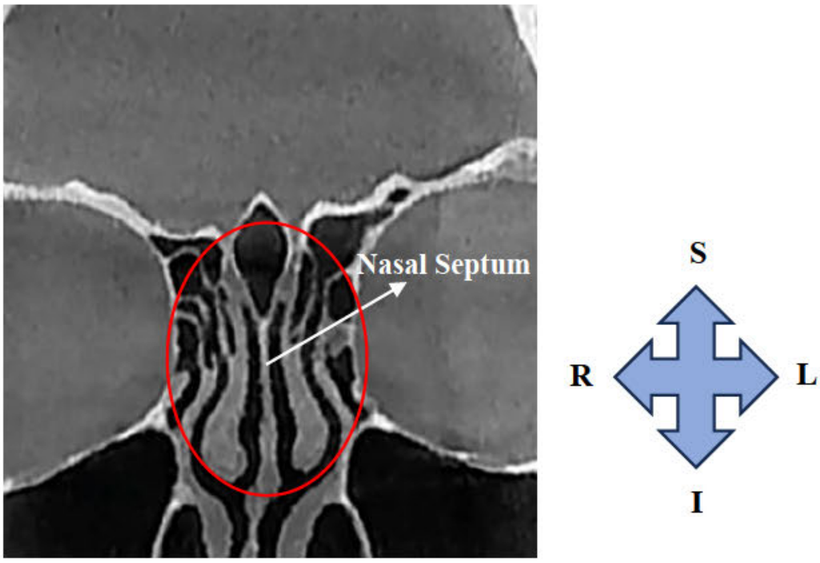

Figure 3: Image showing asymmetry of the nasal cavity (circled in red) in coronal view. Adapted from (Okumuş, 2022)**.**

(ii) Crista Galli

In the anterior cranial fossa, the crista galli is a significant landmark whose position can affect the cribriform plate (Kasai *et al.,* 2019). The crista galli stretches out vertically from the ethmoid bone, it is also situated in the midline above the cribriform plate. As a result, the likelihood of the cribriform plate being damaged can be affected by how the crista galli are positioned in relation to it (Bell *et al.,* 2004).

In a study by Kim *et al.* (2012), they found that if the crista galli is unnecessarily bulging or angled in too close to the cribriform plate, that can build risks of injury to the cribriform plate from injury or tension. Likewise, if the crista galli is dislodged or broken, this might possibly cause damage to the cribriform plate, which can prompt cerebrospinal liquid spillage and neurological deficits (Severson *et al.,* 2023). Due to its anatomical variations the crista galli can be categorised into three morphological types, the teardrop, tubular and ossified (Komut and Golpinar, 2021). To determine the crista galli's type according to its classifications, height, width and length are measured (Table 1) (Ozturk *et al.,* 2024). In a study be Komut and Golpinar (2021) the teardrop type was the most common in males and the tubular type was the most relevant in females (Table 2). Whereas, in a study by Golpinar *et al.* (2022), the teardrop type was the most common in females and the tubular type was the most common in males (Table 2).

Table 1: Sexual dimorphism in crista galli measurements (n = 113)

Study by	Sex	Height (mean ± SD) (mm)	Width (mean ± SD) (mm)	Length (mean ± SD) (mm)	Methodology
(Golpinar *et al.,* 2022)	Male (n=31)	13.64 ± 1.68	2.82 ± 0.69	16.10 ± 1.20	Dried skulls
	Female (n=27)	10.24 ± 1.44	4.64 ± 1.10	14.12 ± 1.17	
(Komut and Golpinar, 2021)	Male (n=30)	16.28 ± 2.41	2.59 ± 1.00	14.50 ± 1.90	CT scans
	Female (n=25)	12.17 ± 2.27	4.55 ± 1.22	11.06 ± 1.73	

Table 2: Comparison of the types of the crista galli to different sex (n (%))

Study by	Sex		Classification
	Males	Females	
(Golpinar *et al.,* 2022)	30 (27.80)	78 (72.20)	Tear drop type
	44 (74.60)	15 (25.40)	Tubular type
	34 (85)	6 (15)	Ossified type
(Komut and Golpinar, 2021)	189 (82.9)	39 (17.1)	Tear drop type
	65 (34.2)	125 (65.8)	Tubular type
	13 (11.3)	102 (88.7)	Ossified type

1.2.4 Morphological and Morphometric Variation in the cribriform plate

Several studies have provided a comprehensive description of the cribriform plate, its dimensions, the number of openings for the olfactory nerves, the shape, inclination, and size of the crista galli, as well as the relationship between the cribriform plate and the sphenoid bone (Schmidt, 1974, Samii *et al.,* 1989, Krmpotić-Nemanić *et al.,* 1998, Patron *et al.,* 2015) (Figure 4, Table 3). Different studies have sought to portray the anterior cranial fossa and cribriform region in terms of sex and laterality for example, according to Jacob and Kaul (2014), the right side of the length is higher than the left, whilst according to Coelho *et al.* (2018) the left side is significantly lower than the right side (Table 3). Kawahara *et al.* (1968) described the cribriform plate's surface contour as five distinct patterns: in Type I, the lines on a superficial level split from the middle and spread towards the back. Type II has lines that are practically straight, moving towards a particular region called the planum sphenoidale (Figure 5). Lines of Type III are nearly parallel and close to one another. Both sides of Type IV have average fixing points in the middle. Finally, Type V is shaped like a diamond/rhomboid, with the middle being the widest and the front and back being the narrowest (Figure 5). Based on the olfactory fossa morphological fluctuation, the manual measurement of distances in instances of thin and profound fossae are unrealistic to be determined (Papadopoulos-Manolarakis *et al.,* 2022) (Figure 4). Other researchers have endeavoured to more likely portray the cribriform plate by describing its connection to related structures. The Keros classification, which describes the relationship between the ethmoidal roof and the cribriform plate in relation to the depth of the olfactory groove, is one of the most frequently cited systems (Keros, 1962).

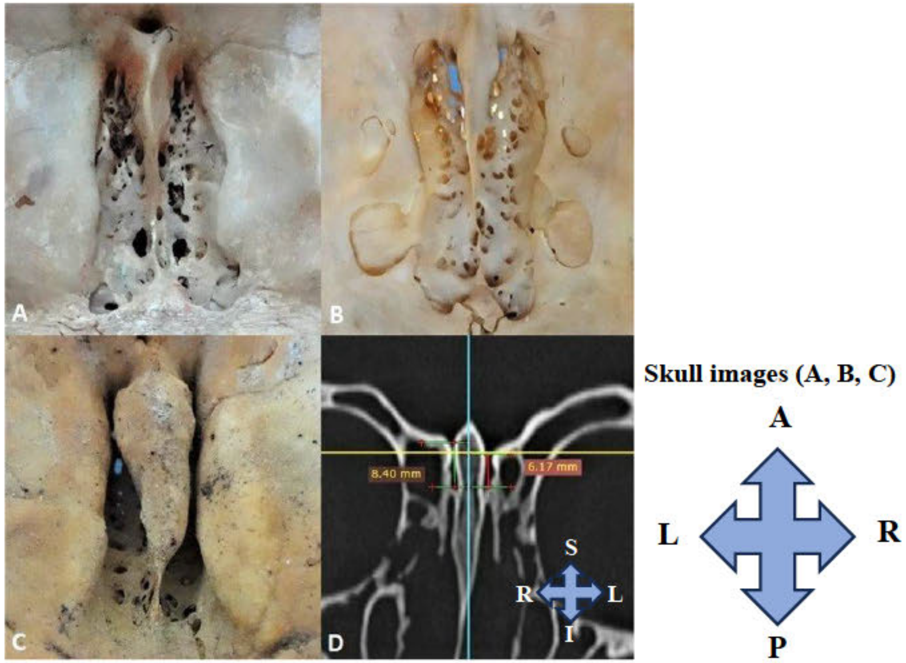

Figure 4: Images showing the cribriform plates variations on bones and CT scans. A and B- wide and shallow fossa (axial view); C narrow and deep fossa, which hinders ability to achieve repeatability in measurements (axial view); D- to overcome challenges in C, D was utilized to solve challenges (coronal view). Adapted from (Papadopoulos-Manolarakis *et al.,* 2022).

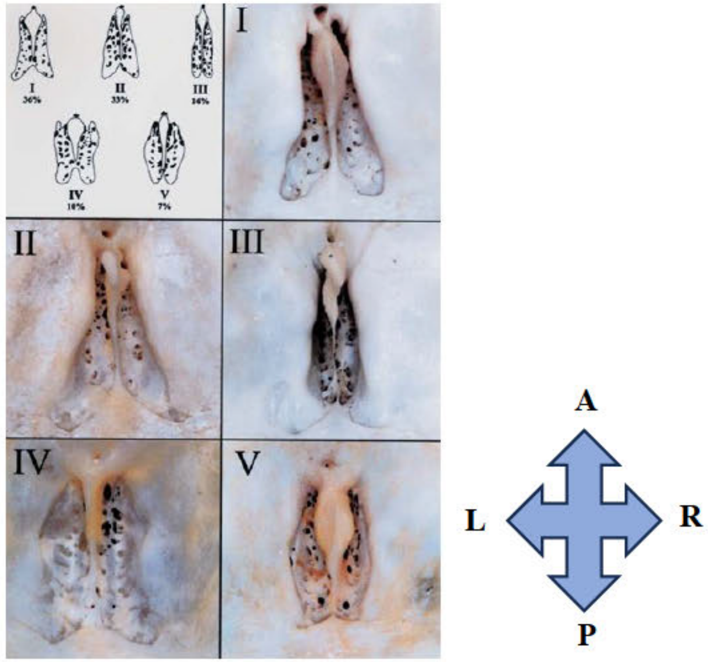

Figure 5: Image in axial view showing different types of the cribriform plate according to Kawahara in axial view. Adapted from (Vasvári *et al.,* 2005b).

Keros measured the maximum LLCP height to create a method for classifying olfactory fossa depths. Keros Type I is given when the depth is less than or equal to 3 mm, Type II is from 4 to 7 mm, and Type III is greater than 7 mm (Nair, 2012) (Figure 6, Table 4). According to (Jabaz and Abedtwfeq, 2022), the size and shape of the paranasal sinuses are among the most variable structures and the same person may have an asymmetric ethmoid roof height. Type III is the most dangerous and significant sort of endoscopic sinus medical procedure and has an extremely thin cribriform plate (Sasmal *et al.*, 2022). Several studies on the ethmoid roof and olfactory fossa based on the Keros classification in various populations have been carried out over the years (Bista *et al.,* 2010, Adeel *et al.,* 2013, Erdogan *et al.,* 2015, Salroo *et al.,* 2016).

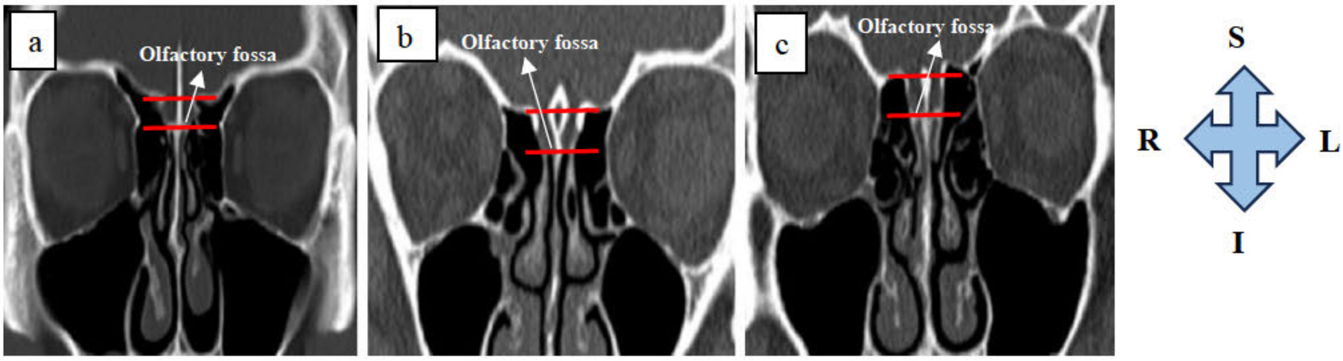

Figure 6: According to the Keros classification, CT images of three types of olfactory fossa in the coronal plane showing Keros classification in coronal view **(a)** Keros type I **(b)** Keros type II **(c)** Keros type III, respectively. Adapted from (Karatay and Avcı, 2021).

Table 3: Sex variation in association of the cribriform plate in both sides/Morphological variations of the cribriform plate measurements by sex

Study by	Sex	Length (mm)		Width (mm)		Depth (mm)		No. of foramina	Country
		R. side	L. side	R. side	L. side	R. side	L. side		
(Jacob and Kaul, 2014)	-	21.30 (±3.40)	20.90 (±3.60)	-	-	-	-	-	India
(Coelho *et al.,* 2018)	-	21.15 (±0.59)	21.41 (±0.60)	4.57 (±0.22)	4.49 (±0.21)	-	-	-	USA
(Jabaz and Abedtwfeq, 2022)	Male	-	-	-	-	4.80±1.68	4.69±1.54	-	Iraq
	Female	-	-	-	-	4.88±1.50	4.44±1.50		
(Papadopoulos -Manolarakis *et al.,* 2022)	-	22.29 (±2.16)	22.10 (±2.44)	-	-	-	-	-	Greece

Table 4: Sex related Keros' classification variations in the right and left sides (n (%))

Study by	Right Side		Left Side		Keros Type
	Male	Female	Male	Female	
(Jabaz and Abedtwfeq, 2022)	17 (18.9)	14 (14.1)	14 (15.5)	16 (16.1)	I
	62 (68.9)	76 (76.8)	69 (76.7)	78 (78.8)	II
	11 (12.2)	9 (9.1)	7 (7.8)	5 (5.1)	III
(Shrestha *et al.,* 2018)	42 (41.7)	46 (45.5)	45 (44.6)	41 (40.6)	I
	8 (7.9)	4 (3.96)	6 (5.9)	9 (8.9)	II
	1 (0.9)	0 (0)	0 (0)	0 (0)	III
(Naaz *et al.,* 2022)	20 (60.6)	13 (39.4)	20 (52.6)	18 (47.4)	I
	108 (51.4)	102 (48.6)	114 (54.5)	95 (45.5)	II
	11 (84.6)	2 (15.4)	5 (55.6)	4 (44.4)	III

Aside the Keros types and classification, there is also the Yenigun classification based on the anterior ethmoidal artery (AEA) and ethmoid roof and evaluating the olfactory fossa as transverse. According to this classification, as the length of the canal of the anterior ethmoidal artery and the incidence of the artery increases, the risk of injury increases (Yenigun *et al.,* 2016, Sağlam *et al.,* 2024). On the account that Keros type and classification is the most widely and frequently used type, hence this study employed Keros type and classification for the construction of the data collection tables (Keros, 1962). On that note, since the Keros type and classification is based on the depth of the ethmoid roof which may be asymmetrical on the same individual, that affect the location of the AEA on either side of the skull (Kolo and Abdullahi, 2024).

The AEA is a significant blood vessel branching from the ophthalmic artery, supplying the nasal mucosa and ethmoid sinuses. Its location and course exhibit considerable anatomical variation, making it a crucial landmark to identify and protect during endoscopic sinus surgery and skull base procedures (Szczepanek *et al.,* 2024). The AEA penetrates the lateral lamella of the cribriform plate and then enters the olfactory fossa, where it crosses the superior aspect of the anterior ethmoid sinus, specifically traversing the roof of the anterior ethmoid air (Alsaied, 2017), running either "non-hanging" within a bony canal at the base of the skull or hanging below the base of the skull with dehiscence of the AEA bone covering (Zinreich *et al.,* 2019) (Table 5). It is associated to a crucial structure within the ethmoid sinus which poses a significant risk of iatrogenic injury (Bortoli *et al.,* 2017); subsequently, cautious dissections and controls should be exercised at the level of the AEA (Yang *et al.,* 2009). Studies done in Iraqis and Korean populations, the AEA was frequently located within the skull (Moon *et al.,* 2001, Jabaz and Abedtwfeq, 2022) (Table 5). When injured, the AEA may continue to bleed inside the orbit, resulting in an orbital hematoma that requires decompression or may cause amaurosis or decreased visual acuity (Ferrari *et al.,* 2017).

