# COMPUTED TOMOGRAPHY OBTAINED ADULT ORBITAL AND EYEBALL VOLUMES IN RELATION TO AGE AND GENDER AT MOI TEACHING AND REFERRAL HOSPITAL.

**BY**

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**THESIS SUBMITTED TO SCHOOL OF MEDICINE, MOI UNIVERSITY IN PARTIAL FULFILMENT FOR THE AWARD OF A MASTER OF MEDICINE IN DIAGNOSTIC RADIOLOGY AND IMAGING**

# DECLARATION

This thesis is my original work and has not been presented for a degree in any other university. No part of this proposal may be reproduced without the permission of the author and/or Moi University.

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# DEDICATION

This research is expressly dedicated to the Almighty God. To my late father Mr. Joseph Ng'etich and mum Mrs. Everline Ng'etich who laid a firm foundation for my academic journey; my late grandmother Mrs. Rose Kogo for her ever encouraging words towards academic excellence. To my uncle Dr. Job Ngetich who has constantly offered academic mentorship throughout my academic journey. I owe this to you all.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| **2D** | Two Dimension |
| **3D** | Three Dimension |
| **CT** | Computed Tomography |
| **EV** | Eyeball Volume |
| **GOK** | Government of Kenya |
| **IREC** | Institutional Research and Ethics Committee |
| **MOH** | Ministry of Health |
| **MRI** | Magnetic Resonance Imaging |
| **MTRH** | Moi Teaching and Referral Hospital |
| **OV** | Orbital Volume |

# OPERATIONAL DEFINITION OF TERMS

| | |
|---|---|
| **Adult** | A person older than the age of 18 years (WHO, 2020) |
| **Emmetropia** on the | Normal refractive state of an eye where rays are well focused retina creating a well-focused image. |
| **Enophthalmos** | Posterior displacement of the eyeball in the anteroposterior plane within the orbit. |
| **Eyeball** | Globe structure within the orbit that receives light and transforms it into signal to be transmitted to the brain for vision to occur. |
| **Eyeball volume** | Estimated amount of space occupied by the eyeball calculated using a special software by tracing margins on CT images |
| **Hyperopia** | A vision problem where one can see distant objects clearly but not near ones due to focusing rays from near objects behind the retina. |
| **Myopia** | A vision state where one can see near objects clearly but not distant ones due to focusing rays from distant objects in front of the retina. |
| **Orbit** | part of the facial skeleton that caves in to accommodate the eyeball and other related structures such as the eyelids, ocular muscles, blood vessels and nerves. |
| **Orbital volume** | Estimated amount of space occupied by the orbit calculated using a special software by tracing margins on CT images |
| **Visual Acuity** | A measure of capability of an eye to discern detail of objects, figure or letters from a given distance. |

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## ABSTRACT

**Background:** The orbit is an intricate structure on the upper part of the face that houses the eyeball, muscles, optic nerve, lacrimal gland, orbital fat, blood vessels and nerves. Dimensions and volumes of the orbit and eyeball have not been clearly elaborated in the African population. They are crucial to ophthalmologists, reconstructive surgeons, radiologists and designers of eye protective equipment and prosthesis. The dimensions and volumes differ with various demographic factors such as age, gender and ethnicity. Few studies have been done in Sub-Saharan Africa and in the local Kenyan population. Earlier measurements were two dimensional (2D) measured directly on cadavers or skulls, afterwards volumes were obtained using mathematical formulae. The advent of three dimensional (3D) imaging such as Computed Tomography (CT) has made it possible to accurately estimate orbital and eyeball volumes using computer software. This study aims to establish the orbital and eyeball volumes for the local black Kenyan population in relation to age and gender for use in orbit-ocular related surgery, diagnosis of orbit-ocular disease and manufacture of prosthesis as well as protective equipment.

Objective: To determine adult orbital and eyeball volumes in relation to age and gender at Moi Teaching and Referral Hospital using CT scan.

**Methods**: This was a cross sectional study done at the Department of Radiology and Imaging, Moi Teaching and Referral Hospital between 1st September 2021 and 31st August 2022. Sample size of 475 adult participants was determined using Naduvilath et al, (2000) formula for estimating sample size for ophthalmology studies from a population of 1796 patients which was the total number of patients done CT scanning in the selected CT room in the previous year. Systematic random sampling was used where every third patient was selected. They were then screened for orbital and ocular anomalies and those with abnormal findings excluded. Patients underwent head CT scan at the Philips 64 slice CT scan room using protocol for the orbit. Images were then stored in a Digital Versatile Disk Read Only Memory (DVD-ROM). The discs were then singly loaded to a computer and volumes obtained using the gold standard manual segmentation method with assistance of the Eclipse software version 16.1 by tracing the edge contours of both the orbit and eyeball in two subsequent steps for each structure. A structured questionnaire was used to record data which was then entered to an Excel sheet. Continuous variables were analyzed using descriptive statistics of mean, median, standard deviation and interquartile range. Categorical variables were presented in frequency tables. Chi square and Pearson correlation was used to test for associations. A p-value of $<0.05$ was regarded as statistically significant.

**Results**: The study included 458 participants with a mean age of $41.1 \pm 20$ years and median age of 35 years. The youngest patient was 18 years old while the oldest was 98 years old. The number of male patients was 291 (63.5%). The mean volume of the male orbit was $22.57 \pm 2.98$ cm³. The female orbit was smaller measuring $21.47 \pm 2.87$ cm³ with the difference being statistically significant ($p<0.001$ for both orbits). The eyeball volume for females was $5.44 \pm 0.93$ cm³ while that of males measured $5.41 \pm 0.93$ cm³ with the difference being not statistically significant ($p=0.802$ for the right eye, $p=0.647$ for left eye). There was an associated increase in orbital volume with age ($r=0.0932$, $p=0.046$ for the right orbit, $r=0.089$, $p<0.057$ for the left orbit) with no statistical significance. There was an associated decrease in eyeball volume with age but with both sides having no statistical significance ($r=-0.024$, $p=0.612$ for the right eyeball, $r=-0.039$, $p=0.405$ for the left eyeball).

**Conclusion:** The male orbital volume was larger with a mean of $22.57 \pm 2.98$ cm³, while that of females had a mean of $21.47\pm 2.87$ cm³. There was no difference in eyeball volume measurements among males and females measuring $5.41 \pm 0.93$ cm³ and $5.44 \pm 1.14$ cm³ respectively**.** There was no significant difference of eyeball volume with age for both genders, while there was decrease in size with increase in age for both genders.

**Recommendation:** The observed variation of orbital volumes with gender should be taken into consideration in orbit-ocular clinical practice and implant manufacture.

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background

The orbit and eyeball are two dependent structures that are meticulously arranged in the upper part of the face. The orbit is a cave-like structure intricately sculptured to accommodate the eyeball and other structures including eyelids, muscles, nerves, blood vessels, lacrimal gland and orbital fat (Shyu *et al.*, 2015). The eyeball occupies about 20 % of the orbit's volume. The two structures are of interest particularly during surgical reconstruction as the outcome impacts greatly on the facial aesthetics of patients (Bontzos *et al*., 2019).