Table 5: The frequency of anterior ethmoidal artery location to the skull on both sides (n (%))

Study by	Sex	AEA location	Laterality		Country	Methodology
			R. side	L. side		
(Moon *et al.,* 2001)	-	Below	10 (14.3)		South Korea	CT scans
			60 (85.7)			
(Jabaz and Abedtwfeq, 2022)	-	Below	77 (40.7)	79 (41.8)	Iraq	CT scans
		Within	112 (59.3)	110 (58.2)		

Various factors like horizontal lamella design, AEA course, and unevenness of olfactory fossa depth are significant anatomical variations in functional endoscopic sinus surgery (Jacob and Kaul, 2014). Since the anatomic variations are incredibly diverse, careful planning is ideally tailored preoperatively with the aid of a CT scan rather than relying solely on standard intraoperative landmarks (Nair, 2012). There is a significant dissimilarity in the content of preoperative sinus CT imaging reports, highlighting the need for standardized reporting to ensure accurate and consistent communication of critical anatomical information (Deutschmann *et al.,* 2013).

Furthermore, complications may occur more frequently during surgery if the depth and anatomical variations of the olfactory fossa are not considered in preoperative imaging (Erdem *et al.,* 2004). Preoperative assessments of the ethmoid rooftop, anterior cranial fossa and related bone designs nearby the olfactory fossa will give a more secure course during a medical procedure and lessen postoperative difficulties (McMains, 2008). During endoscopic sinus surgery, there may be an increased risk of intracranial penetration due to the asymmetry in the depth of the olfactory fossa on both sides or the height of the ethmoidal roof (Karatay and Avcı, 2021).

1.3. Problem Statement

The cribriform plate is the thinnest portion of the base of the skull, which is susceptible to trauma and fractures during endoscopic surgery (Gomez and Pickup, 2023). More so, naso-septal development also plays an indirect role in the size and shape of the cribriform plate, so it is vital to know most variations of the cribriform plate to decrease the likelihood of developing fatal complications (Vasvári et al., 2005b). In addition, previous studies have documented high cases of cerebrospinal fluid (CSF) leakage following endoscopic surgery, and persistent CSF leak leads to headache syndrome (Yilmazlar *et al.,* 2006, Cai *et al.,* 2022). This was due to the dura overlying the cribriform plate being thin and tightly adherent to the skull, hence, fractures of the cribriform plate can easily tear the dura and lead to leakage of CSF into the nasal cavity. Once the dura is compromised, the patient is at risk for ascending infections, such as meningitis, pneumocephalus, and even brain tissue herniation into the nasal cavity and paranasal sinuses (Kühnel and Reichert, 2015). Another common complication of cribriform plate fracture is anosmia, or loss of smell, which is usually caused by injury to the olfactory bulb (Vallee, 2021).

Empirical evidence has revealed that about 80% to 90% of cases of cribriform plate fractures are brought on by blunt force trauma to the face (Kühnel and Reichert, 2015). A significant injury mechanism and a direct frontal trauma or blow to the frontal region are required for cribriform plate fracture. This fracture is usually linked to other fractures of the facial bone, and it rarely occurs by itself. As a result, there are no data on the specific causes of cribriform plate fracture alone. Generally, the most widely recognized reason for midface crack in adults is car accidents, which account for almost 66% of cases, followed by human attacks/assaults at 21%, and falls at 9%. Work related wounds and sports-related wounds make up a more modest rate (Gomez and Pickup, 2023).

Given the need to reduce potential fracture of the cribriform plate and injury to associated structures, this study will provide normative data towards understanding of the variations in the cribriform plate that exist in different sexes, laterality and how variations of associated structures could impact on surgical outcomes of specimen and samples in KZN population.

1.3 Significance of study

The cribriform plate is a significant construction that isolates the nasal cavity from the cerebrum, and any harm to it can cause CSF to spill from the nose (CSF rhinorrhoea). Trauma, infection, or tumours can cause CSF rhinorrhoea, which can result in meningitis and other serious neurological complications (Ozaki *et al.,* 2024).

To reach the olfactory epithelium, which is responsible for the sense of smell, the olfactory nerve fibres pass through the cribriform plate's small perforations (Drake *et al.,* 2009). Anosmia (loss of sense of smell) and hyposmia (reduced sense of smell) can result from damage to the cribriform plate caused by trauma or tumours (McNeill and Carrie, 2015)

During nasal and sinus surgeries, the cribriform plate is a delicate structure that must be handled with care because damage to the cribriform plate may result in CSF leakage, meningitis, or brain injury (Coelho *et al.,* 2018). Therefore, the cribriform plate is a critical anatomical structure in the head and neck region, with clinical importance in olfactory capability, neurological problems, and surgeries.

Given these complications, this study will add to the existing knowledge about the morphology and morphometry of cribriform plate. It will also reveal the variations that exists among KZN population with regards to sex, and how related structures (nasal cavity, crista galli) affect the cribriform plate which, will guide surgeons during surgeries.

1.4 Aim

The aim of this study was to observe, measure and record the shape, forms and the variations in dimensions of cribriform plate in relation to sex and laterality on both the bones and the CT scans of a selected KZN population.

1.5 Hypothesis

Null Hypothesis*:* There is no significant difference in the variations of the cribriform plate between the KZN population and those reported in studies conducted in high-income countries.
Alternative Hypothesis: The variations in the cribriform plate of the KZN population are significantly different from the values obtained in studies conducted in high-income countries.

1.6 Objectives

The specific objectives of this study were as follows:

1. To examine the morphological and morphometric changes of the cribriform plate in relation to sex and laterality on bones CT scans of a selected KZN population.
2. To evaluate the relationship between the morphology of cribriform plate, crista galli and nasal cavity on bones and CT scans of KZN population.
3. To compare sexual dimorphism of the cribriform plate to different KZN population groups (Black, Coloured, White and Indian) on bones and CT scans.

1.7 Methodology

1.7.1Materials and Methods

Fifty-eight (58) bones of the cribriform plate were obtained from the Department of Clinical Anatomy at the University of KwaZulu Natal (Nelson R. Mandela School of Medicine campus) and Durban University of Technology (Ritson campus), and fifty-five (55) CT scans (Ingenuity CT 6 slice, Germany) were obtained from King Edward VIII Hospital. The specimens belong to body donors who willingly donated their bodies after signing an informed consent form. In this study the cribriform plate on bones was investigated on a superior view without the calvarium and on CT scans, it was assessed from the coronal view. The osteological parameters were measured using the vernier calliper (Model 0-150 x 0.01 MM – IS13241-150, South Africa), depth gauge (Model 850-502, China) and the RadiAnt DICOM Viewer 2023.1 (64-bit) on CT scans. To ensure validity, a sample of at least 10 skulls were subjected to the morphometric procedure. These were then subsequently CT-scanned and the cribriform plate parameters were calculated using the CT scanners' internal software. The reported values were compared to those of the manual method and any significant systematic error/bias was corrected. Reliability was ensured by consistently measuring thrice by the intra-observer done under standard conditions.

1.7.2 Parameters

(i) Morphological parameters

This study observed the shapes and recorded the forms and variations of the cribriform plate using the Kawahara method and the Keros type and classification (Keros, 1962, Kawahara *et al.,* 1968). The justification for employing this method is based on the account that, Kawahara method is the standard and reliable method which was commonly used to classify the cribriform plate.

(ii) Morphometric parameters

The measurements were taken as below, all units were in millimetres:

A = cribriform plate length, left (maximum anteroposterior distance of the surface of olfactory fossa from the most anterior to the most posterior point on the left side).

B = cribriform plate length, right (maximum anteroposterior distance of the surface of olfactory fossa from the most anterior to the most posterior point on the right side).

C = cribriform plate width (left distance between lateral lamella of the cribriform plate and medial border of crista galli on the left).

D = cribriform plate width, right (distance between lateral lamella of the cribriform plate and medial border of crista galli on the right).

E = Cribriform plate depth (vertical height of the olfactory fossa)

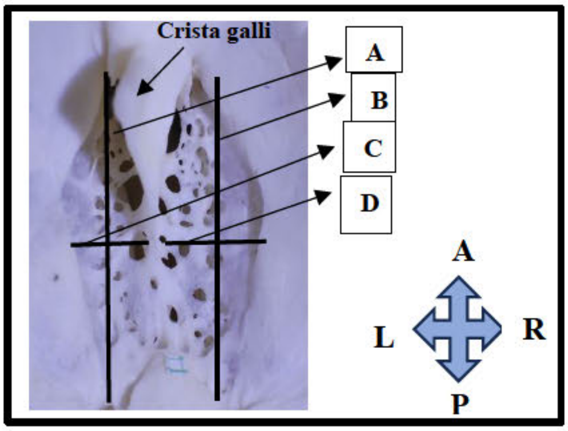

Figure 7: This figure shows how the morphometric parameters were recorded in the cribriform area of both bones and CT scans (axial view). Adapted from (Coelho *et al.,* 2018).

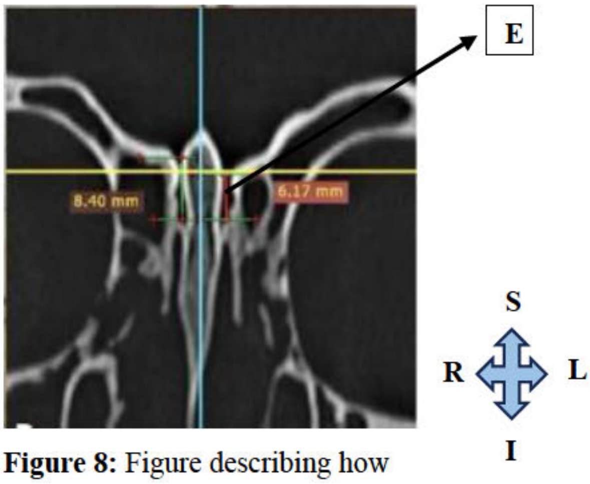

Figure 8: Figure describing how measurements of depth in both bones and CT scans were taken (coronal view). Adapted from (Papadopoulos-Manolarakis *et al.,* 2022).

1.7.3 Associated structures to the cribriform plate

The morphology of the crista galli was examined to see how it affects the cribriform plate. The symmetry and asymmetry of the nasal cavity was also observed to investigate how it affects the morphology and morphometry of the cribriform plate. The course of the AEA was identified based on these anatomical landmarks: the anterior ethmoid foramen which is a notch on the medial orbital wall or the anterior ethmoid sulcus on the olfactory fossa lateral wall. The AEA course was identified on either side separately and classified as being within or separate from the skull base (Figure 9).

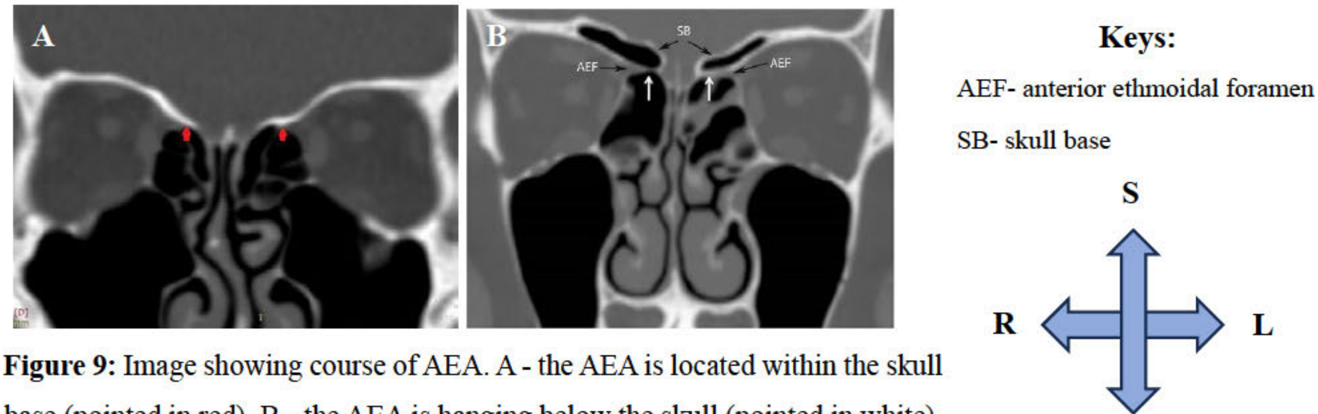

Figure 9: Image showing course of AEA. A - the AEA is located within the skull base (pointed in red), B - the AEA is hanging below the skull (pointed in white). Adapted from (Abdullah *et al.,* 2019, Jabaz and Abedtwfeq, 2022).

1.7.4 Ethical and gatekeeper **Approval**

Ethical approval for this research was sought and obtained from the Biomedical Research Ethics Committee (BREC) with ethical number BREC/00005687/2023 of the University of KwaZulu Natal and from the Department of Health King Edward VIII Hospital selected in this study upon application. Anonymity and confidentiality were always maintained in this study. The information gathered would only be used for research purposes. The names of the patients were not recorded. After the study is finished, the CT images and electronic data will be destroyed in accordance with the University of KwaZulu-Natal research ethics regulation which is 5 years after the completion of the project. To safeguard all images' data and information, a password protected access control was implemented on the personal computer (workstation) used for this study.

1.7.5 Inclusion criteria

1.7.5.1 CT scans

CT scans that were composed of ages above 10 years old, as the cribriform plate has been completely ossified by 10 years. CT scans that had a clear insight of the cribriform plate.

1.7.5.2 Bones/Osteology

Bones that were composed of ages above 10 years old. Bones that were not eroded on the cribriform plate and related structures.

1.7.6 Exclusion criteria

1.7.6.1 CT scans

CT scans of subjects under 10 years old. CT scans that were foggy/dim on the cribriform plate.

Bones that were eroded in the cribriform plate and related structures.

1.7.6.2 Bones/Osteology

Bones of subjects under 10 years old. Bones that were eroded in the cribriform plate and related structures.

1.7.7 Materials

Instruments for measurement were digital vernier calliper, spreading calliper, depth gauge, dissecting kit on bones and the RadiAnt DICOM Viewer 2023.1 (64-bit) on CT scans.

1.7.8 Statistical analysis

The statistical data analysis was conducted in R Statistical computing software of the R Core Team, 2020 (South Africa), version 3.6.3. The results were presented in the form of descriptive and inferential statistics.

Where applicable, the descriptive statistics of numerical measurements were summarized as the minimum, maximum, quartiles, interquartile range, means, standard deviation and the coefficient of variation. On the other hand, the categorical variables were described as counts and percentage frequencies where simple and multiple bar charts were also used to visually display the categorical variables.

Depending on the distribution of the numerical variables between two independents groups, mean or median differences were assessed using either a t-test or Wilcoxon Rank Sum respectively.

To determine the association between categorical variables, a Chi-Square Test was used and when the distribution of the cross-tabulations contained an expected value of less than five, a Fisher's exact test was applied. In the case of a significant difference between the Chi-Square or Fisher exact test, a row-wise paired z-test was used as a post hoc analysis following the omnibus tests (Chi-Square or Fisher exact test). All the inferential statistical analysis tests will be conducted at 5% levels of significance.

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BRIDGING TEXT

FROM CHAPTER ONE TO TWO

Chapter one above presented a concise background information on cribriform plate, detailed analysis of literature, problem statement, significance of study, aim, hypothesis, objectives, methodology, ethical approval, data management, inclusion and exclusion criterion and statistical analysis. It also highlights the significance of the cribriform plate clinically in terms of variations of morphometry bilaterally between males and females of the cribriform plate as it differs between sexes of different populations (Lebowitz *et al.,* 2001, Romualdo Rueff-Barroso *et al.,* 2021). Based on literature, the cribriform plate differs between sexes of different populations, hence this study was carried out on the South African population.

The next chapter, chapter two entails data collected from CT scans as they are commonly used by surgeons to analyse the anatomy of the human body, sought to expand South African literature in terms of morphology, morphometry and related structures of the cribriform plate between males and females of a selected KwaZulu-Natal population. For efficient surgical planning and successful surgical results, knowledge of such variances is essential. There is, however, a paucity of literature in morphological variations of the cribriform plate globally.

The writing, formatting, and presentation of this work have all been done in accordance with the criteria from the College of Health Sciences of the University of KwaZulu-Natal. This document uses the Harvard referencing style for its bibliography. This manuscript is under review on Surgical and Radiologic Anatomy journal for publication with manuscript number: 9e927f0c-ed44-4d82-b3ab-04e3b4fff2dd.

CHAPTER TWO:

MANUSCRIPT ONE

Computed Tomography Investigation of Cribriform Plate and Associated Structures in KwaZulu-Natal population: Dimensional, Morphometric and Sex-related Variations

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2.1 Abstract

Introduction: The cribriform plate is a small bony structure located in the middle of the anterior cranial fossa. It has several olfactory foramina for the olfactory nerves to pass through. The cribriform plate is an importance structure in endoscopic sinus surgery, skull base surgery, and forensic identification. However, there is paucity of literature regarding its morphological variations and sexual dimorphism within the African populations which impacts these procedures. To better understand the anatomical variations and the clinical significance of the cribriform plate, this study investigated the morphology, morphometry, and sexual dimorphism of the cribriform plate using CT scans of a select KwaZulu-Natal (South Africa) population.