#### 1.1.1 The Orbit

The orbit is an intricate conical structure on the upper part of the face that houses the eyeball, muscles, optic nerve lacrimal gland, orbital fat, blood vessels and nerves. Its curvilinear walls have foramina and fissures where structures transcend through and irregularities where muscles, capsules and ligaments attach (Turvey & Golden, 2012). The orbital anterior entrance dimensions range from 36 - 47 mm in width and 26 - 42 mm in height. Its volume ranges from 17.05 $cm^3$ to 29.30 $cm^3$ with the subject's age, race and gender (Dutton & Waldrop, 2011). The orbital depth measures about 38.7 mm to 55.4 mm as portrayed by Bekerman *et al*, (2014). These measurements however vary among the general population with age, gender as well as ethnicity (Munguti *et al*, 2012)

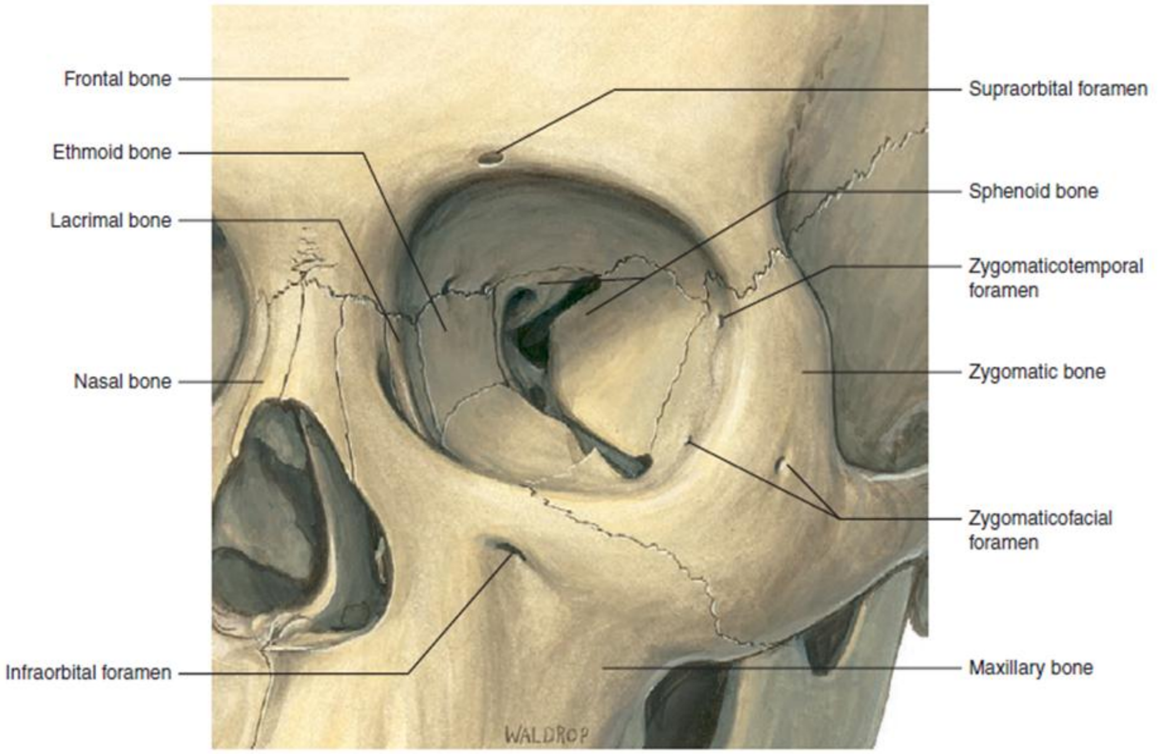



***Figure 1: Orbital bony structure.***

***Adapted from Atlas of Clinical and Surgical Orbital Anato*my (Dutton & Waldrop, 2011)**

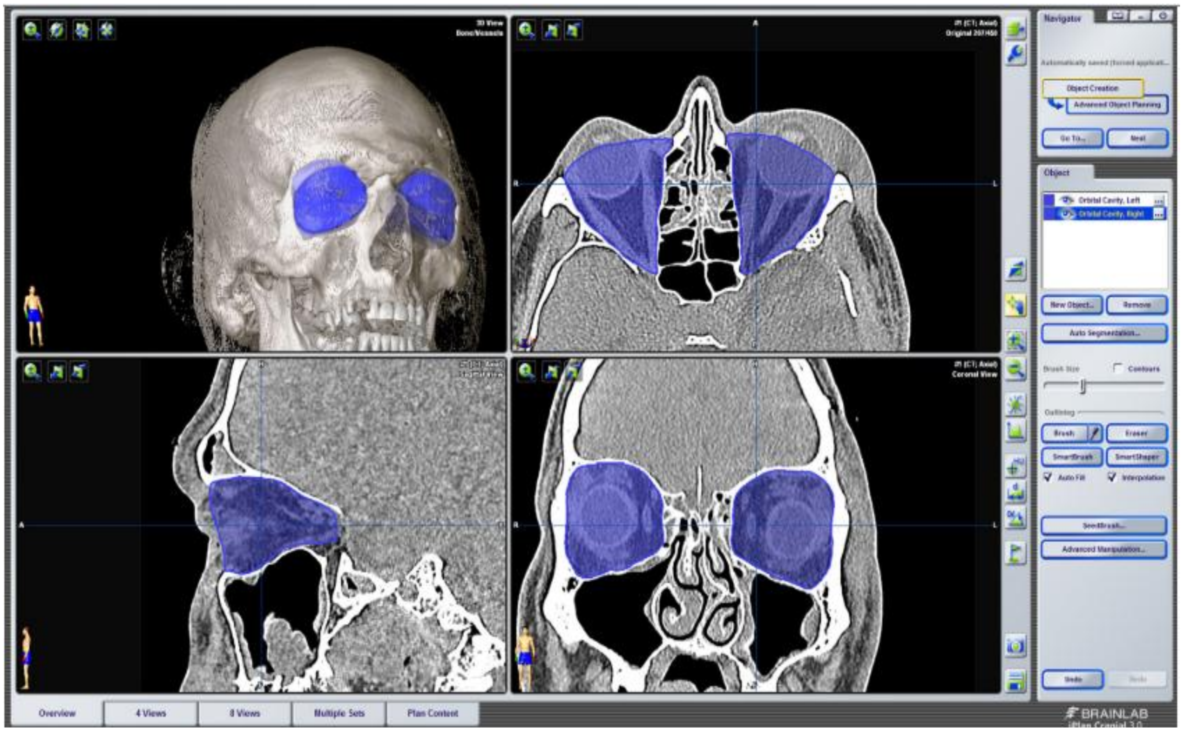



***Figure 2: Orbital volume traced in blue***

*Adapted from Jansen et al., (2016)*

**1.1.2 The Eyeball**

The eyeball on the other hand is a spherical structure within the orbit that houses the structures that enable vision. Its anteroposterior diameter measures about 2.4 cm, vertical diameter about 2.3 cm and horizontal diameter about 2.35 cm (Snell, 1998). Its mean eyeball volume approximately measures 5.23 $cm^3$ with a range of 3.43 – 7.03 $cm^3$ (Igbinedion & Ogbeide, 2013). It is subdivided into anterior and posterior segments by the lens. The anterior segment is subdivided into an anterior chamber and posterior chamber by the iris. The posterior segment consists of vitreous humor, choroid, retina and sclera (Netter, 2010). These measurements also vary in the general population (Bekerman *et al*., 2014).

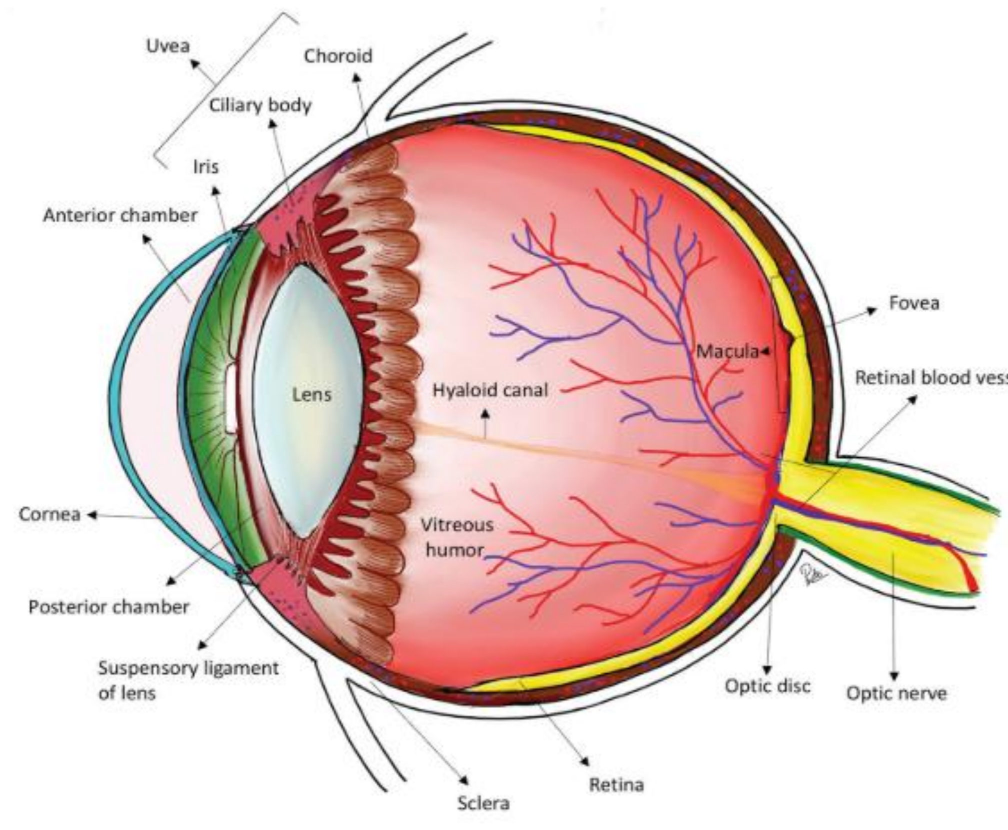



***Figure 3: The eyeball and its structures***

***Adapted from Essentials of Ophthalmology, 7th Edition (Samar, 2019)***

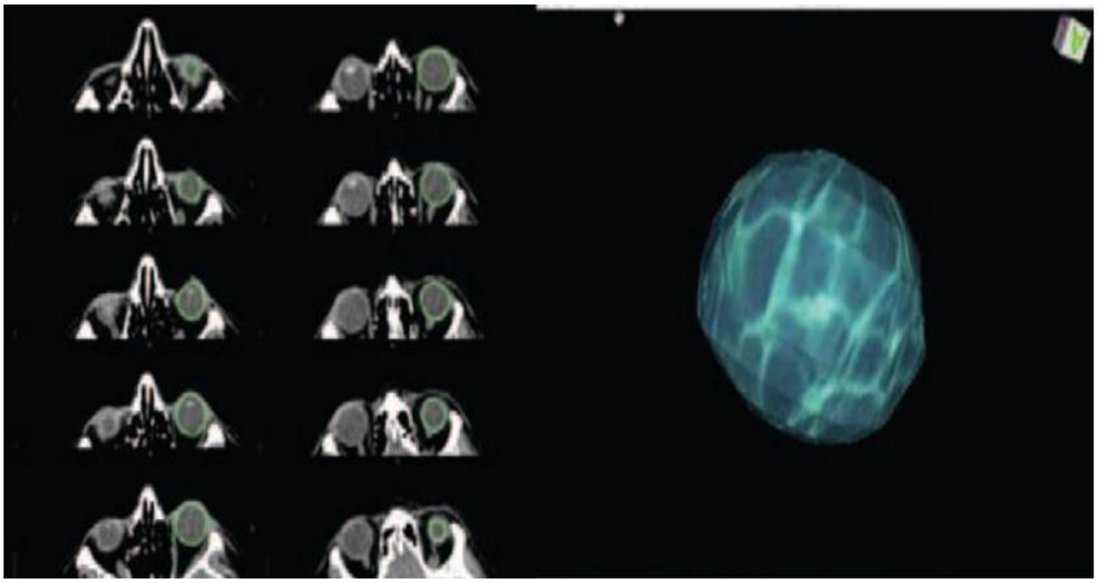


***Figure 4: Eyeball volume tracing and extraction.***

*Adapted from Acer et al., (2011)*

### 1.1.3 Orbital and Eyeball Volumes

Thorough understanding of the orbital and ocular measurements is important in various disciplines of medicine that interact with the orbit and its structures (Weaver *et al.,* 2010). For radiologists, it is important that they know the normal ranges of the orbital dimensions so that they make accurate reports of pathologies of the orbit and its structures including the eyeball such as phthisis bulbi. Ophthalmologists require a more insightful understanding on the depth of the orbit to avoid injury to structures especially the optic nerve during intraoperative dissection. Facial reconstructive and maxillofacial surgeons also require expansive knowledge of the orbit in order to ensure there is good reconstruction of the orbit in cases of injury. It is desired that the aim of reconstructive surgery is to restore the normal pre-trauma orbital volume (Bontzos *et al*., 2019). Anesthesiologists require this knowledge to ensure accurate administration of local periorbital anesthesia (Munguti *et al*., 2012). The measurements are also necessary for manufacture of eye protective equipment and prostheses where their design sizes should be tailored to the local population ranges (Weaver *et al.*, 2010).

There is observed distinct variation in orbit and eyeball dimensions among various races, age and gender. Munguti *et al,* (2012) found out the skull orbital measurements of the Central Kenyan population were slightly larger compared to Caucasians. Igbinedion & Ogbeide (2013) in West Africa sought to establish the normal CT ocular volume in Nigeria as a reference for Africans and found out that eyeball volume correlated with age up to 50 years of age where the ocular volume began to reduce. Anibor & Ighodae (2016) also attempted to analyze the orbital index of Adult Bini Nigerians and found out that they are of microseme category. Weaver *et al*, (2010) assessed the normal eyeball and orbital measurements for the North Carolina, USA population using CT scan images.

Earlier researches on the normal anthropometric measurements of the orbit used skulls and direct measurements were obtained from them such as the ones done by Munguti *et al*, (2012). The same has been done in virtually all races which showed variation among them (Mekala *et al.,* 2015). With the advancement in technological imaging, it has been possible to get dimensions on patients using the available medical imaging modalities such as ultrasound, x-ray, CT scan and MRI. Anibor & Ighodae (2016) has used x-rays to determine the orbital index of adult Bini Nigerians but many other better studies have been done using the CT scan because of its ability to produce 3D reconstructed images of particularly of the bone, while few others have been done using MRI.

The use of CT scan is the preferred method of estimating the orbital anthropometric measures because of its ability to show the bony structures well. It can also allow good 3D reconstruction of the orbit which will be important in calculation of volume (Shyu *et al.*, 2015). With assistance of computer software, manual segmentation of the orbit and eyeball can be easily obtained among the living and serves as the gold standard. Additionally, CT scan gives a relatively good view of the ocular globe and muscles (Kokilam, 2010). It has therefore offered an easier way of acquiring reconstructed orbit of patients and also a view of the soft tissues which is not possible with skull and cadaveric geometric studies (Shyu *et al.*, 2015).