Materials and methods: Fifty-five (55) CT scans of the cribriform plate were assessed from the axial and coronal views. Morphology of the cribriform plate was recorded based on the Kawahara method, morphometry and related structures of the cribriform plate were investigated to identify any sexual dimorphism.

Result: Type IV of cribriform plate was the most prevalent in males (26.7%) and Type I and II of cribriform plate was the most common in females (both 28.0%). All morphometric parameters were observed to be slightly higher in males on both sides except for the length on the right side of females which was 20.6±3.73 compared with 20.3±3.78 mm for males. The teardrop type of the crista galli was the most common type with 53.3% on males and 64.0% on females. Keros classification Type II was the most prevalent in both sexes (on the right side, males had 63.33% and females had 68% and; on the left side, males had 63.33% and females had 72%), and Keros Type III (on the right, males had 3.33% and females had 4% and; on the left, males had 10% and females had no Type III identified) was the least identified within the KwaZulu-Natal population. On the right and left sides of both sexes the AEA was commonly located below the skull base. Black male South Africans had a right side of cribriform plate that was longer (20.6 mm), whereas White South African males had a right side of cribriform plate that was slightly smaller (19.7 mm). Compared to White South African females, Black South African females have a longer right side of the cribriform plate. The cribriform plates' width and depth in Black South African females had lower means than White South African females on both sides.

Conclusion**:** The outcomes of this study reveal that no statistical significance was found in the morphology and morphometry parameters of the cribriform plate within the SA population. Although there was no statistical significance, the variations observed may impact surgical planning, especially in procedures involving the anterior skull base such as functional endoscopic sinus surgery and removal of tumours.

Keywords: Cribriform plate, CT scans, Morphology, Morphometry, Sexual dimorphism

2.2 Introduction

The floor of the anterior cranial fossa is formed mainly in its median region by the cribriform plate (sieve plate) of the ethmoid bone fitted into the ethmoidal notch of the frontal bone (Vasvári *et al.,* 2005a, Chemas-Velez *et al.,* 2023). The cribriform plate, as described by Helwany and Bordoni (2020) is a delicate and complex structure with numerous small foramina that the olfactory nerve fibers pass through. The nasal cavity and the olfactory bulb are connected by these foramina, which assist in the transmission of smell-related sensory information (Gomez and Pickup, 2023).

Besides its role of providing a passage for the olfactory nerves to transmit sensory information from the nasal cavity to the brain in olfaction van Gijn and Dunne (2022), the cribriform plate is also a significant border between the nasal cavity and the cerebrum that prevents the spread of contaminations/ infections between the two (Helwany and Bordoni, 2020). Moreover, the cribriform plate is a key area of interest in many medical fields due to its unique structure and functions, especially in neurosurgery and otolaryngology (Romualdo Rueff-Barroso *et al.,* 2021).

The anatomical and functional importance of the cribriform plate extends to its clinical significance in various medical procedures and conditions (Gomez and Pickup, 2023). The cribriform plate is frequently associated with head injuries, specifically those involving the frontal region of the skull, due to its close connection to the olfactory nerve fibres and the brain (Helwany and Bordoni, 2020). Fractures or disruptions to the cribriform plate can cause an injury to the olfactory nerves and that most likely leads to a leakage of cerebrospinal fluid into the nasal cavity requiring attentive evaluations by medical experts (Ahilasamy *et al.,* 2021). It is important for clinicians and researchers to know about the cribriform plate's structure and functions because it provides more information on the mechanisms that regulate smell and the balance between the nasal cavity and the cerebrum (Ahilasamy *et al.,* 2021).

Additionally, the specific characteristics of the cribriform plate have implications for surgical procedures in the craniofacial region (Coelho *et al.,* 2018). To minimize the risk of iatrogenic injuries and to preserve the cribriform plate's important functions related to olfaction and protection of the brain, procedures such as endoscopic sinus surgery and some approaches to the skull base require detailed understanding of its anatomy (Alazzawi *et al.,* 2012).

Furthermore, the evaluation of the cribriform plate in relation to various pathologies, such as tumours and inflammatory processes affecting the ethmoid bone and adjacent structures, has also been improved by advancements in neuroimaging techniques (Gunbey *et al.,* 2018). Patients with conditions involving this anatomical region have benefitted from more precise diagnosis and treatment planning as a result of the detailed understanding/ image of the cribriform plate through the likes of magnetic resonance imaging and CT scans (Sasmal *et al.,* 2022). Therefore, for surgeons to give an exact diagnosis there is a need to understand the morphology (size and shape) and morphometry (length, width and depth) of the cribriform plate.

Keros type III was more common in males than in females, and LLCP height was higher in males ($p<0.05$) (Gibelli *et al.,* 2022), whilst, there was no statistically significant sex difference in the cribriform plate depth measurements taken from males and females (Erdem *et al.,* 2004) Asymmetry of the cribriform plate means that it is not evenly shaped or sized on both sides, this could be due to various factors, such as congenital abnormalities, trauma, or diseases affecting the skull or nasal cavity (Drake *et al.,* 2012). If there is significant asymmetry, it could potentially affect the function of the olfactory nerve and may be associated with conditions such as anosmia (loss of smell) or other neurological issues (Gomez and Pickup, 2023). However, the implications would depend on the extent and cause of the asymmetry, and would likely require evaluation by a medical professional, possibly with imaging studies like CT scans or magnetic resonance imaging, to determine any potential impact on health or function (Erdem *et al.,* 2004). In a study by Adeel *et al.* (2013) to study Keros classification in relation to sex, they discovered that Keros Type I was seen in 38 sides in males and 8 sides in females, which was statistically significant. Keros Type II was seen in 46 and 29 sides in males and females, respectively, Keros Type III was seen 18 sides in males and 15 sides in females. Both Type II and Type III were not statistically significant. Moreso, accidental injuries of the lateral lamella of the cribriform plate and the anterior ethmoidal artery are the main potential risks during endoscopic surgery, and may cause disastrous consequences (Souza *et al.,* 2009).

Given the extensive investigation and documentation on the morphological classification and morphometry analysis of the cribriform plate in terms of laterality and sex in various population. However, sexual dimorphism that exists in the morphology and morphometry of the cribriform plate as well as related structures in KwaZulu-Natal population in CT scans and bone samples remains unexplored. Thus, this study was designed to explore the differences of the cribriform plate on the right and left sides of the different sexes, as well as how structures related to the cribriform plate influence it in the various population groups of the KwaZulu Natal population.

2.3 Methodology

2.3.1 Materials and Methods

Fifty-five (55) CT scans (30 males and 25 females) of the cribriform plate were obtained from King Edward VIII Hospital, that were 10 year and above in Durban South Africa with ethical number BREC/00005687/2023. The CT scans were assessed from the axial view and coronal view, slice thickness 2.0mm. The parameters were measured using the Radiant Dicom Viewer 2023.1 (64 – bit). The reported values were compared to those of the manual method and any significant systematic error/bias was corrected. Reliability was ensured by consistently measuring thrice by a competent person done under standard conditions.

2.3.2 Parameters

2.3.2.1 Morphological parameters

This study observed and recorded the forms, shapes and variations of the cribriform plate using the Kawahara method where we observed the five different shapes/types (Type I: The lines start in the middle and spread out towards the back, like a fan. Type II: The lines are straight and go towards a specific area called the planum sphenoidale. Type III: The lines are almost parallel to each other and are close together. Type IV: The lines have a fixed point in the middle on both sides, like a balance point. Type V: The pattern is shaped like a diamond or rhomboid, with the middle being the widest part and the front and back being the narrowest) (Kawahara *et al.,* 1968) (Figure 13). The Keros type and classification where we classified the olfactory fossa into Type I, II and III was employed (Keros, 1962). The justification for employing this method is based on the account that, Kawahara method is the standard and reliable method which other methods build on.

2.3.2.2 Morphometric parameters

The measurements were taken as below all units were in millimetres (Figure 10 and Figure 11):

A = cribriform plate length, right (maximum anteroposterior distance of the surface of the olfactory fossa from the most anterior to the most posterior point on the right side).

B = cribriform plate length, left (maximum anteroposterior distance of the surface of the olfactory fossa from the most anterior to the most posterior point on the left side).

C = cribriform plate width, right (distance between LLCP and medial border of crista galli on the right).

D = cribriform plate width, left (distance between LLCP and medial border of crista galli on the left).

E = Cribriform plate depth

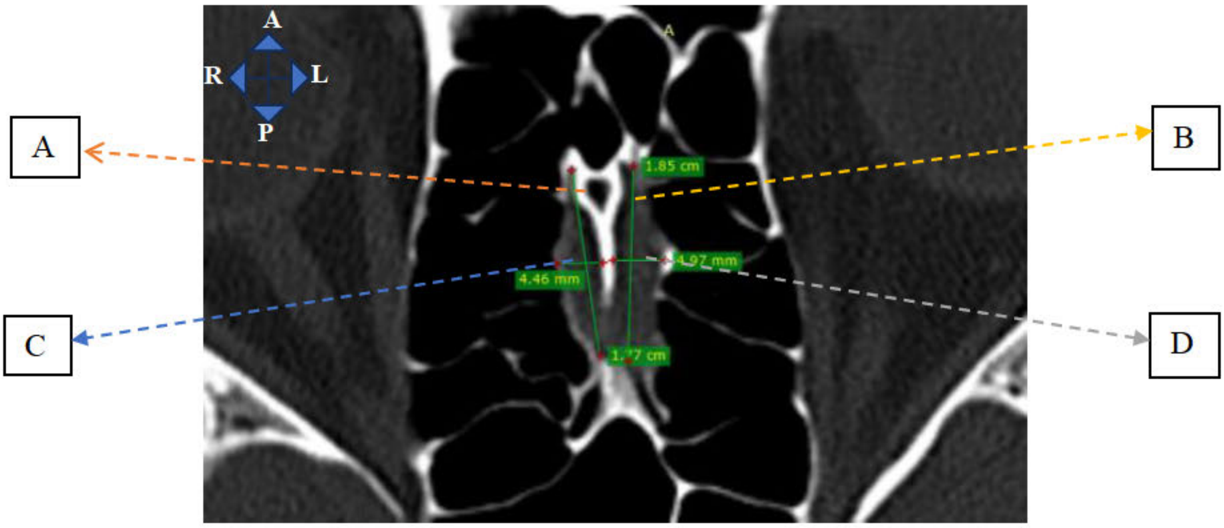

Figure 10: Image in axial view showing measurements of the length and depth on both sides of the cribriform plate.

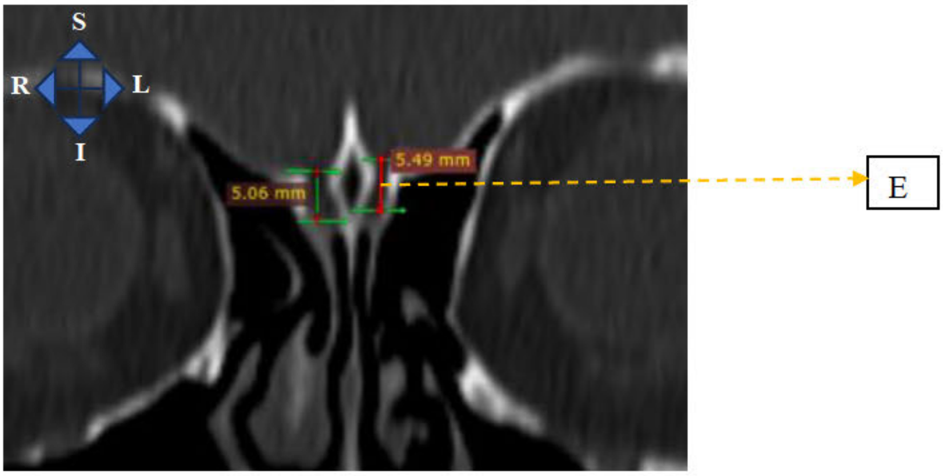

Figure 11: Image in coronal view showing measurements of left and right depths of the cribriform plate.

2.3.3 Associated structures to the cribriform plate

The morphology of the crista galli was examined to see how it affects the cribriform plate by measuring the length, width and height of crista galli to determine its type/shape. The symmetry and asymmetry of the nasal cavity was also observed to investigate how it affects the morphology and morphometry of the cribriform plate. The AEA course was identified on either side separately and classified as being within or separate from the skull base (Figure 12).

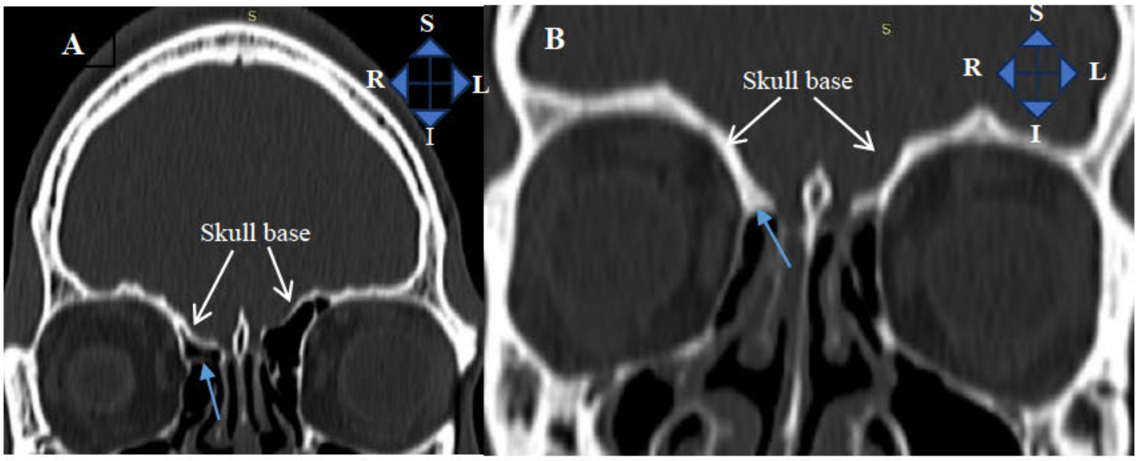

Figure 12: Images in coronal view showing location on the AEA. A – blue arrow indicating AEA below the skull base, B – blue arrow indicating AEA within the skull.

2.3.4 Ethical and gatekeeper Approval

Ethical approval for this research was obtained from the Biomedical Research Ethics Committee (BREC), reference number: BREC/00005687/2023 and from National Health Research Database (NHRD). Anonymity and confidentiality were always maintained in this study. The information gathered was only used for research purposes. The names of the patients were not recorded.

2.3.5 Inclusion criteria

CT scans were composed of ages above 10 years old, as the cribriform plate has been completely ossified by 10 years and CT scans that had a clear insight of the cribriform plate.

2.3.6 Exclusion criteria

CT scans of subjects under 10 years old. CT scans that were distorted on the cribriform plate.

2.3.7 Statistical analysis

Results were statistically be analysed using R Core Team, 2020, version 3.6.3 software. Measurements of mean, standard deviation, maximum and minimum were calculated using Microsoft Excel software. Averages on both sides were calculated. Sample t-tests were used in morphometry parameters to determine if there are any significant differences between laterality measurements within sexes. Fisher's Exact tests were used to analyses types of the cribriform plate and crista galli. The artery is either located "within" or "below" the skull base, with Chi-square tests indicating whether there is a statistically significant difference between these distributions. P-value was considered significant if less than 0.05.

2.4 Results

2.4.1 Morphology of the cribriform plate in relations to sex

This study observed all five different types of the cribriform plate. In males, both Type I and Type II (Figure 12) were observed to be 23.3%. Type III, Type IV and Type V (Figure 13) were discovered to be 13.3%, 26.7% and 13.3%, respectively. In females, Type I was observed to be 28.0%, Type II to be 28.0%, Type III to be 20.0%, Type IV to be 16.0% and Type V to be 8.0%. Even though there was no statistical significance between both sexes ($p = 0.820$), Type IV was the most common in males and Type IV was less common in females.

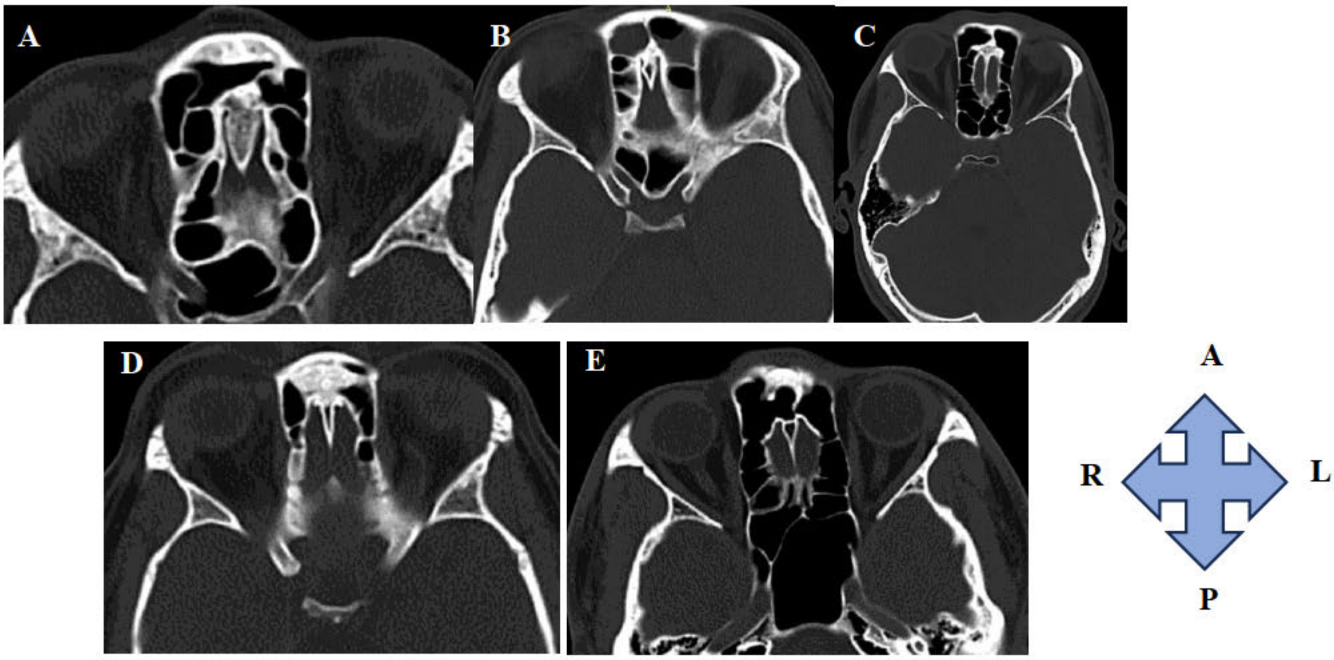

Figure 13: Images in axial view showing five types of the cribriform plate. A – Type I, B – Type II, C – Type III, D – Type IV and E – Type V.

2.4.2 Morphometry of the cribriform plate in relations to sex and laterality

The mean length of males on the right side was 20.3±3.78 mm which was slightly smaller than that of females which was 20.6±3.73 mm, whilst the mean length on the left side for males was 20.1±4.34 mm and 20.0±3.84 mm for females. The width and depth on the right side for males were 4.78±1.30 mm and 4.72±1.44 mm, respectively. On the right side of females, the width was 4.19±1.05 mm and depth median was 4.70 mm. Width on the left side was 4.33 mm (median) for males and 4.18±0.97 mm for females. The depth on the left side for males was a bit bigger with the value of 5.15±1.65 mm and females being 4.94±1.40 mm. None of the parameters were statistically significant.

2.4.3 Associated structures to the cribriform plate

The ossified type of the crista galli was the least detected type with 20.0% of males and 12.0% of females. The teardrop was the most common type with 53.3% on males and 64.0% on females. Tubular type was 26.7% of males and 24.0% of females (Figure 14).

The location of the AEA in females on both left and right sides was least observed within the skull with just 20.0% and below the skull it was found to be 80.0%. In males of the right side, it was 36.7% within the skull and 63.3% below the skull. On the left side of males, it was discovered to be 26.7% within the skull and 73.3% below the skull. However, none was statistically significant.

Keros classification type III was least identified classification type on the right side in both males and females. It was also the least identified on the left side in males and in females the was no Keros Type III determined (Table 6). Keros Type II was the most common type on the left and right side of the olfactory fossa. On the right side in males, it was determined to be 63.33% and 68% in females and on the left side 63.33% was found in males and 72% in females (Table 6). Keros Type I was 33.33% and 28% on the right side of males and females, respectively. Males were discovered to have 26.67% and females has 28% of Keros classification Type I (Table 6).

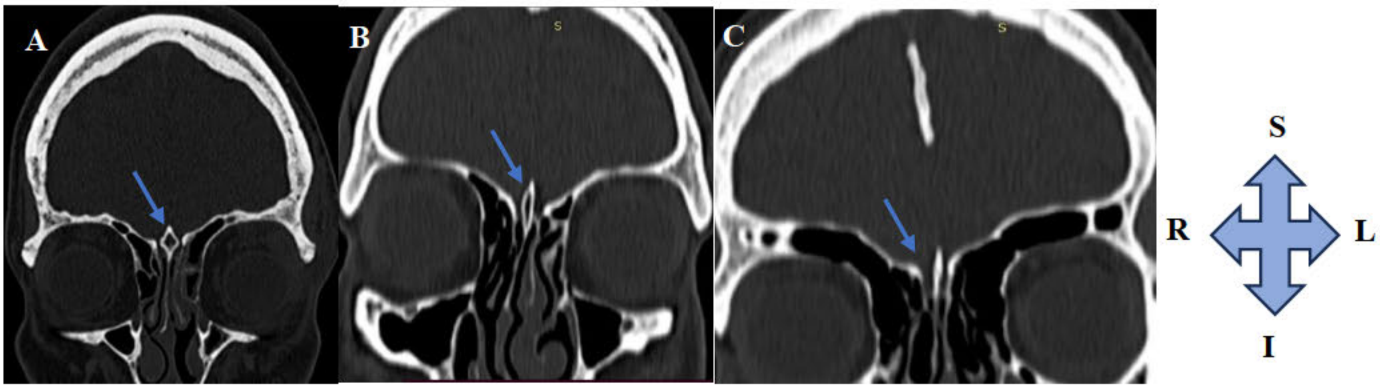

Figure 14: Images in coronal view showing different shapes/ types of the crista galli (pointed by blue arrow). A – Teardrop, B – Tubular, C – Ossified.

Table 6: Distribution of olfactory fossa based on Keros classification according to their sides and sex on CT

Keros Type	Right, n (%)		Left, n (%)	
	Male	Female	Male	Female
I	10 (33.33)	7 (28)	8 (26.67)	7 (28)
II	19 (63.33)	17 (68)	19 (63.33)	18 (72)
III	1 (3.33)	1 (4)	3 (10)	0 (0)

2.4.4 Sexual dimorphism on different KZN population groups

This study observed length on the right side of males to be 20.6±2.90 mm in Black South Africans and 19.7±5.49 mm in White South Africans, whilst the length of males on the left sides was 20.0±3.91 mm in Black South Africans and 20.3±5.46 mm in White South Africans. The length of females on the right side was 19.9±4.19 mm in White South Africans and 20.7 mm was the median for Black South Africans. Furthermore, on the left side the length was 20.1±3.71 mm in Black South Africans and 19.7±4.46 mm in White South Africans.

The width on the right and left side for male Black South African was 4.87±1.24 mm and 4.02 mm (median), respectively. Whereas on White male South Africans the width was 4.56±1.48 mm and 4.55±0.89 mm. On females, the width on the right and left side of Black South Africans was 4.00±1.05 mm and 4.17±1.06 mm, whilst the same width on White South Africans was 4.68±0.94 mm on the right side and 4.20±0.78 mm on the left side.

On Black male South Africans the depth on the right side was 4.70±1.59 mm and on the left side it was 4.96±1.68 mm. White South African males had a mean average depth of 4.77±1.12 mm on the right side and 5.60±1.55 mm on the left side. Black South African females had a depth mean average of 4.74±1.56 mm on the right side and 4.81±1.26 mm on the left side. White female South Africans had a depth of 6.16±2.68 mm on the right side and 5.26±1.78 mm on the left side.

Cribriform plate Type IV on males was the most prevalent in Black South Africans with 33.3%, Type II being second most common with 23.8%, followed by Type IV, Type I and Type III with 19.0%, 14.3% and 9.5%, respectively. On White South African males, the most common type in males was Type I with 44.4%, followed by Type II and Type III both with 22.2%, followed by Type IV with 11.1%. Type II was the most dominant type with 33.3% on Black South African females, followed by Type III with 27.8%, followed by type I with 22.2%, followed by Type IV with 11.1% and Type V with 5.6% was the least. Type II and Type V were the least common types in White South African females with 14.3%, followed by Type IV with 28.6% and the most prevalent type/shape was Type I with 42.9%. There was not identification of Type V and Type III in White South African males and females, respectively. All the above measured and observed parameters did not show statistical significance ($p \geq 0.05$).

2.5 Discussion

The cribriform plate is a structure located in the middle of the anterior cranial fossa., which is essential in olfaction (Gomez and Pickup, 2023). This study sought to understand anatomical variations of the cribriform plate and its relationship to related structures in the KZN population. The study aimed to provide valuable insights that could enhance surgical outcomes, patient safety and potentially reduce the incidence of complications associated with cribriform plate injuries.

2.5.1 Morphology of the cribriform plate in relations to sex

The cribriform plate morphology for this current study revealed no significant difference between the males and females in terms of cribriform plate types, suggesting a balanced distribution. Numerous anatomical variations, such as thickness and porosity, asymmetry, olfactory fossa depth, deviation, or curvature, can be found in the cribriform plate (ADMIŞ, 2024). The Kawahara method, which builds on the Keros classification by highlighting both the depth and the symmetry, was employed in this investigation (Keros, 1962, Kawahara *et al.,* 1968).

Type I: 25.5%, Type II: 25.5%, Type III: 16.4%, Type IV: 21.8%, and Type V: 10.9% was the total for cribriform plate types for both males and females. Several studies have also demonstrated that populations can differ greatly in the cribriform plate morphology, for example, research on the ethmoidal roof in Asian population found that Keros Type II (moderate depth) was the most common in various groups, with population related variations highlighted (Abdullah *et al.,* 2019, Zahedi *et al.,* 2023). Keros Type II was the most prevalent type in our data, which is consistent with the widely observed fact that moderate depths are the most common (Floreani *et al.*, 2006) (Figure 15). The data of this current study showed 73.33% of symmetry in males with either Type I, II or III on both sides and 26.67% was asymmetrical. In females, 72% was symmetrical with Type I or Type II on both sides and 28% was asymmetrical. The total percentage of deeper cribriform plates in the South African population, which are Types IV and V, is approximately 32.7%. This suggests that a significant proportion of patients may be at risk of iatrogenic damage and could point to geographical or demographic differences (Runciman *et al.,* 2000).

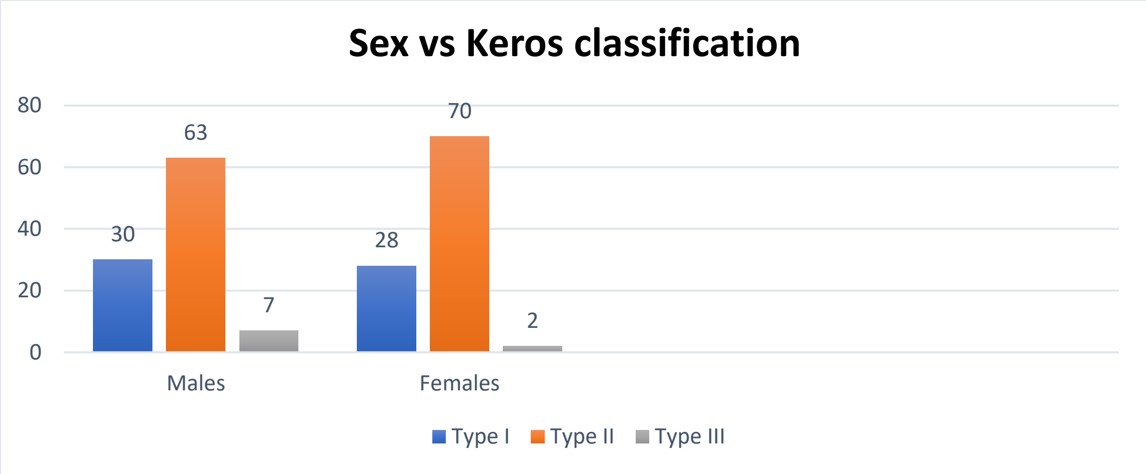

Figure 15: Overall graph illustrating percentages of Keros classification in males and females.

2.5.2 Morphometry of the cribriform plate in relations to sex and laterality

Although there was no statistical significance in the morphometry of the males and females in our data, this observation aligns with a previous study that documented larger parameters in males compared to females (Abdelghani *et al.,* 2024). The justification for this may be attributed to the deeper olfactory fossae, resulting in higher cribriform plates in males as revealed by a previous study by (Keros, 1962). According to a report by Shama and Montaser (2015), females are more likely to have Keros Type I, which is shallower, but males are more likely to have Keros Type II or III, which correspond to deeper fossae but is not comparable with the current study as males had a most Keros classification Type I than females on both sides. There is not much literature on other cribriform plate's parameters, but this study observed the width of males on the right and left side to be 4.78±1.30 mm and 4.33 mm (median), on the right and left side of females was 4.19±1.05mm and 4.18±0.97 mm (Table 7). These results suggest that males have a slightly larger width compared to females which is accordance with a study by Gunbey *et al.* (2018) who observed the width to be 3.51±0.84 mm on males and 3.32±0.89 mm.

Males typically have larger and deeper cribriform plates due to their greater craniofacial characteristics, which increases the depth of the olfactory fossa and the accompanying surgical risks in males, according to a study by (Adeel *et al.,* 2013). The findings of this study reveal that depth of males on the left side was 5.15±1.65 mm which was higher than females which was 4.94±1.40 mm (Table 7). These results may be reflecting a population specific characteristic. Additionally, there is also no statistically significant difference between the left and right sides in our data (p-values ≥ 0.05). This implies that there is no clear dominance of one side over the other in the morphometry and morphology of the cribriform plate in the South African population. Although the cribriform plate morphology is normally/commonly symmetrical, Erdem *et al.* (2004) discovered that there can be slight asymmetry between the right and left sides, especially in the depth parameter. A study carried out in

American population on the right side identified a mean length of 21.15 ±0.59 mm and mean width of 4.57 ±0.22 mm and on the left side observed a mean length of 21.41 ±0.60 mm and mean parameters except for the width on the right side in males which was 4.78±1.30 mm (Coelho *et al.,* 2018). The absence of lateral variation in this study is however consistent with the findings of other investigations, such as (Salroo *et al.,* 2016, Sasmal *et al.,* 2022), where the little asymmetry that was found was not statistically significant. Although asymmetries are occasionally reported in other research, most studies, including this one, indicate no significant asymmetry in the cribriform plate between the right and left sides (Erdem *et al.,* 2004).

Table 7: Sexual dimorphism association of the cribriform plate in both sides

Study by	Sex	Length (mm)		Width (mm)		Depth (mm)		Country
		R. side	L. side	R. side	L. side	R. side	L. side	
(Jacob and Kaul, 2014)	-	21.3 (±3.4)	20.9 (±3.6)	-	-	-	-	India
(Coelho *et al.*, 2018)	-	21.15 (±0.59)	21.41 (±0.60)	4.57 (±0.22)	4.49 (±0.21)	-	-	USA
(Jabaz and Abedtwfeq, 2022)	Male	-	-	-	-	4.8±1.678	4.69±1.54	Iraq
	Female	-	-	-	-	4.88±1.50	4.44±1.5	
(Papadopoulos -Manolarakis *et al.*, 2022)	-	22.29 (±2.16)	22.10 (±2.44)	-	-	-	-	Greece
Current study	**Males**	**20.3±3.78**	**20.1±4.34**	**4.78±1.30**	**4.33***	**4.72±1.44**	**5.15±1.65**	**South Africa**
	Females	**20.6±3.73**	**20.0±3.84**	**4.19±1.05**	**4.18±0.97**	**4.70***	**4.94±1.40**	

(* - is the median (Q1-Q3) as there was uneven distribution of data.)