Several studies have been done in Kenya to obtain orbital dimensions by Munguti *et al*., (2012). This was however done on skulls in the National Museum from one region of the country which may not be fully representative of dimensions in the living. It also does not reflect the variance of measurements among the various age groups. A further study by Munguti *et al,* (2013) assessed the variance in the orbital indices with gender but still utilized skull geometric measures. Igbinedion & Ogbeide (2013) measured the normal ocular volume of Nigerians using CT scan but ignored the orbital parameters. Ogbeide & Usuale (2007) had earlier used ultrasonography to obtain eyeball measurements which were then used to calculate eyeball volume. The study however yielded volumetric figures that were unusually high compared to findings in other studies.

This study therefore aimed to assess the orbital and ocular volumes of adults in relation to age and gender as seen at MTRH using CT scan geometric reconstruction. The findings will help in understanding the normal measurements for the local populations which can be applied to delineate pathology, reduce complications resulting from orbital surgeries and also serve as references for manufacture of ophthalmologic prosthesis and hardware for the local population.

## 1.2 Problem Statement

Volumes of eyeball and orbit for the Kenyan population have not been established for use in referencing despite knowledge on their importance and availability of modern non-invasive imaging methods. Studies that have been done locally were mainly dimensions of the orbit obtained from skulls at the Nairobi Museum which could not allow for analysis on parameters such as age and gender. The dimensions and volumes used are also obtained from the Caucasian population despite the knowledge of the variable dimensions among the various ethnicities (Munguti *et al*., 2012).

Inappropriate restoration of orbital integrity during orbital reconstructive surgeries has led to cases of post-surgical enophthalmos. It is therefore important that the pre-surgical orbital volume is restored accurately to reduce the rate of enophthalmos and increase post-surgical aesthesis and patient satisfaction (Ye, Kook, & Lee, 2006). Orbital prosthesis used in orbital fracture repair and eyeball replacement also have to be manufactured with the right dimensions to accurately match individuals in the targeted population with the assistance of 3D reconstructed images from modalities such as CT scan and MRI (Thaworanunta & Shrestha, 2016).

While there are limited studies done on orbital and eyeball volumes and their importance in management of orbital disease in Kenya, there is need for understanding of the same due to increased need for orbital reconstructive surgeries as a result of increased incidence of motor-vehicle orbital injuries (Manana, 2014). At Moi Teaching and Referral Hospital, facial injuries resulting in facial disfigurement have also been attributed to psychiatric morbidity such as alcohol abuse, depression, suicidal behavior, anxiety disorder and antisocial behavior (Juma *et al.,* 2020).

There are no reference values to suit the local population for reference by specialists who interact with the orbit and eyeball. Prosthetic and implant manufacturers also don't have the dimensions for use in manufacturing prototypes for the local African population which may result in incorrect size of implant and eventually poor aesthetic facial outcome. Implants should be made with measurements that fit to the dimensions of the local population demographics (Thaworanunta & Shrestha, 2016).

## 1.3 Justification

Orbital and ocular volumes for the local Kenyan and East African population have not been clearly established despite their importance and the fact that there is variation among the different ethnicities (Munguti *et al*., 2012). These measurements are important not only in clinical management of orbital disease but also in manufacture of prostheses and implants. Orbital dimensions are important to ophthalmologists while interpreting pathology and conducting orbital surgeries, information on orbital depth is important in minimizing structural damage during orbital surgery (Weaver *et al*., 2010). This evokes the need for local measurements that suit the local population.

Orbital injury secondary to motorcycle and other road traffic accidents is on a sharp rise in Kenya (Manana, 2014). As such there is need for maxillofacial and plastic reconstructive surgeries to those affected. These surgeons require orbital measurements when conducting orbital reconstructive procedures with an aim of ensuring that pre-trauma orbital volume is achieved as much as possible (Ye *et al*., 2006). During maxillofacial orbital reconstruction, the aim is to restore the orbital volume to the initial volume for maximum aesthetic results (Ahmed *et al.,* 2019). Hence the need for local ranges.

The measurements are also important to radiologists while interpreting images concerning the orbit and delineating presence and absence of pathology and hence local reference values are needed (Khademi & Bayat, 2016). The dimensions are crucial in designing and manufacturing eye prostheses and implants (Thaworanunta & Shrestha, 2016). The right size of eyeball prosthesis is important in reducing complications such as eyeball implant migration (extrusion and intrusion), reduced mobility and need for replacement, hence the right size of implant should be selected (Vasiliki & Potter, 2004). This evokes the need for local reference values to be utilized locally as proposed by the Kenyan Ministry of Health National Eye Health Strategic Plan (2021).

The dimensions of the Kenyan orbit assessed in two studies by Munguti *et al*., (2012, 2013) utilized direct geometric measurements on the skull in one region of Kenya and could not delineate gender parameter differences as proposed by Anibor & Ighodae, (2016). This study is aimed at filling this gap by establishing the orbital and ocular volumes and the difference among males and females for the local Kenyan population at Moi Teaching and Referral Hospital (MTRH) using head CT scans.

CT scanning imaging modality is selected because of its competent ability to give a good resolution of the bony structure of the orbit as well as the eyeball (Igbinedion & Ogbeide, 2013). The findings of the study will be used as baseline references for the Kenyan population and black Africans in general during clinical diagnosis and management of orbital disease.

### 1.4 Research Question

What are the adult CT obtained orbital and ocular volumes in relation to age and gender at MTRH?

### 1.5 Objectives

#### 1.5.1 Broad Objective

To determine adult CT orbital and ocular volumes in relation to age and gender at MTRH.

#### 1.5.2 Specific Objectives

1. To determine adult CT orbital volumes at MTRH.
2. To establish adult CT eyeball volumes at MTRH.
3. To assess how adult CT orbit and eyeball volumes relate with age and gender at MTRH.

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Introduction

This chapter will present in detail the literature done by scholars in an attempt to answer the study problem. It has the following sections: The Orbit and its volume, the Eyeball and its volume, Orbit and eyeball volumes variance with the various population parameters of age, gender and ethnicity and utility of the two volume parameters.

### 2.2 The Orbit

#### 2.2.1 Bony Orbit Anatomy

The orbits are two intricate caves on the upper part of the facial skeleton that accommodates the structures of vision. The orbit is described as a conical structure since its walls are curvilinear. However, some literature describe the orbit to be a pyramid shaped structure with four walls, an apex and a base. The orbital walls are holed by fissures and foramina and have several irregularities where orbital ligaments, capsules and muscles attach. The orbital apex is located posteriorly towards the optic canal where the optic canal traverses from the brain to attach to the posterior aspect of the eyeball. Its base is the outer rim where the four bony orbital walls coalesce to form a near circular shape. The walls are the roof made up the frontal and sphenoid bones; the floor formed by the zygomatic, palatine and maxillary bones; the medial wall formed by the sphenoid, ethmoid, lacrimal and maxillary bones; and the lateral wall formed by the sphenoid, frontal and zygomatic bones. This gives the dimensions that include the base height, base width and depth to apex (Turvey & Golden, 2012).

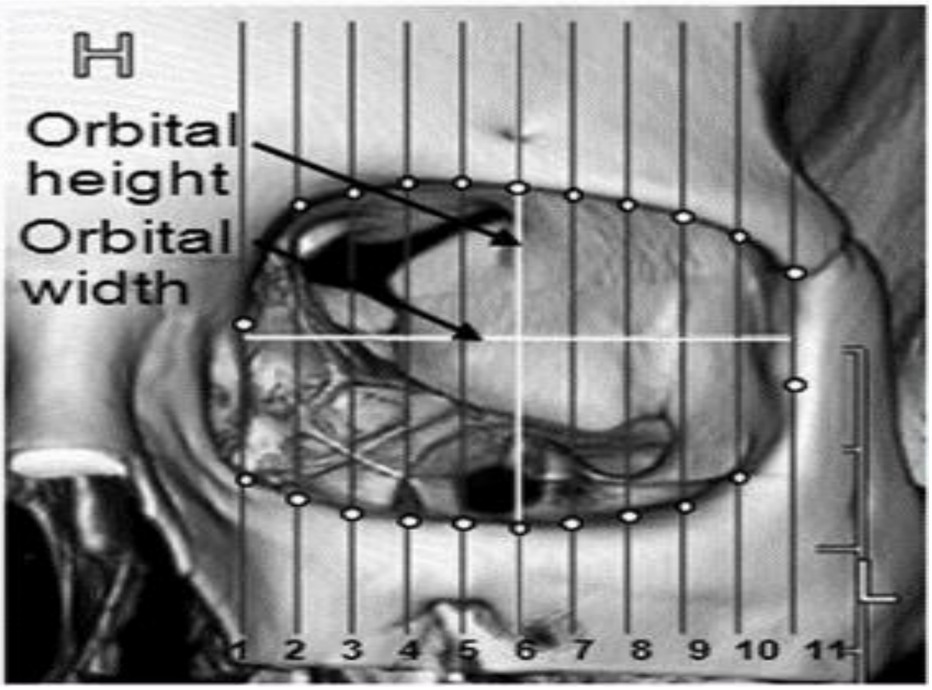



***Figure 5:3D CT reconstructed orbital entrance of the orbit showing base height and width.***

***Adapted from CT based 3D orbit and eyeball measurement (Weaver et al., 2010)***

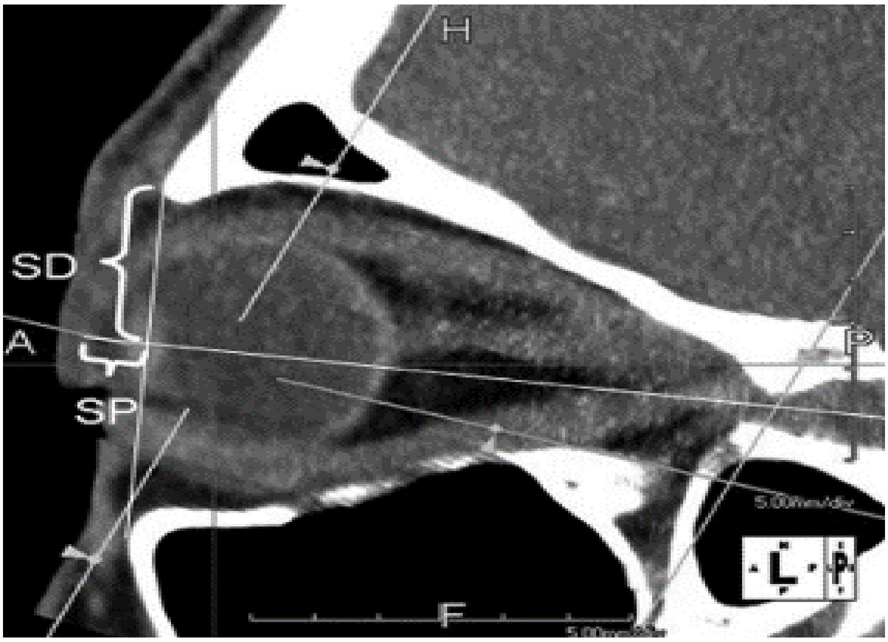



***Figure 6: CT sagittal view of the orbit showing the depth.***

***Adapted from CT based 3D eyeball and orbit measurements (Weaver et al., 2010)***

### 2.2.2 Osteology of the orbit

The orbit is a pyramid made of seven bones that form four walls: the lateral wall that consists of the sphenoid greater wing, the frontal and zygomatic bones anteriorly; the medial wall that is made up of lesser wing of sphenoid, the ethmoid, lacrimal and frontal process of the maxillary bones; the floor that consists of zygomatic bone, orbital process of the palatine bone and orbital part of the maxillary bone; and roof that is made up of the sphenoid and the frontal bones. Together they result in a conical structure with an entrance, also known as orbital rim and an apex at the posterior end where the optic canal sits (Turvey & Golden, 2012)**.**

The orbital rim has a breadth of about 43 mm and height of about 34 mm. The depths of the various walls however differ. The medial wall depth measures about 32-53mm measured from the anterior most edge of the lacrimal crest up to the apex, averaging to about 42 mm. The roof measures approximately 46 mm with a range of 35-59 mm spanning from the supraorbital foramen to apex. The lateral wall approximately measured about 47 mm from the fronto-zygomatic suture to the apex with a range of 39-55 mm. The floor measured from the infraorbital canal to the apex measures about 48mm with a range of 41-57 mm (Dutton & Waldrop, 2011).

#### The Orbital Rim

This can as well be termed as the orbital entrance. It is the external bony edges of the orbit that give an almost round shape. The rim can be said to have four parts – the superior, medial, inferior and lateral. The superior is the most protruded especially in males and is made up of the frontal bone. It harbors the supra-orbital foramen on its medial side where the supraorbital neurovascular bundle traverses.

Medially, the rim is less prominent and is made up of the maxillary and frontal bones. At the lower part of the medial wall, there is the lacrimal fossa. The inferior rim is made up of the maxillary and zygomatic bones medially and laterally respectively. The infraorbital foramen emerges about 4 – 10 mm from the mid-portion of the medial rim. The lateral wall on the other hand is the thickest and is made up of the zygomatic and frontal bones meeting at the fronto-zygomatic suture. It is important to note that all these bones are buttressed by all the adjacent bones for maximum protection of orbital contents from trauma (Dutton & Waldrop, 2011).