2.5.3 Associated structures to the cribriform plate

The position of the crista galli varies, therefore, understanding its anatomic variances can sometimes change the way that clinical and surgical decisions are made (Hajiioannou *et al.,* 2010). Embryologically, crista galli is formed during the mesethmoidal cartilage, which is derived from the pre-sphenoidal cartilage, along with the central structures of the anterior skull base and the perpendicular plate of ethmoid bone (Scott, 1953, Hajiioannou *et al.,* 2010). In an effort to try and find any relationship between the cribriform plate and the crista galli, this study on KZN (South Africa) population discovered that the most prevalent type of the crista galli in both sexes is the teardrop followed by the tubular and ossified type, respectively which is in agreement with a study that was carried out in the Anatolian population that also observed 52.2% of teardrop type, 28.5% of tubular type, and 19.3% of ossified type in the crista galli of both males and females combined (Golpinar *et al.,* 2022). The morphology of the crista galli can also impact olfactory function. A teardrop-shaped crista galli may correlate with variations in the olfactory bulb's position and size, potentially affecting the olfactory nerve's integrity. This could lead to variations in the sense of smell among individuals, with implications for diagnosing and treating conditions related to olfactory dysfunction (Keşkek and Aytuğar, 2021). Understanding these variations can help clinicians better assess and manage patients with anosmia or hyposmia (Hernandez *et al.,* 2023).

In the current study the location of the AEA on the right side combined was 29.1% within the skull base and 70.9% were below skull base and the location on the left side combined was 23.6% of AEAs within the skull base and 76.4% were below it (Table 8). This distribution confirms earlier research that indicates a comparable predominance of the AEA situated below the base of the skull. This variation is significant because endoscopic sinus surgery and other surgical procedures put AEAs situated below the base of the skull at greater risk, and these findings support the fact that AEA positioning below the skull base is a common variation (Abdullah *et al.,* 2019, Szczepanek *et al.,* 2024). A meta-analysis found that 43.1% of patients have the AEA below, whereas 56.9% of cases have it inside or at the level of the skull base (Szczepanek *et al.,* 2024). The findings of this study appear to reveal a little higher prevalence of this anatomical variation than the meta-analysis average, with roughly 70–76% of AEAs positioned below the skull base (Szczepanek *et al.,* 2024).

Several studies have investigated the asymmetry of the olfactory fossa with regards to its importance in endoscopic sinus surgeries and skull base surgeries using Keros classification, which categorizes the depth of the olfactory fossa (Keros, 1962, Skorek *et al.,* 2017, Karatay and Avcı, 2021). Studies carried out by (Naidu *et al.,* 2022, Sağlam *et al.,* 2024) discovered Keros Type II to be most prevalent in their studies. The current study observed Keros Type II as the most common in both male and females, which contradicts the reports of a study by (Elwany *et al.,* 2010) who observed Type I as the most common in females.

Table 8: The frequency of AEA location to the skull on both sides

Study by	Sex	AEA location	Laterality n (%)		Country	Methodology
			R. side	L. side		
(Yang *et al.,* 2009)	-	Below	5 (16.7)		China	Cadaveric skulls
		Within	25 (83.3)			
(Jabaz and Abedtwfeq, 2022)	-	Below	77 (40.7)	79 (41.8)	Iraq	CT scans
		Within	112 (59.3)	110 (58.2)		
Current study	**Males**	**Below**	**19 (63.33)**	**22 (73.33)**	**South Africa**	**CT scans**
		Within	**11 (36.67)**	**8 (26.67)**		
	Females	**Below**	**20 (80)**	**20 (80)**		
		Within	**5 (20)**	**5 (20)**		

2.5.4 Sexual dimorphism in different KZN population groups

There are noticeable differences between Black and White South Africans when it comes to sexual dimorphism in the KZN population. These results demonstrate variations in the length, width, depth, and shape of the cribriform plate between groups and between sexes. The differences in the cribriform plate's length between Black and White South African males may have significant implications as the variation may necessitate tailored surgical approaches based on the patient's population group. Surgeons must be aware of these anatomical differences to minimize the risk of complications such as CSF leaks or damage to the olfactory bulbs during procedures involving the nasal cavity or anterior skull base (Coelho *et al.,* 2018). Similar trends can be seen in these female dimensions, with Black South African females having a longer right side than White females. Simultaneously, differences were seen in the cribriform plates' width and depth, where White South African females on both sides typically have greater means than Black South African females, whereas a study conducted in Turkish population males had larger width and depth compared to females (Gunbey *et al.,* 2018).

Comparatively, research on craniometry in other populations reveals both similarities and variations. For example, the patterns of sexual dimorphism observed in White South Africans are similar to those observed in Asian populations, where males have typically larger cribriform plate dimensions (Katwal *et al.,* 2023). Differences in craniofacial characteristics have also been found in studies conducted populations across in Africa (Steyn and İşcan, 1998, Franklin *et al.,* 2006), these differences are consistent with different genetic and environmental factors that influence sexual dimorphism (Cenac, 2024). These differences highlight the need for specialized methods for population-specific features and are crucial in domains such as forensic anthropology for precise ancestry and sex determination (Krüger *et al.,* 2015).

The findings of this study suggests that distinct variations emphasize the significance of taking regional and ethnic characteristics into account when assessing cranial morphology, even though some sexual dimorphic traits in the KZN population are consistent with larger African and worldwide trends.

2.6 Conclusion

While there were no statistical significances in the cribriform plates morphology and morphometry based on sex or lateral symmetry in this study, the small noticeable differences in our findings on the anatomical features may increase the risk of iatrogenic injury, particularly in endoscopic surgeries. This study emphasizes the need for careful preoperative assessment, particularly in populations with a high prevalence of complex cribriform plate types.

2.7 Limitations

This study had limitations in the sample size.

2.8 References

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BRIDGING TEXT

FROM CHAPTER TWO TO THREE

In the above chapter 2 (manuscript 1), an analysis of the cribriform plate on Computerised Tomography (CT) scans to determine sexual dimorphism of South African population was executed. Morphology was analysed via shape, dimensions (length, width and depth) were measured and the crista galli, anterior ethmoidal artery were also analysed as associated structures of the cribriform plate bilaterally between males and females and compared to previous studies globally to emphasize variations between populations.

The next chapter (chapter 3) is an attempt to enlarge on literature of the cribriform plate on dried skulls/bones as most literature in on CT scans. Since the cribriform plate is the roof of the ethmoid bone and is in-between delicate structures of the anterior cranial fossa, it is important for surgeons to be knowledgeable about the variations of that specific population to minimize iatrogenic injuries during frontal functional endoscopic sinus surgery as previous studies reported that there are slight variations between populations (Adeel *et al.,* 2013, Shama and Montaser, 2015). This study investigated its anatomical variations in terms of morphometry, morphology and the structures related to it.

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CHAPTER THREE:

MANUSCRIPT TWO

Sexual Dimorphism, Morphology, and Morphometry of the Cribriform Plate in Skulls from KwaZulu-Natal Populations: Osteological Assessment

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3.1 Abstract

Introduction: The cribriform plate is a delicate landmark of the ethmoid bone between the brain and nasal cavity, which houses the olfactory bulb and serves as a channel for olfactory nerves. Existing literature primarily focuses on general anatomical descriptions without addressing population-specific variations and their impact on surgical outcomes and olfactory function. This study aimed to investigate sexual dimorphism, morphology, and morphometry of the cribriform plate on bone samples of selected KwaZulu-Natal (KZN) populations.

Materials and methods: This study investigated fifty-eight (58) dried skulls bilaterally. Morphological, morphometric, and related structures were accessed to determine the sexual dimorphism of the South African population who are 10 years and above.

Result: Cribriform plate Type IV was the most prevalent shape in males, while Types I and IV were the most common in females. On the right and left sides of both sexes, the length, width and depth parameters were slightly higher in males except for the width on the left side, which was higher in females. The number of olfactory foramina were higher in females. The crista galli's ossified shape (41.9%) and teardrop shape (51.9%) were the most common types in males and females, respectively. Keros classification Type II was the most determined type on both sides of the olfactory fossa in both sexes. Width on the left side of Black (5.18±1.51 mm) and White (3.93±1.18 mm) South African males was the only parameter that was statistically significant, $p = 0.019$.

Conclusion: This study suggests a sex and population-specific medical assessments of cribriform plate and associated structures due to the noticeable variations in cribriform plate which may impact the olfactory functions and surgical outcomes.

Keywords: Cribriform Plate, Human Skulls, Morphology, Morphometry, Sexual dimorphism

3.2 Introduction

Sexual dimorphism is the term used to describe differences in size, morphology, or other phenotypic characteristics between male and female members of the same species (Mori *et al.,* 2022). Although sexual dimorphism in humans is typically less pronounced than in other species, it can be observed in numerous skeletal components. This is frequently the result of endocrinological influences, which have different effects on male and female bone growth and development (Lassek and Gaulin, 2022, Mori *et al.,* 2022). This effect therefore creates a variation in sex during bone growth and development. Several bones and associated structures which includes pelvis, sternum, radius, ulna, skull, clinoid process, foramina, Sella turcica and cribriform plates have been revealed to be sexually dimorphic (Hlatshwayo *et al.,* 2024).

The cribriform plate, a vital part of the human ethmoid bone, is an interesting structure to explore because of its capability to show dimorphic qualities (Bird *et al.*, 2014). The cribriform plate is a fragile, perforated structure that forms the roof of the nasal cavity and serves as a conduit for the olfactory nerves, which transmit sensory information from the olfactory receptors to the olfactory bulb in the brain (Dorland, 1925, Drake *et al.*, 2009, Yu and Wang, 2019). More understanding on the morphological and morphometric variations of the cribriform plate among males and females can add value to forensic anthropology where the exact distinguishing of sex from skeletal remains is essential. Additionally, anatomical variation of the cranial base is essential for the improvement of precise prosthetic devices for reconstructive medical procedures and possible differences in the olfactory region for surgical procedures such as endoscopic sinus surgery (Romualdo Rueff-Barroso *et al.*, 2021, Nusse, 2022).

Therefore, an analysis into the cribriform plate's sexual dimorphism may display patterns of clinical significance in fields like neurosurgery, otolaryngology, anthropology, and forensics (Naikanur *et al.,* 2022). Furthermore, such findings could play a part in helping to understand sex-specific prevalence or show specific illnesses and conditions involving the olfactory system and associated neurological pathways (Rai *et al.,* 2018).

The predicted findings of this study are expected to add to the current information on sexual dimorphism in human skeletal morphology, with particular focus on the cribriform plate. These predicted results might explain factors like hormones, genetics and environmental conditions that contribute to the noticed dimorphic qualities (Martínez Abadías, 2007, Coelho *et al.*, 2018). However, while existing studies have explored sexual dimorphism in human skeletal morphology, there remains a significant gap in the literature specifically addressing the cribriform plate. Most research has focused on broader skeletal features without investigating the subtle variations of the cribriform plate across different populations groups. Additionally, while factors such as hormones, genetics, and environmental conditions have been suggested to influence dimorphic qualities, there is limited empirical evidence directly linking these factors to the morphological and morphometric characteristics of the cribriform plate (Kühnel and Reichert, 2015). Furthermore, the existing literature often lacks a comprehensive analysis of the right and left side variations of the cribriform plate within specific populations, such as those in KZN. With the increase of injuries relating to the cribriform plate such as fractures, encephalocele/meningocele and infections, this study intends to conduct a comprehensive investigation of the sexual dimorphism observed in the morphology, morphometry, and related structures of the cribriform plate on the right and left sides of different population groups of the KZN.

3.3 Methodology

3.3.1 Materials and methods

Fifty-eight (58) dried skulls (31 males and 27 females) of the cribriform plate were obtained from the University of KwaZulu Nal and Durban University of Technology. The skulls were assessed from the superior view. The dimensions were measured using the digital vinier calliper and depth gauge. Reliability was ensured by consistently measuring thrice.

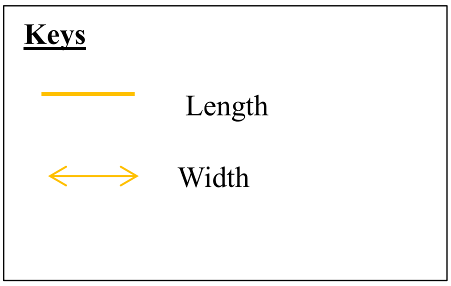
3.3.2 Parameters

3.3.2.1 Morphological parameters

In this study the method of Kawahara of classifying the cribriform plate into five different shapes was employed (Type I**:** Lines start in the middle and spread outwards towards the back. Type II: Lines are mostly straight and head towards a specific area called the planum sphenoidale. Type III: Lines are almost parallel and very close to each other. Type IV: Both sides have average points that attach in the middle. Type V: Lines form a diamond/rhombus shape, with the middle being the widest part and the front and back being the narrowest) (Kawahara *et al.,* 1968) (Figure 18). The Keros type and classification was employed to observe and record variation of the depth/ olfactory fossa of the cribriform plate viz, Type I, Type II, Type III (Keros, 1962) (Table 9). The fact that the Kawahara method is the standard and reliable method from which all other methods originate serves as the basis for this approach.

3.3.2.2 Morphometric parameters

The measurements were taken as below all units were in millimetres. The cribriform plate length, on both the left and the right side was measured from the most anterior to the most posterior point on each side. The cribriform plate width was measured between lateral lamella of the cribriform plate and medial border of crista galli on the left and the right side. Cribriform plate depth was measured from the floor olfactory fossa to the highest point of the olfactory fossa using depth gauge and digital vernier calliper.



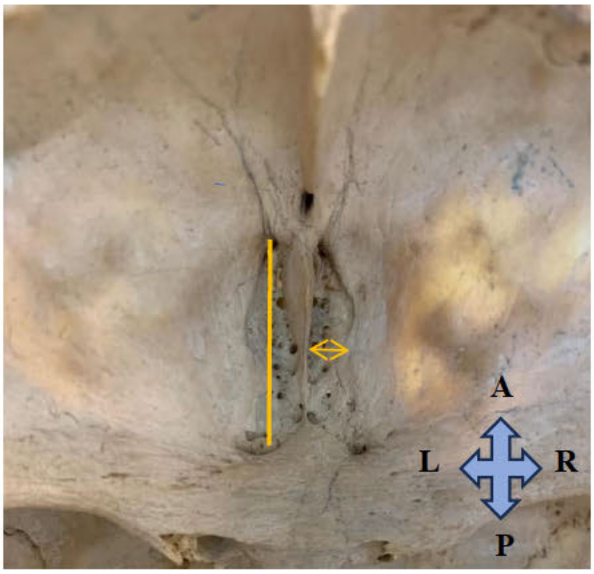


Figure 16: Image in axial view showing measurements of the length and width of the cribriform plate.

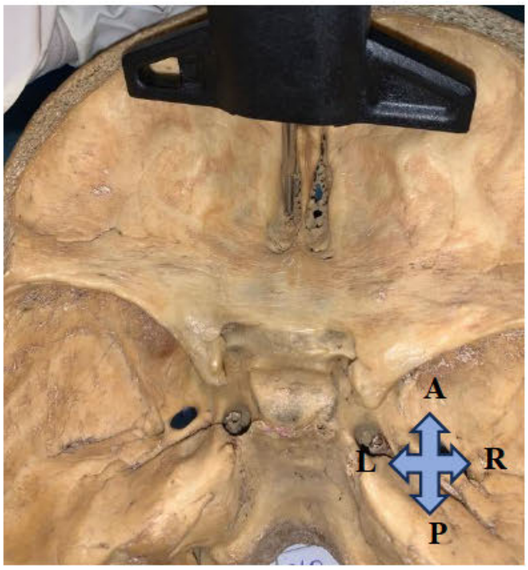


Figure 17: Image in axial view showing measurements of left and right depths of the cribriform plate.

3.3.3 Associated structures to the cribriform plate

By measuring the length, width, and height of the crista galli to determine its type and shape, the morphology of the crista galli was examined to determine how it affects the cribriform plate. The nasal cavity's symmetry and asymmetry were also observed to see how it affected the cribriform plate's morphology and morphometry. Keros classification, which describes the relative position of the ethmoidal roof to the cribriform plate

3.3.4 Ethical and gatekeeper Approval

The Biomedical Research Ethics Committee (BREC) reference number: BREC/00005687/2023 and the National Health Research Database (NHRD) granted this study ethical approval. In this study, confidentiality and anonymity were always upheld. The collected data was only used for research purposes. The patients' names were not recorded.

3.3.5 Inclusion criteria

Dried skulls of subjects above 10 years that are not eroded on and around the cribriform plate region.

3.3.6 Exclusion criteria

Dried skulls that have deformities on the cribriform plate.