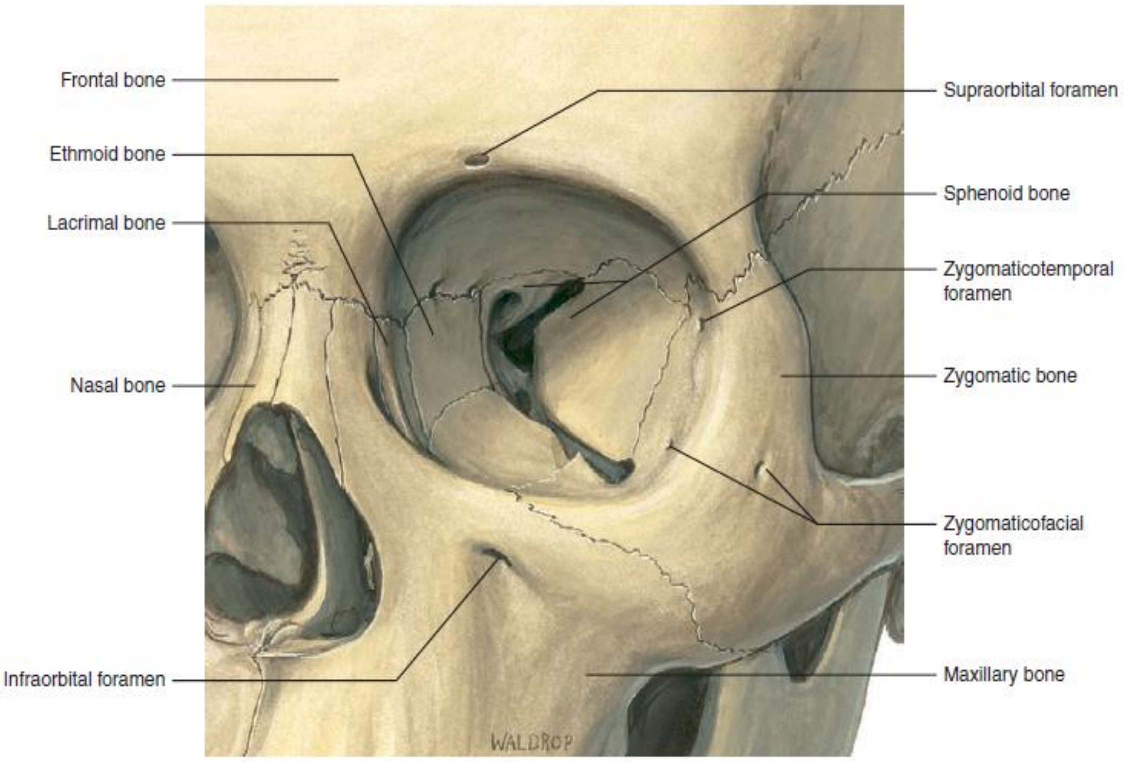



***Figure 7: Bones of the orbit, frontal view of the left orbit showing orbital rim.***

***Adapted from Atlas of Clinical and Surgical Orbital Anato*my (Dutton & Waldrop, 2011)**

**Orbital Floor**

The orbital floor is made up of the zygomatic bone, the palatine orbital process and the maxillary bone orbital process. The main surface area of the orbital floor is contributed by the maxillary bone forming the center. The medial side is bordered by the lacrimal and ethmoid bones. On the lateral side lies the zygomatic bone. The palatine bone lies at the posterior-most aspect of the orbital floor at the apex, usually fused with the maxilla in adults. The floor curves cephalad via the superior orbital fissure past the inferior orbital fissure. Of note is that this wall does not extend up to the orbital apex but rather terminates at the pterygopalatine fossa. It is therefore the shortest floor measuring about 3.5 – 4.0 cm in length. This orbital floor is also evidently the most rugged with the greatest static loading, hence is associated with fractures in orbital trauma (Dutton & Waldrop, 2011). When such fractures do occur, orbital fat and soft tissues can herniate to the maxillary sinus can also occur as a complication (Alinasab *et al*., 2011).

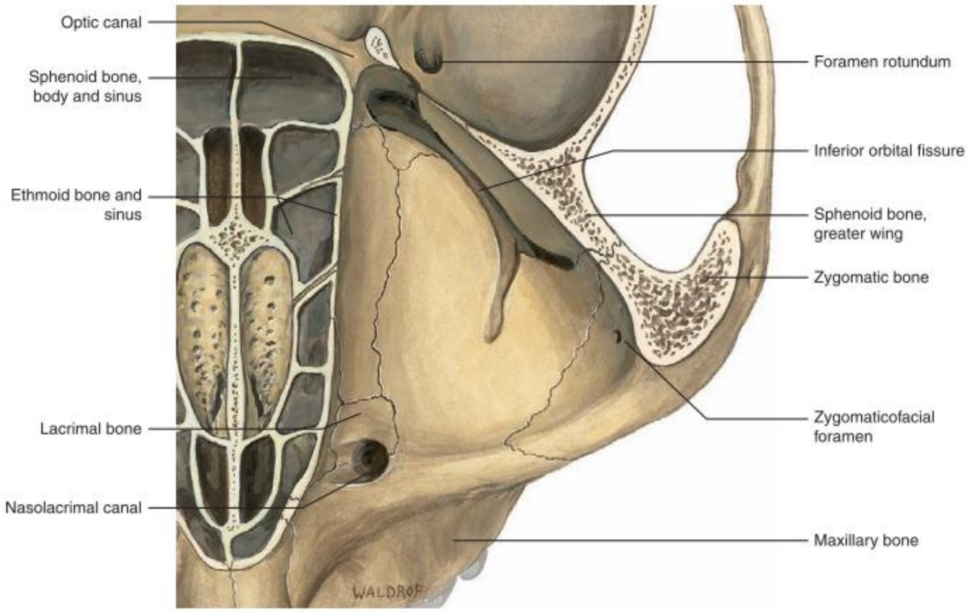



***Figure 8: Orbital Floor bones - Cranial view***
*Adapted from Atlas of Clinical and Surgical Orbital Anatomy (Dutton & Waldrop, 2011)*

## Medial Orbital Wall

The medial orbital wall is made by the sphenoid bone lesser wing, ethmoid bone, lacrimal and the maxilla frontal process. It is almost parallel to the sagittal plane and has a thin wall that borders the orbit and the nasal space as well as ethmoid sinus distally. The measurement between the two medial orbital walls is approximated to be 2.5 cm and is called the inter-orbital distance(Munguti *et al.*, 2013). The wall measures approximately 4.2 cm with a range of 3.2 to 5.3 cm measured between lacrimal crest anteriorly and optic canal posteriorly. It is also the most fragile orbital wall owing to the thin morphology of the bones sometimes termed as membranous or paper thin, also known as lamina papyracea (Dutton & Waldrop, 2011).

On the anterior aspect, the medial wall is made by the thick frontal process of the maxillary bone. On the anteroinferior aspect lies the lacrimal fossa where the lacrimal sac. Posterior to the frontal bone lies the thin, small and fragile lacrimal bone which borders the lacrimal fossa posteriorly. Behind the lacrimal bone lies the ethmoid bone which is also extremely fragile with its walls measuring about 0.3 mm. It is easily fractured in orbital blow out fractures and surgery resulting in orbital emphysema due to communication with the ethmoid paranasal sinus. The frontal bone makes the superior orbital wall harboring both the anterior as well as the posterior ethmoidal foramina. At the apex and posteriorly, it is shaped by the sphenoid lesser wing which also forms the optic canal (Irsch *et al.*, 2009).

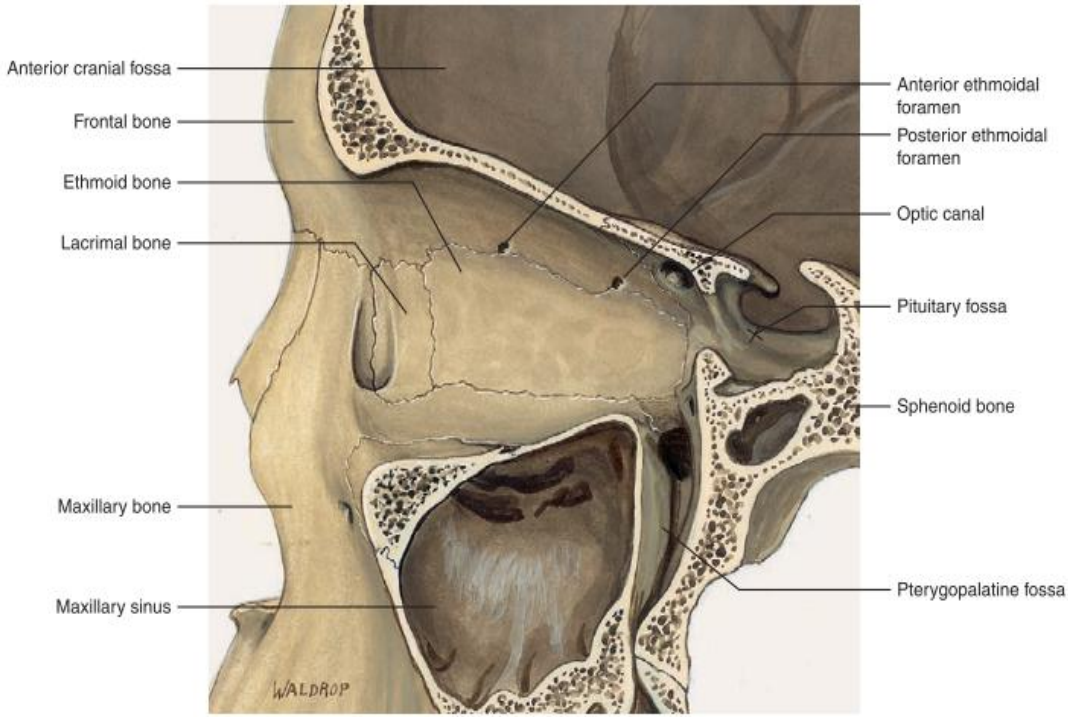



***Figure 9: Medial Orbital Wall - Lateral view***

*Adapted from Atlas of Clinical and Surgical Orbital Anatomy (Dutton & Waldrop, 2011)*