3.3.7 Statistical analysis

R Core Team, 2020, version 3.6.3 was used to conduct a statistical analysis of the results. Calculations were made for the mean, standard deviation, maximum, and minimum measurements. On both sides between males and females, averages were calculated. To see if there were any significant differences in laterality measurements between individual specimens, t-tests of one sample were applied. The statistical significance value was taken as $p < 0.05$.

3.4 Results

3.4.1 Morphology of the cribriform plate in relations to sex

Type IV was the most prevalent shape in males with 35.5%. Type V was the least with 9.7%. Type I was observed in 25.8% subjects whilst type II and III were observed in 12.9% and 16.1%, respectively. In females, both Type I and IV were detected on 22.2% subjects and Types II, III, and V were observed in 18.5% subjects each (Figure 18).

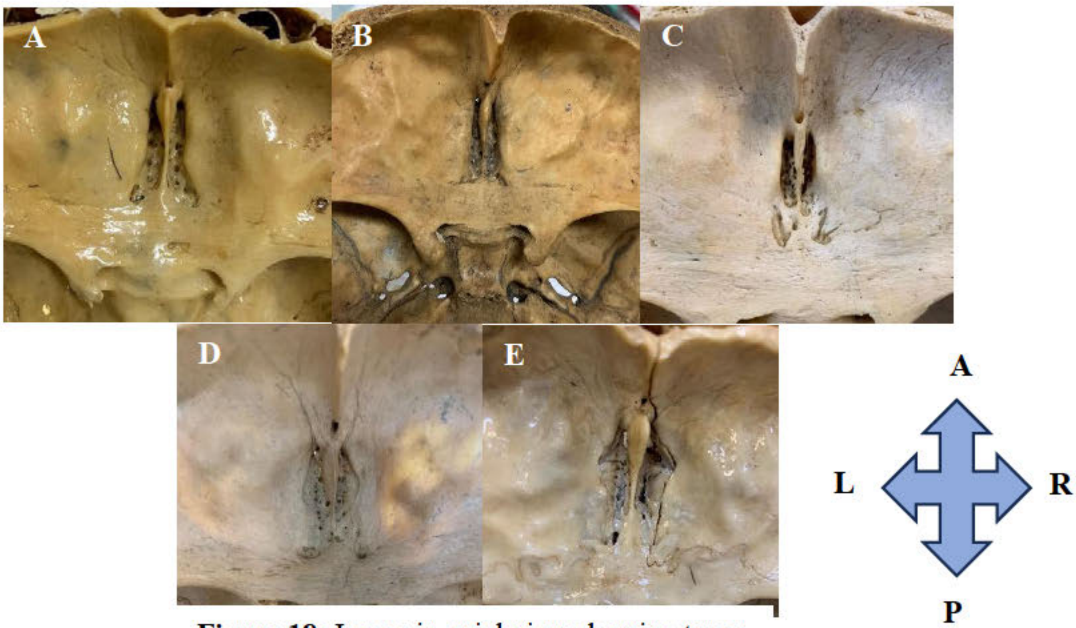


Figure 18: Image in axial view showing types of the cribriform plate. A – Type I, B – Type II, C – Type III, D – Type IV and E – Type V.

3.4.2 Morphometry of the cribriform plate in relations to sex and laterality

In males most parameters were slightly bigger than in females, although none was statistically significance. On the right side the mean length was 22.6±2.83 mm for males and 22.4±2.51 mm for females, whereas, on the left side the mean length for males was 22.7±2.64 mm and 22.1±2.40 mm on females. The width on the right side, of males was 4.98±1.30 mm and of females was 4.60 mm (median). On the left side the width was the only less parameter of males with 4.66±1.49 mm than that of females which was 4.70±1.23 mm. Depth on the right in males was 5.10±1.33 mm and in females was 4.66±1.6 mm, on the left side in males was 5.12±1.21 mm and was 4.59±1.42 mm on females. The number of foramina on the cribriform plate was determined to be higher in females than in males, the values in females was 50.3±15.60 mm and in males was 47.9±13.10 mm.

3.4.3 Associated structures to the cribriform plate

The anterior ethmoidal artery location could not be identified in dried skulls. The morphology of the crista galli was classified into three types viz, teardrop, tubular and ossified types. The tubular type was the least common in both males and females with 25.8% in males and 29.6% in females (Figure 19). The most common type in males was the ossified shape with 41.9% whereas in females, it was teardrop shape with 51.9%. The teardrop shape was 32.3% in males and the tubular shape was 29.6% in females (Figure 19). All the shapes were not statistically significant. The teardrop type of the crista galli was detected mostly in Type IV of the cribriform plate. The tubular type was less identified in Type III of the crista galli. Again, in Type IV of the cribriform plate, the ossified shape was mostly determined.

Keros classification Type II was the most determined type on both sides of the olfactory fossa, on the right side, males had 80.65% and females had 59.26%. On the left side, males had 80.65% and females had 70.37% (Table 9). On both the right and left side males were discovered to have 3.23% of Keros Type III. Keros Type III in females was only found on the right side to be 3.70%, none was discovered on the left side (Table 9). Keros Type I on the right side in males was 16.13% and on females it was 37.04% whereas, on the left side in males it was again 16.13% and 29.63% in females.

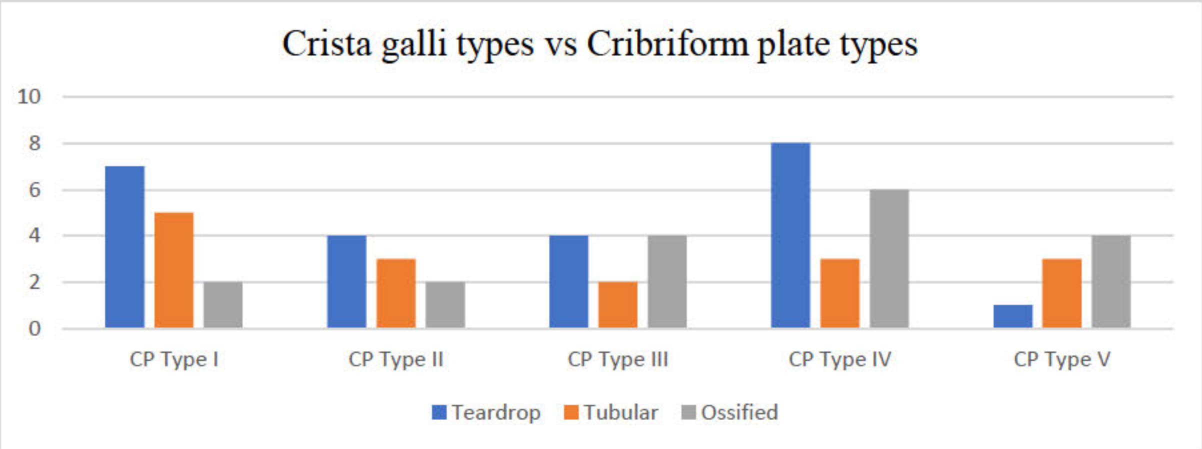


Figure 19: Illustration showing distribution of the types of crista galli on different types of the cribriform plate.

Table 9: Distribution of olfactory fossa based on Keros classification according to their sides and sex on skulls

Keros Type	**Right, n (%)**		**Left, n (%)**	
	Male	Female	Male	Female
I	5 (16.13)	10 (37.04)	5 (16.13)	8 (29.63)
II	25 (80.65)	16 (59.26)	25 (80.65)	19 (70.37)
III	1 (3.23)	1 (3.70)	1 (3.23)	0 (0)

3.4.4 Sexual dimorphism on different KZN population groups.

The length parameter in males was observed to be greater in Black South Africans on both sides (23.4±3.16 mm on the right and 23.4±2.88 mm on the left) compared to White South African males (21.5±1.84 mm on the right and 21.7±1.97 mm on the left). The length did not have a statistical significance in males, on the right-side p = 0.054 and p = 0.077 on the left side. The Black South African females also had longer length on the right (23.1±2.62 mm) and left side (22.8±2.64 mm) compared to the right (21.6±2.16 mm) and left side (21.2±1.79 mm) of White South African (Table 10).

The width in Black South African males on the right side was observed to be 5.28±1.44 mm and on the left side to be 5.18±1.51 mm. White South African males had a mean width of 4.56±0.98 mm on the right and 3.93±1.18 mm on the left side. The width on the left side between Black and White South Africans was statistically significant, $p \leq 0.019$. The widths median on the right side of females was 4.60 mm for Black South Africans and on the left side the mean average was 4.76±1.30 mm. Whereas White South African females had a mean width of 4.71±0.73 mm on the right and a median of 4.22 mm on the left (Table 10).

Depth in males of Black South Africans was 5.00±1.55 mm on the right and 5.00±1.22 mm on the left side. White South African males had a mean depth of 5.24±0.996 mm on the right and 5.29±1.24 mm on the left side. The depth for Black South African females was 4.58±1.20 mm on the left and 4.75±1.07 mm on the right side. White South African females had a depth of 4.76±2.08 mm on the right and 4.39±1.80 mm on the left side (Table 10).

The most prevalent cribriform plate type in Black South African males was Type IV which was 33.3%, followed by Type III which was 22.2%, followed by Type I and Type II which were 16.7% and lastly Type V which was 11.1%. In White South African males, the most dominant types were Type I and Type IV which were 38.5% and the least common types were Type II, Type III and Type V which all were 7.7%. In Black South African females, the cribriform plate Type I was the most prevalent type with 26.7%, second followed by Type II, Type IV and Type V which all were 20.0% and lastly Type III which was 13.3%. White South African females least cribriform plate type observed was Type I, Type II and Type IV which all were 16.7% and the most common types were Type III and Type IV which were 25.0%.

3.5 Discussion

The cribriform plate is a vital structure that plays an important role in olfaction and cranial anatomy. This study should provide valuable data on the anatomical variations the cribriform plate in the KZN population, particularly in sexual dimorphism and morphometric characteristics as there is paucity of literature, especially in Africa. These findings can inform surgical outcomes by providing insights into the anatomical diversity present within this specific population (KwaZulu Natal, South Africa).

3.5.1 Morphometry of the cribriform plate in relations to sex and laterality

In this study, the distribution of the cribriform plate types between sexes showed no statistically significant difference ($p = 0 .727$). Type IV was the most prevalent shape observed (35.5% in males and 22.2% in females). These findings contribute to the body of literature on population-specific anatomical variations, emphasizing the importance of considering population differences in craniofacial anatomy especially for medical evaluation and surgical planning (Bhaskar *et al.,* 2013) . Type V, representing a smaller proportion, was slightly more frequent in females (18.5%) than males (9.7%). Type IV was found to be more common in this population in both males and females, suggesting average fixated points in the middle of the cribriform plate in both males and females. This current study contrasts with the study by Vasvári et al. (2005b) who observed Type I to be more prevalent, however their study had no distribution of males and females. Diverse populations' studies on the cribriform plate showed various morphological variations of the cribriform plate such as asymmetry of the olfactory fossa (Abdullah *et al.,* 2019, Romualdo Rueff-Barroso *et al.,* 2021). This study determined 93.33% of symmetrical olfactory fossa in males and 6.67% of asymmetry, whilst, in females we observed 74.07% of symmetrical olfactory fossa and 25.93% of asymmetry, which could be due to anatomical variations unique to the South African cohort that are related to geography or population group (Alraddadi, 2021).

The number of foramina in the cribriform plate provides important information regarding olfactory nerve distribution (López-Elizalde *et al.,* 2018). Males in this study had a mean number of foramina that was slightly smaller (47.9 ± 13.1 mm) than females (50.3 ± 15.6 mm), but the difference was not statistically significant ($p=0.534$). The coefficient of variation (CV%) was 27.3% for males and 31.1% for females, indicating a somewhat wider range in these population-specific females. While the difference in the number of foramina between males and females in this study was not statistically significant, the trend suggests that females may have a greater distribution of olfactory nerves, potentially contributing to enhanced olfactory perception (Doty and Cameron, 2009). This finding underscores the importance of considering anatomical variations in clinical practice and encourages further investigation into the relationship between cribriform plate morphology and olfactory function (Smith, 2021).

The results of this study, which are consistent with a study by Romualdo Rueff-Barroso *et al.* (2021)that highlight the variety in cribriform plate morphology without notable sex-based differences, indicate no significant sexual dimorphism in the number of foramina or cribriform plate morphology. However, the higher prevalence of Type IV cribriform plate in this study suggests a regional or population anatomical variation that could have implications for surgical planning and risk assessment, especially in relation to the number of foramina, as seen in studies by (Escalard *et al.,* 2019, Boulton *et al.,* 2023). In surgical operations involving the anterior skull base, the number of foramina is still a crucial aspect to consider because an increased number may increase the risk of damage to the olfactory nerves (Plou *et al.,* 2023).

3.5.2 Morphometry of the cribriform plate in relations to sex and laterality

In the South African population, the mean length of the cribriform plate on both sides does not show significant differences between males and females on both sides. The observed longer/higher length of the cribriform plate on the right side in females suggests potential anatomical adaptations that may influence olfactory function. This finding could indicate that females may possess unique olfactory characteristics or sensitivities, warranting further investigation into the implications of cribriform plate morphology on sensory perception and clinical outcomes in KZN. These findings are in alignment with a previous study by Abdelghani *et al.* (2024), which revealed slight variability among populations but no significant variation the in cribriform plate length based on sex. For instance, a study conducted in the American population by Coelho *et al.* (2018) revealed somewhat greater mean lengths on both sides, with the right and left sides measuring 21.15 mm and 21.41 mm, respectively (Table 10).

There are no noticeable variations in the cribriform plate's mean width between males and females. Males' median width on the right side is 4.94 mm (Table 10), while females' median width is 4.60 mm there is no statistical significance (p-value = 0.691). Likewise, the mean width on the left side is 4.70 mm for females and 4.66 mm for males (p-value = 0.910). These results support those of Gunbey *et al.* (2018), who observed that, although the difference is usually statistically small, males often had somewhat greater cribriform plate widths than females. As Saylisoy *et al.* (2014) pointed out, the variation in width between populations on the left and right sides emphasizes the significance of region-specific anatomical investigations, they discovered a slightly smaller mean width on the left side of Turkish population.

There is a small increase in variability in the cribriform plate depth between the sexes, but there was no statistically significant difference, with a p-value of 0.263, the mean depth on the right side is 5.10 mm for males and 4.66mm for females. The mean depth on the left side, with a p-value of 0.127, is 5.12 mm for males and 4.59 mm for females (Table 10). These results are in in accordance with previous studies, which showed that males typically had somewhat deeper olfactory fossae (Shama and Montaser, 2015). According to Adeel *et al.* (2013) and Madani *et al.* (2020) males often have deeper cribriform plates on the left and right sides although these findings were not statistical significance. This was also the case with the current study. Similar results have been observed by other research involving a variety of populations, including American, Asian, and Middle Eastern groups. In a study carried out by Erdem *et al.* (2004), they did not find any significant changes in cribriform plate morphometry related to sex. Rather than being solely related to sex, slight variations in size are frequently linked to craniofacial traits unique to a community (Arnold, 2017).

The cribriform plate morphometry of the South African population does not exhibit any noticeable sexual dimorphism (Table 10), which is consistent with findings from previous research (Saylisoy *et al.,* 2014, Gunbey *et al.,* 2018). The small variances that have been noticed might reflect larger anatomical and demographic changes, which would support the requirement for population-specific data in clinical practice.

One of the notable strengths of this study is the comprehensive investigation of the number of olfactory foramina associated with the cribriform plate, a parameter that has not been extensively explored in previous research (Table 10). By systematically documenting the number of foramina, this study provides valuable insights into the anatomical variations that may influence olfactory nerve pathways and, consequently, olfactory function. This focus on foramina not only enhances our understanding of the cribriform plate's morphology but also underscores the potential implications for surgical interventions involving the nasal cavity and anterior skull base. Overall, the investigation of olfactory foramina represents a significant advancement in the literature, providing a foundation for future research and clinical applications related to the cribriform plate and its associated structures.