**Orbital Roof**

The roof is triangular in shape and made by the frontal and sphenoid bones. The lateral and major surface area of it is shaped by the frontal bone while the medial and small contribution is made by the sphenoid lesser wing. The lacrimal gland rests on the anterior superior and lateral portion of the orbital roof. This wall is thin and forms a boundary between the orbit and the anterior cranial fossa as well as frontal paranasal sinus. It measures approximately 4.6 cm from the rim to the anterior end of the optic canal (Irsch, 2009; Netter, 2010).

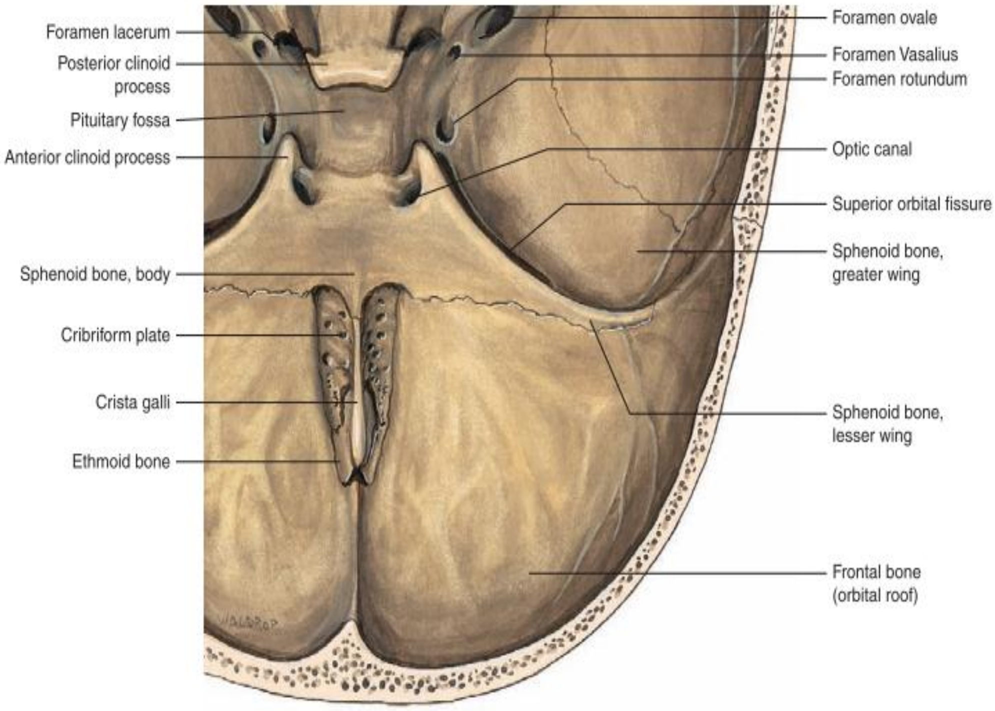



***Figure 10: Orbital Roof***
***Adapted from Atlas of Clinical and Surgical Orbital Anatomy (Dutton & Waldrop, 2011)***

**The Orbital Lateral Wall**

The orbital lateral wall is made by the sphenoid greater wing in the apical aspect, frontal and zygomatic bones anteriorly. The bones are least projected to allow for lateral vision. It is worth noting that this is the thickest orbital wall, probably because of its lateral and subcutaneous relation. Therefore it offers formidable protection to the orbital structures. The two lateral orbital walls make a ninety degree angle when two imaginary lines are drawn along them until they intersect. Its length measures approximately 4.7 cm with a range of 3.9 to 5.5 cm from the rim to the anterior edge of the optic canal. Its junction with the roof contains the superior orbital fissure (Dutton & Waldrop, 2011; Snell, 1998).