Table 10: Showing sexual dimorphism association of the cribriform plate in both sides

Study by	Sex	Length (mm)		Width (mm)		Depth (mm)		No. of foramina	Country
		R. side	L. side	R. side	L. side	R. side	L. side		
(Jacob and Kaul, 2014)	-	21.3 (±3.4)	20.9 (±3.6)	-	-	-	-	-	India
(Coelho *et al.,* 2018)	-	21.15 (±0.59)	21.41 (±0.60)	4.57 (±0.22)	4.49 (±0.21)	-	-	-	USA
(Jabaz and Abedtwfeq, 2022)	Male	-	-	-	-	4.8±1.678	4.69±1.54	-	Iraq
	Female	-	-	-	-	4.88±1.50	4.44±1.5		
(Papadopoulos -Manolarakis *et al.,* 2022)	-	22.29 (±2.16)	22.10 (±2.44)	-	-	-	-	-	Greece
Current study	**Males**	**22.6±2.83**	**22.7±2.64**	**4.98±1.30**	**4.66±1.49**	**5.10±1.33**	**5.12±1.21**	**47.9±13.1**	**South Africa**
	Females	**22.4±2.51**	**22.1±2.40**	**4.60***	**4.70±1.23**	**4.66±1.61**	**4.59±1.42**	**50.3±15.6**	

(* - is the median (Q1-Q3) as there was uneven distribution of data)

3.5.3 Associated structures to the cribriform plate

The anatomy of associated structures, such as the crista galli and the asymmetry of the olfactory fossa, plays a crucial role in shaping the morphometry and functionality of the cribriform plate (Snell, 2010). These structures can impact surgical risks, olfactory function, and anatomical and developmental variations observed in different populations (Şahan *et al.,* 2019, Schäfer *et al.,* 2021). The cribriform plate is closely related to several crucial structures within the anterior cranial fossa, including the ethmoid bone, frontal bone, sphenoid bone, and the nasal cavity (Chong, 2017).

The crista galli was divided into three categories in the current study: ossified (31.0%), teardrop (41.4%), and tubular (27.6%). A study reported that a larger (teardrop-shaped) crista galli may cause the cribriform plate to experience more mechanical stress, which may then result in structural variations like thinning or changes in cribriform plate porosity (Uçar *et al.*, 2021). These variations could increase the possibility of cerebrospinal fluid leakage during surgical procedures (Prosser *et al.*, 2011).

This study highlighted the difference in crista galli types between sexes, with a higher prevalence of the teardrop type in females (51.9%), which is similar to a study by Komut and Golpinar (2021) study, who also observed the teardrop type which affected 82.9% of females as the most prevalent type. Also, in this current study the most common identified type in males was the ossified type which is in agreement with a study by Golpinar *et al.* (2022). This suggests that females may have a slightly more complex crista galli structure, which could have an impact on surgical planning, although in a study on the Turkish population, they observed the tubular type as the most prevalent on both males and females (Vuralli et al., 2023).

The olfactory fossa which houses the olfactory bulb is a depression in the ethmoid bone. Its symmetry and depth are essential for understanding how the cribriform plate is structured (Romualdo Rueff-Barroso *et al.,* 2021). Uneven cribriform plate dimensions might result from the olfactory fossa's asymmetry, while the right and left sides of the olfactory fossa usually exhibit symmetry, a number of studies, including this one, have noted that there can occasionally be mild asymmetries, particularly in the depth parameter which is associated with Keros classification (Lebowitz *et al.,* 2001, Adeel *et al.,* 2013). This study observed Keros Type I as most common in females (37.04%) than males (16.13%) on the right side and on the left side to be more frequent in females (29.63%) compared to males (16.13%). The above results are consistence with a study by Athamneh *et al.* (2015) who also observed Keros Type I as the most prevalent in females. Even though males were dominant both on the right and left side, Keros Type II was the most dominant type in South African population on both males and females [right side, males (80.65%) and females (59.26%); left side, males (80.65%) and females (70.37%)], which is not in agreement with a study Paber *et al.* (2008) that was carried out in Filipino population, who observed Keros Type I as the most prevalent.

Although, the presence of asymmetry can still have an impact on surgical results and olfactory function, the current investigation did not find a significant statistical difference in cribriform plate asymmetry based on sex. Reducing the risks associated with these delicate anatomical regions and improving pre-surgical planning can be rendered by an understanding these relationships.

3.5.4 Sexual dimorphism on different KZN population groups.

Cribriform plate's morphology showed distinct differences between Black and White South African populations with respect to sexual dimorphism; these findings are significant for forensic anthropology and craniofacial research. The results demonstrate that Black South African males have larger cribriform plates' lengths than White South African males, with Black males measuring 23.4mm on both sides and White males measuring 21.5mm on the right side and 21.7 mm on the left. Likewise, compared to White South African females, Black South African females displayed greater cribriform plate lengths. The findings of this study support the reports of Coelho *et al.* (2018) who found the length value to be 21.15±0.59 mm on the right side and 21.41±0.60 mm on the left side.

Black South African males and females had higher mean values of the width parameter compared to White South Africans, however, males' width was greater compared to females on both sides which agrees with a study by Gunbey *et al.* (2018) who also observed larger width in males (3.512 mm) than females (3.319 mm). A study by Krüger *et al.* (2015) analysed sexual dimorphism on cranial morphology among modern South African, they observed that White South African males achieved higher scores when examining trait scores for sex and population. This current study also observed that the depth parameter was higher in White South African males on both sides and only on the right side in females.

Surprisingly there is paucity of literature on the shapes of the cribriform plate. This study observed cribriform plate Type IV as the most prevalent type on both Black and White South African males. Type I was the most observed type in Black South African females and Types III and IV were most common in White South African females.

3.6 Conclusion

This study concludes that males in South African population usually exhibits larger dimensions in cribriform plate morphology and morphometry, whereas females had more foramina and a higher prevalence of Keros Type I. This sexual dimorphism was minor but notable. The specific anatomy of the cribriform plate, crista galli, and olfactory fossa must be understood to minimize difficulties during endoscopic procedures such as endoscopic endonasal surgery, functional endoscopic sinus surgery, olfactory neuroblastoma surgery which is where the significance of these anatomical variations for clinical practices lies. This study therefore suggests a sex and population-specific medical assessments of cribriform plate and associated structures due to the slightly noticeable variations in cribriform plate which may impact the olfactory functions and surgical outcomes.

3.7 Limitations

This study encountered limitations in the sample size as there was shortage of other populations/ethnicities and most skulls were damaged in the cribriform plate.

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CHAPTER FOUR:

SYNTHESIS

4.1 Discussion

Cribriform plate, Types I and II in cephalometric tomography (CT) scans were both the most common types overall and the most common type in females whereas Type IV was the most prevalent in males. The location of the anterior ethmoidal artery (AEA) was predominantly below the skull base in both sexes, which is crucial for surgical considerations as AEAs below the skull base are more prone to injury during endoscopic sinus surgery. However, in males' noticeable portion was within the skull base. Teardrop type of the crista galli on CT scans was also the most common type on both sexes. Only the left length parameter was detected to be higher in females than males in CT scans. On bones, cribriform plate Type IV was the most prevalent on both males and females. The teardrop type of the crista galli was again the most common type. Females were detected to have a higher mean of olfactory fossa foramina (50.3±15.6 mm) than males (47.9±13.1 mm). The number of foramina remains an important consideration in anterior skull base surgical procedures because an increased number may increase the risk of damage to the olfactory nerve (Escalard *et al.,* 2019). Males had larger parameters except for the width on the left side which was higher in females. These variations in the dimension of the cribriform plate leads to variations associated with Keros classification and asymmetry of the olfactory fossa and that implies that a considerable number of patients may be vulnerable to iatrogenic injury, which may indicate regional or demographic differences (Runciman *et al.,* 2000). Also, the fact that there was no statistical significance difference between sexes and laterally in South African population suggests that the morphometry and morphology of the cribriform plate in the South African population do not strongly prevail one aspect over the other.

On CT scans, Black South African males had longer length on both sides. The right width of the cribriform plate in Black South African males was also higher than White South African males. Whereas White South African males had a greater depth on both sides of the cribriform plate. In the osteological sample, Black South African males had greater length and width, on both sides than White South African males and the depth parameter was higher in White South African males.

In females, on CT scans, Black South Africans had higher length on both sides compared to White South Africans and White South Africans had larger values of width and length on both sides compared to Black South Africans. In the osteological sample, females had a larger dimension (length width and depth) on most sides except for the depth on the right side which was higher in White South Africans.

Additionally, the five cribriform plate types were found on both males and females of Black and White South Africans. On the CT scans, Type V and Type III in males and females, respectively were not detected in males and females of White South Africans. Males had higher values in most parameters and similar results have been found in studies on other North American populations, where males tend to have greater cranial measurements than females, suggesting sexual dimorphism both within and between populations (Krüger *et al.,* 2015). Cranial characteristics in this study exhibit subtle sexual dimorphism, mirroring the slight trend differences observed in research on Black and White South Africans. This would suggest that genetic and environmental factors caused differences in the two groups' cranial development (Krüger *et al.,* 2015).

4.2 Conclusion

In conclusion, these results may reflect a population specific characteristic of cribriform plate. The observed minor variations may be indicative of more significant demographic and anatomical alterations, which would lend validity to the need for population-specific data in medical care to reduce injuries during endoscopic surgeries.

4.3 Recommendation

- For the future, it is recommended for research to be done on the morphology and morphometry of the cribriform plate in respect to different age groups so that studies on the types/shapes of the cribriform plate in different African populations can be warranted.

- A larger sample size of different population groups within the KZN population are recommended for future studies for better representation of the population.

4.4 References

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APPENDIX A: FULL ETHICAL APPROVAL

UNIVERSITY OF
KWAZULU-NATAL
INYUVESI
YAKWAZULU-NATALI

03 July 2024

Miss Nondumiso Ngiphiwe Hlatshwayo (219013482)
School of Laboratory Medicine & Medical Science
Westville

Dear Miss Hlatshwayo,

Protocol reference number: BREC/00005687/2023
Project title: Investigation of sexual dimorphism, morphology, and morphometry of the cribriform plate in KwaZulu-Natal populations: Osteological and radiological assessment
Degree: MMedSci

EXPEDITED APPLICATION: APPROVAL LETTER

A sub-committee of the Biomedical Research Ethics Committee has considered and noted your application.

The conditions have been met and the study is given full ethics approval and may begin as from 03 July 2024. Please ensure that any outstanding site permissions are obtained and forwarded to BREC for approval before commencing research at a site.

This approval is valid for one year from 03 July 2024. To ensure uninterrupted approval of this study beyond the approval expiry date, an application for recertification must be submitted to BREC on RIG on the appropriate BREC form 2-3 months before the expiry date.

Any amendments to this study, unless urgently required to ensure safety of participants, must be approved by BREC prior to implementation.

Your acceptance of this approval denotes your compliance with South African National Research Ethics Guidelines (2024), South African National Good Clinical Practice Guidelines (2020) (if applicable) and with UKZN BREC ethics requirements as contained in the UKZN BREC Terms of Reference and Standard Operating Procedures, all available at http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx.

BREC is registered with the South African National Health Research Ethics Council (REC-290408-009). BREC has US Office for Human Research Protections (OHRP) Federal-wide Assurance (FWA 678).

The sub-committee's decision will be noted by a full Committee at its next meeting taking place on 13 August 2024.

Yours sincerely,

[redacted]

Prof S Singh
Chair: Biomedical Research Ethics Committee

Biomedical Research Ethics Committee
Chair: Professor S Singh
UKZN Research Ethics Office Westville Campus, Govan Mbeki Building
Postal Address: Private Bag X54001, Durban 4000
Email: BREC@ukzn.ac.za
Website: http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx

Founding Campuses: Edgewood | Howard College | Medical School | Pietermaritzburg | Westville

INSPIRING GREATNESS

APPENDIX B: DoH APPROVAL

KWAZULU-NATAL PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

DIRECTORATE:

Physical Address: 330 Langalibalele Street, Pietermaritzburg
Postal Address: Private Bag X9051
Tel: 033 395 2805/ 3189/ 3123 Fax: 033 394 3782
Email:

Health Research & Knowledge Management

NHRD Ref: KZ_202309_007

Dear Ms NN Hlatshwayo
(UKZN)

Approval of research

1. The research proposal titled **'Investigation of sexual dimorphism, morphology, and morphometry of the cribriform plate in KwaZulu-Natal populations: Osteological and radiological assessment'** was reviewed by the KwaZulu-Natal Department of Health (KZN-DoH).

   The proposal is hereby **approved** for research to be undertaken at King Edward VIII Hospital.

2. You are requested to take note of the following:
   a. ***Kindly liaise with the facility manager BEFORE your research begins.*** *This is to ensure that conditions in the facility are conducive to the conduct of your research. These include, but are not limited to, an assurance that the numbers of patients attending the facility are sufficient to support your sample size requirements, and that the space and physical infrastructure of the facility can accommodate the research team and any additional equipment required for the research.*
   b. *All research conducted in KwaZulu-Natal must comply with government regulations relating to Covid-19. These include but are not limited to: regulations concerning social distancing, the wearing of personal protective equipment, and limitations on meetings and social gatherings.*
   c. *Please ensure that you provide your letter of ethics re-certification to this unit, when the current approval expires.*
   d. *Provide an interim progress report and final report (electronic and hard copies) when your research is complete to* ***HEALTH RESEARCH AND KNOWLEDGE MANAGEMENT, 10-102, PRIVATE BAG X9051, PIETERMARITZBURG, 3200*** *and e-mail an electronic copy to hrkm@kznhealth.gov.za*
   e. *Please note that the Department of Health shall not be held liable for any injury that occurs as a result of this study.*

For any additional information please contact Mr. X Xaba on 033-395 2805.

Yours Sincerely

[redacted]

Dr E Lutge
Chairperson, Provincial Health Research Committee
Date: 14/09/2023

GROWING KWAZULU-NATAL TOGETHER

APPENDIX C: FUNDING

- National Research Foundation Postgraduate Scholarship (Masters): 2023 – 2024

APPENDIX D: TURNITIN REPORT

Thesis submitted to turnitin final

ORIGINALITY REPORT

7%	6%	7%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	jag.journalagent.com Internet Source	1 %
2	Daniel H. Coelho, Taylor S. Pence, Mostafa Abdel-Hamid, Richard M. Costanzo. "Cribriform plate width is highly variable within and between subjects", Auris Nasus Larynx, 2018 Publication	1 %
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APPENDIX E: STATISTICAL ANALYSIS 1

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Methodolody	CT (N=55)	OESTEOLOGY (N=58)	p-value	Overall (N=113)
Sex			Chisq., p = 0.907	
Male	30 (54.5%)	31 (53.4%)		61 (54.0%)
Female	25 (45.5%)	27 (46.6%)		52 (46.0%)
Race			Chisq., p = 0.122	
Black	39 (70.9%)	33 (56.9%)		72 (63.7%)
White	16 (29.1%)	25 (43.1%)		41 (36.3%)

CT

Sex	Male (N=30)	Female (N=25)	p-value	Overall (N=55)
Length right in mm			t-test	
Mean±SD(CV%)	20.3±3.78(18.6)	20.6±3.73(18.1)	0.798	20.5±3.73(18.2)
Median(Q1-Q3)	20.0(17.9-22.9)	20.5(18.2-22.5)		20.0(18.1-22.9)
n(Min-Max)	30(10.4-28.6)	25(14.0-31.9)		55(10.4-31.9)
Length left in mm			t-test	
Mean±SD(CV%)	20.1±4.34(21.6)	20.0±3.84(19.2)	0.944	20.0±4.08(20.4)
Median(Q1-Q3)	19.3(17.9-22.7)	19.6(17.6-22.3)		19.6(17.8-22.5)
n(Min-Max)	30(10.2-30.3)	25(11.6-30.9)		55(10.2-30.9)
Width right in mm			t-test	
Mean±SD(CV%)	4.78±1.30(27.1)	4.19±1.05(25.0)	0.075	4.51±1.21(26.9)
Median(Q1-Q3)	4.69(3.82-5.57)	3.99(3.34-5.02)		4.63(3.52-5.29)
n(Min-Max)	30(2.48-7.96)	25(2.49-5.86)		55(2.48-7.96)
Width left in mm			Ranksum	
Mean±SD(CV%)		4.18±0.972(23.3)		
Median(Q1-Q3)	4.33(3.53-5.02)	4.09(3.67-4.69)	0.660	4.16(3.61-4.90)
n(Min-Max)	30(2.15-9.03)	25(2.42-6.75)		55(2.15-9.03)
Depth right in mm			Ranksum	
Mean±SD(CV%)	4.72±1.44(30.6)			
Median(Q1-Q3)	4.74(3.66-5.65)	4.70(3.66-6.01)	0.673	4.73(3.66-5.77)
n(Min-Max)	30(2.48-8.02)	25(2.54-11.5)		55(2.48-11.5)
Depth left in mm			t-test	
Mean±SD(CV%)	5.15±1.65(32.0)	4.94±1.40(28.4)	0.608	5.05±1.53(30.3)
Median(Q1-Q3)	5.01(3.98-5.90)	4.63(3.80-5.70)		4.92(3.91-5.81)
n(Min-Max)	30(2.59-8.89)	25(2.26-7.64)		55(2.26-8.89)

Sex	Male (N=30)	Female (N=25)	p-value	Overall (N=55)
Cribriform plate type			Fisher's, p = 0.820	
Type 1	7 (23.3%)	7 (28.0%)		14 (25.5%)
Type 2	7 (23.3%)	7 (28.0%)		14 (25.5%)
Type 3	4 (13.3%)	5 (20.0%)		9 (16.4%)
Type 4	8 (26.7%)	4 (16.0%)		12 (21.8%)
Type 5	4 (13.3%)	2 (8.0%)		6 (10.9%)
AEA location right			Chisq., p = 0.175	
Within	11 (36.7%)	5 (20.0%)		16 (29.1%)
Below	19 (63.3%)	20 (80.0%)		39 (70.9%)
AEA location left			Chisq., p = 0.562	
Within	8 (26.7%)	5 (20.0%)		13 (23.6%)
Below	22 (73.3%)	20 (80.0%)		42 (76.4%)
Crista galli type			Fisher's, p = 0.754	
Ossified	6 (20.0%)	3 (12.0%)		9 (16.4%)
Teardrop	16 (53.3%)	16 (64.0%)		32 (58.2%)
Tubular	8 (26.7%)	6 (24.0%)		14 (25.5%)

Sex	Male (N=31)	Female (N=27)	p-value	Overall (N=58)
Length right in mm			t-test	
Mean±SD(CV%)	22.6±2.83(12.5)	22.4±2.51(11.2)	0.774	22.5±2.66(11.8)
Median(Q1-Q3)	22.5(20.7-23.9)	22.8(20.8-24.0)		22.6(20.7-24.1)
n(Min-Max)	31(17.6-30.0)	27(17.6-27.1)		58(17.6-30.0)
Length left in mm			t-test	
Mean±SD(CV%)	22.7±2.64(11.6)	22.1±2.40(10.9)	0.368	22.4±2.52(11.3)
Median(Q1-Q3)	22.1(21.0-24.3)	22.0(20.5-23.6)		22.0(20.8-23.9)
n(Min-Max)	31(17.9-30.2)	27(17.2-27.3)		58(17.2-30.2)
Width right in mm			Ranksum	
Mean±SD(CV%)	4.98±1.30(26.1)			
Median(Q1-Q3)	4.94(3.91-5.73)	4.60(4.03-5.24)	0.691	4.79(3.99-5.48)
n(Min-Max)	31(2.85-8.37)	27(3.35-8.17)		58(2.85-8.37)
Width left in mm			Ranksum*	
Mean±SD(CV%)	4.66±1.49(32.1)	4.70±1.23(26.2)		
Median(Q1-Q3)	4.57(3.71-5.46)	4.30(3.94-5.26)	0.910	4.45(3.89-5.26)
n(Min-Max)	31(2.26-8.38)	27(2.52-8.01)		58(2.26-8.38)
Depth right in mm			t-test	
Mean±SD(CV%)	5.10±1.33(26.2)	4.66±1.61(34.6)	0.263	4.90±1.47(30.1)
Median(Q1-Q3)	5.14(4.42-5.95)	4.41(3.51-5.63)		4.81(4.00-5.93)
n(Min-Max)	31(2.05-8.21)	27(0.840-8.19)		58(0.840-8.21)
Depth left in mm			t-test	
Mean±SD(CV%)	5.12±1.21(23.7)	4.59±1.42(31.0)	0.127	4.87±1.33(27.3)
Median(Q1-Q3)	4.96(4.49-6.05)	4.79(3.82-5.53)		4.86(4.08-5.64)
n(Min-Max)	31(2.94-8.01)	27(0.700-7.07)		58(0.700-8.01)

Sex	Male (N=31)	Female (N=27)	p-value	Overall (N=58)
Cribriform plate type			Fisher's, p = 0.727	
Type 1	8 (25.8%)	6 (22.2%)		14 (24.1%)
Type 2	4 (12.9%)	5 (18.5%)		9 (15.5%)
Type 3	5 (16.1%)	5 (18.5%)		10 (17.2%)
Type 4	11 (35.5%)	6 (22.2%)		17 (29.3%)
Type 5	3 (9.7%)	5 (18.5%)		8 (13.8%)
Crista galli type			Chisq., p = 0.138	
Ossified	13 (41.9%)	5 (18.5%)		18 (31.0%)
Teardrop	10 (32.3%)	14 (51.9%)		24 (41.4%)
Tubular	8 (25.8%)	8 (29.6%)		16 (27.6%)
Number of foramina			t-test	
Mean±SD(CV%)	47.9±13.1(27.3)	50.3±15.6(31.1)	0.534	49.0±14.2(29.0)
Median(Q1-Q3)	45.0(40.0-57.0)	50.0(36.5-59.0)		48.0(38.5-57.8)
n(Min-Max)	31(25.0-88.0)	27(27.0-90.0)		58(25.0-90.0)

APPENDIX F: STATISTICAL ANALYSIS 2

Xxx
CT -Male

Race	Black (N=21)	White (N=9)	p-value	Overall (N=30)
Length right in mm			t-test	
Mean±SD(CV%)	20.6±2.90(14.1)	19.7±5.49(27.9)	0.537	20.3±3.78(18.6)
Median(Q1-Q3)	20.0(18.7-22.4)	18.8(16.0-24.4)		20.0(17.9-22.9)
n(Min-Max)	21(16.3-28.6)	9(10.4-26.8)		30(10.4-28.6)
Length left in mm			t-test	
Mean±SD(CV%)	20.0±3.91(19.6)	20.3±5.46(26.9)	0.860	20.1±4.34(21.6)
Median(Q1-Q3)	19.7(18.1-22.2)	18.6(17.6-23.8)		19.3(17.9-22.7)
n(Min-Max)	21(10.9-30.3)	9(10.2-28.4)		30(10.2-30.3)
Width right in mm			t-test	
Mean±SD(CV%)	4.87±1.24(25.4)	4.56±1.48(32.4)	0.557	4.78±1.30(27.1)
Median(Q1-Q3)	4.68(3.87-5.46)	5.05(3.37-5.69)		4.69(3.82-5.57)
n(Min-Max)	21(3.23-7.96)	9(2.48-6.55)		30(2.48-7.96)
Width left in mm			Ranksum	
Mean±SD(CV%)		4.55±0.893(19.6)		
Median(Q1-Q3)	4.02(3.52-4.97)	4.75(4.35-5.20)	0.298	4.33(3.53-5.02)
n(Min-Max)	21(2.15-9.03)	9(2.76-5.40)		30(2.15-9.03)
Depth right in mm			t-test	
Mean±SD(CV%)	4.70±1.59(33.8)	4.77±1.12(23.5)	0.911	4.72±1.44(30.6)
Median(Q1-Q3)	4.62(3.65-5.49)	4.79(4.47-5.70)		4.74(3.66-5.65)
n(Min-Max)	21(2.48-8.02)	9(2.94-6.19)		30(2.48-8.02)
Depth left in mm			t-test	
Mean±SD(CV%)	4.96±1.68(34.0)	5.60±1.55(27.7)	0.335	5.15±1.65(32.0)
Median(Q1-Q3)	4.60(3.82-5.53)	5.49(4.16-6.00)		5.01(3.98-5.90)
n(Min-Max)	21(2.59-8.48)	9(4.01-8.89)		30(2.59-8.89)

Race	Black (N=21)	White (N=9)	p-value	Overall (N=30)
Cribriform plate type			Fisher's, p = 0.229	
Type 1	3 (14.3%)	4 (44.4%)		7 (23.3%)
Type 2	5 (23.8%)	2 (22.2%)		7 (23.3%)
Type 3	2 (9.5%)	2 (22.2%)		4 (13.3%)
Type 4	7 (33.3%)	1 (11.1%)		8 (26.7%)
Type 5	4 (19.0%)	0 (0.0%)		4 (13.3%)

CT -Female

Race	Black (N=18)	White (N=7)	p-value	Overall (N=25)
Length right in mm			Ranksum*	
Mean±SD(CV%)		19.9±4.19(21.0)		20.6±3.73(18.1)
Median(Q1-Q3)	20.7(18.6-22.3)	18.8(17.5-22.9)	0.593	20.5(18.2-22.5)
n(Min-Max)	18(16.2-31.9)	7(14.0-26.1)		25(14.0-31.9)
Length left in mm			t-test	
Mean±SD(CV%)	20.1±3.71(18.4)	19.7±4.46(22.6)	0.816	20.0±3.84(19.2)
Median(Q1-Q3)	19.8(17.8-22.0)	19.6(18.6-21.7)		19.6(17.6-22.3)
n(Min-Max)	18(14.9-30.9)	7(11.6-26.0)		25(11.6-30.9)
Width right in mm			t-test	
Mean±SD(CV%)	4.00±1.05(26.3)	4.68±0.936(20.0)	0.153	4.19±1.05(25.0)
Median(Q1-Q3)	3.99(3.09-4.87)	4.99(3.94-5.34)		3.99(3.34-5.02)
n(Min-Max)	18(2.49-5.70)	7(3.34-5.86)		25(2.49-5.86)
Width left in mm			t-test	
Mean±SD(CV%)	4.17±1.06(25.4)	4.20±0.780(18.6)	0.954	4.18±0.972(23.3)
Median(Q1-Q3)	3.95(3.67-4.77)	4.16(3.89-4.46)		4.09(3.67-4.69)
n(Min-Max)	18(2.42-6.75)	7(3.02-5.51)		25(2.42-6.75)
Depth right in mm			Ranksum*	
Mean±SD(CV%)	4.74±1.56(32.9)	6.16±2.68(43.5)		
Median(Q1-Q3)	4.58(3.62-5.51)	5.33(4.64-6.82)	0.110	4.70(3.66-6.01)

Race	Black (N=18)	White (N=7)	p-value	Overall (N=25)
n(Min-Max)	18(2.54-7.86)	7(3.39-11.5)		25(2.54-11.5)
Depth left in mm			t-test	
Mean±SD(CV%)	4.81±1.26(26.2)	5.26±1.78(33.9)	0.480	4.94±1.40(28.4)
Median(Q1-Q3)	4.53(3.88-5.63)	5.62(3.92-6.38)		4.63(3.80-5.70)
n(Min-Max)	18(2.26-7.35)	7(2.98-7.64)		25(2.26-7.64)
Cribriform plate type			Fisher's, p = 0.337	
Type 1	4 (22.2%)	3 (42.9%)		7 (28.0%)
Type 2	6 (33.3%)	1 (14.3%)		7 (28.0%)
Type 3	5 (27.8%)	0 (0.0%)		5 (20.0%)
Type 4	2 (11.1%)	2 (28.6%)		4 (16.0%)
Type 5	1 (5.6%)	1 (14.3%)		2 (8.0%)

Osteology – Male

Race	Black (N=18)	White (N=13)	p-value	Overall (N=31)
Length right in mm			t-test	
Mean±SD(CV%)	23.4±3.16(13.5)	21.5±1.84(8.6)	0.054	22.6±2.83(12.5)
Median(Q1-Q3)	23.0(21.1-26.0)	22.1(19.9-23.0)		22.5(20.7-23.9)
n(Min-Max)	18(18.6-30.0)	13(17.6-23.5)		31(17.6-30.0)
Length left in mm			t-test	
Mean±SD(CV%)	23.4±2.88(12.3)	21.7±1.97(9.1)	0.077	22.7±2.64(11.6)
Median(Q1-Q3)	22.9(21.2-24.8)	21.8(20.9-22.8)		22.1(21.0-24.3)
n(Min-Max)	18(19.7-30.2)	13(17.9-24.8)		31(17.9-30.2)
Width right in mm			t-test	
Mean±SD(CV%)	5.28±1.44(27.3)	4.56±0.977(21.4)	0.129	4.98±1.30(26.1)
Median(Q1-Q3)	4.99(4.38-6.59)	4.60(3.86-5.30)		4.94(3.91-5.73)
n(Min-Max)	18(3.24-8.37)	13(2.85-6.02)		31(2.85-8.37)

Race	Black (N=18)	White (N=13)	p-value	Overall (N=31)
Width left in mm			t-test	
Mean±SD(CV%)	5.18±1.51(29.1)	3.93±1.18(29.9)	0.019	4.66±1.49(32.1)
Median(Q1-Q3)	4.75(4.16-6.14)	4.06(3.20-4.39)		4.57(3.71-5.46)
n(Min-Max)	18(3.22-8.38)	13(2.26-6.03)		31(2.26-8.38)
Depth right in mm			t-test	
Mean±SD(CV%)	5.00±1.55(31.1)	5.24±0.996(19.0)	0.626	5.10±1.33(26.2)
Median(Q1-Q3)	4.77(4.28-6.19)	5.18(4.56-5.62)		5.14(4.42-5.95)
n(Min-Max)	18(2.05-8.21)	13(3.18-6.84)		31(2.05-8.21)
Depth left in mm			t-test	
Mean±SD(CV%)	5.00±1.22(24.3)	5.29±1.24(23.5)	0.520	5.12±1.21(23.7)
Median(Q1-Q3)	4.74(4.39-5.43)	5.87(4.52-6.12)		4.96(4.49-6.05)
n(Min-Max)	18(3.02-8.01)	13(2.94-6.80)		31(2.94-8.01)
Cribriform plate type			Fisher's, p = 0.641	
Type 1	3 (16.7%)	5 (38.5%)		8 (25.8%)
Type 2	3 (16.7%)	1 (7.7%)		4 (12.9%)
Type 3	4 (22.2%)	1 (7.7%)		5 (16.1%)
Type 4	6 (33.3%)	5 (38.5%)		11 (35.5%)
Type 5	2 (11.1%)	1 (7.7%)		3 (9.7%)

Osteology – Female

Race	Black (N=15)	White (N=12)	p-value	Overall (N=27)
Length right in mm			t-test	
Mean±SD(CV%)	23.1±2.62(11.3)	21.6±2.16(10.0)	0.111	22.4±2.51(11.2)
Median(Q1-Q3)	23.8(21.7-24.6)	22.0(20.5-23.1)		22.8(20.8-24.0)
n(Min-Max)	15(18.6-27.1)	12(17.6-24.1)		27(17.6-27.1)
Length left in mm			t-test	
Mean±SD(CV%)	22.8±2.64(11.6)	21.2±1.79(8.5)	0.090	22.1±2.40(10.9)
Median(Q1-Q3)	22.8(21.3-24.6)	20.8(20.1-22.2)		22.0(20.5-23.6)

Race	Black (N=15)	White (N=12)	p-value	Overall (N=27)
n(Min-Max)	15(17.2-27.3)	12(18.6-24.3)		27(17.2-27.3)
Width right in mm			Ranksum*	
Mean±SD(CV%)		4.71±0.731(15.5)		
Median(Q1-Q3)	4.60(3.74-5.55)	4.60(4.11-5.10)	0.578	4.60(4.03-5.24)
n(Min-Max)	15(3.35-8.17)	12(3.98-6.45)		27(3.35-8.17)
Width left in mm			Ranksum*	
Mean±SD(CV%)	4.76±1.30(27.2)			4.70±1.23(26.2)
Median(Q1-Q3)	4.65(3.96-5.51)	4.22(3.94-4.88)	0.776	4.30(3.94-5.26)
n(Min-Max)	15(2.52-7.37)	12(3.50-8.01)		27(2.52-8.01)
Depth right in mm			t-test	
Mean±SD(CV%)	4.58±1.20(26.1)	4.76±2.08(43.7)	0.787	4.66±1.61(34.6)
Median(Q1-Q3)	4.39(3.51-5.33)	4.49(3.71-6.17)		4.41(3.51-5.63)
n(Min-Max)	15(2.96-6.78)	12(0.840-8.19)		27(0.840-8.19)
Depth left in mm			t-test	
Mean±SD(CV%)	4.75±1.07(22.6)	4.39±1.80(41.0)	0.528	4.59±1.42(31.0)
Median(Q1-Q3)	4.18(3.93-5.43)	4.83(3.19-5.53)		4.79(3.82-5.53)
n(Min-Max)	15(3.47-7.07)	12(0.700-6.73)		27(0.700-7.07)
Cribriform plate type			Fisher's, p = 0.977	
Type 1	4 (26.7%)	2 (16.7%)		6 (22.2%)
Type 2	3 (20.0%)	2 (16.7%)		5 (18.5%)
Type 3	2 (13.3%)	3 (25.0%)		5 (18.5%)
Type 4	3 (20.0%)	3 (25.0%)		6 (22.2%)
Type 5	3 (20.0%)	2 (16.7%)		5 (18.5%)