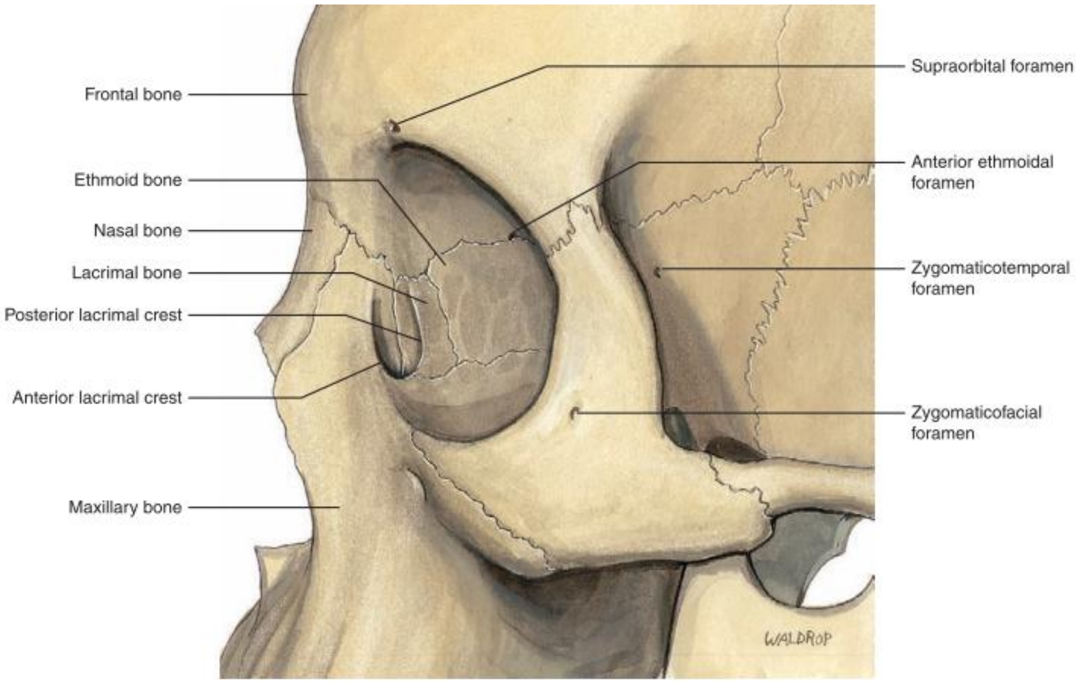



***Figure 11: Orbital lateral wall, lateral view.***

***Adapted from Atlas of Clinical and Surgical Orbital Anatomy (Dutton & Waldrop, 2011)***

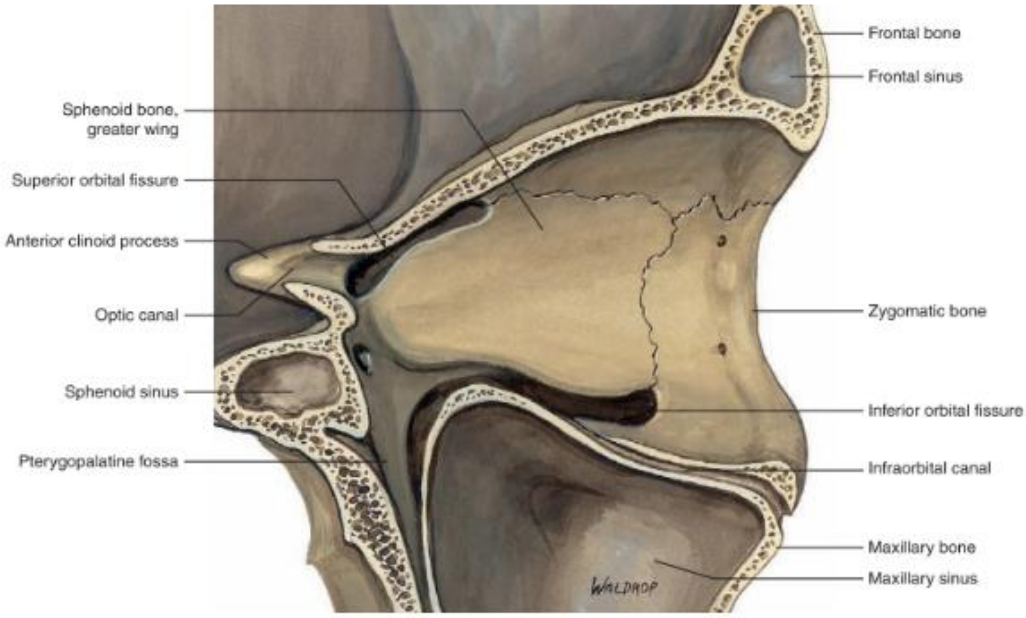



***Figure 12: Orbital lateral wall, medial view***

***Adapted from Atlas of Clinical and Surgical Orbital Anatomy (Dutton & Waldrop, 2011)***

### 2.2.3 Orbital foramina and fissures

#### Inferior Orbital Fissure

This fissure is situated on the orbital floor connecting the orbit to the pterygo-palatine fossa. It is composed of the sphenoid and zygomatic bones laterally and zygomatic bone and maxilla medially. The contents of the canal include the infra-orbital nerve, internal maxillary artery and vein that drains to the pterygoid plexus and sensory division of the maxillary nerve (Dutton & Waldrop, 2011).

#### Superior Orbital Fissure

This fissure is situated at the orbital apex where greater and lesser wings of the sphenoid join the maxilla. It transmits the oculomotor nerve, trochlear nerve, ophthalmic division of Trigeminal nerve and the abducens nerve. In addition, it also conveys the ophthalmic veins (Dutton & Waldrop, 2011; Snell, 1998).

#### Optic Canal

This canal is located medially to superior orbital fissure at the orbital apex. This canal's length measures about 1 cm while its diameter measures about 5mm. The canal traverses the sphenoid bone. It conveys the optic nerve, nerve sheath complex and the ophthalmic artery (Dutton & Waldrop, 2011; Netter, 2010).

#### Nasolacrimal Canal

This canal pierces the inferior, medial orbital wall and houses the nasolacrimal duct which carries tears (Dutton & Waldrop, 2011).

#### Anterior and Posterior Ethmoidal foramina

These two foramina are situated on the medial orbital wall and transmit the anterior and posterior ethmoidal arteries respectively (Dutton & Waldrop, 2011; Irsch *et al*., 2009).

**Cranio-Orbital Foramen**

This foramen is situated on the medial wall of the orbit adjacent to the superior orbital fissure. It transmits the middle meningeal artery which forms an anastomosis with the lacrimal artery (Dutton & Waldrop, 2011).

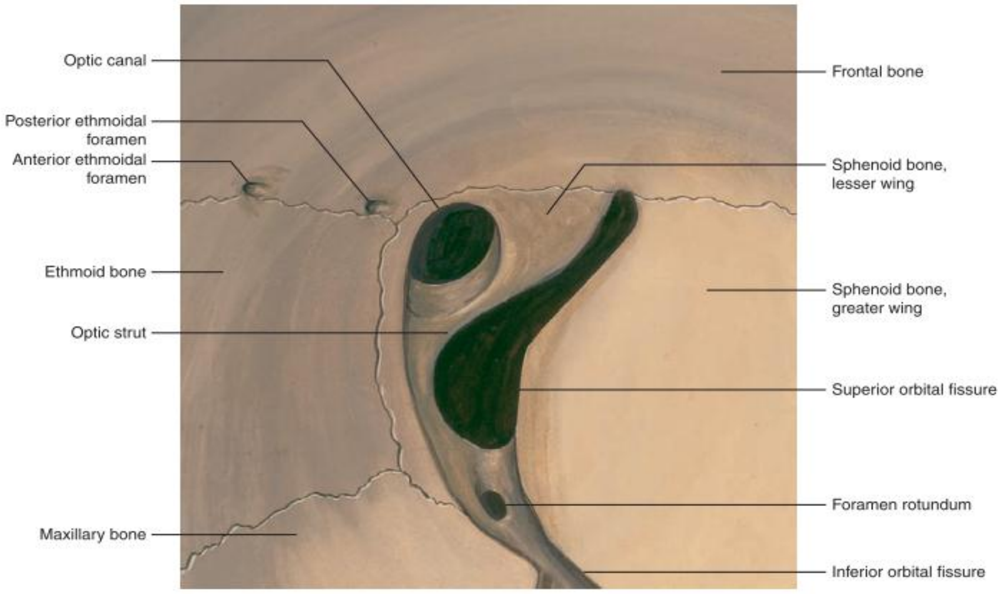



***Figure 13: Orbital fissures and foramina***

*Adapted from Atlas of Clinical and Surgical Orbital Anatomy (Dutton & Waldrop, 2011)*

## 2.3 Orbital Volume

### 2.3.1 Orbital Volume measurements among various ethnicities

The orbital volume measures about 25 $cm^3$ in the general population. CT obtained volumes from various populations however range from 17.05 to 29.30 $cm^3$ (Dutton & Waldrop, 2011). Acer *et al,* (2011) in the study of the orbital volumes at Erciyes University, Kayseri, Turkey found out that the range of orbital volumes is 18.16 to 25.4 $cm^3$. The male orbit was larger with the right orbit having a mean of 22.71 ± 2.8 $cm^3$ while the female right orbit had a mean of 18.47 ± 2.52 $cm^3$. It was a cross-sectional study using a sample of 31 healthy adults, 19 women and 12 men aged between 35 - 45 years. CT images were analyzed by application of the principle of

Cavalieri, a point counting method where a grid is superimposed on axial orbit CT scans and points counted before being subjected to a formula that takes into consideration the slice thickness and number of slices that span the orbit.

The Taiwanese orbital volumes as depicted by Shyu *et al*, (2015) in his cross-sectional study using 3D CT scans yielded a mean orbital volume of 24.3 ± 1.51 $cm^3$ for male right side and 21.1 ± 1.21 $cm^3$ for the female right side. The average volume of the orbit for the left orbit in males was 24.7 ± 1.17 $cm^3$ and 21.1 ± 1.30 $cm^3$ for females depicting that the male orbit is larger compared to females. A sample of 20 Taiwanese adult patients (10 females and 10 males) aged between 16 and 57 years at Chang Gung Memorial Hospital in Taoyan city were done orbital CT scans and then they were analyzed. Their images were constructed into 3D and Osirix software used to estimate the orbital volume.

Bontzos *et al*, (2019) in his study of Effective Orbital Volume at University Hospital of Heraklion, Crete, Greece using MRI images established that the mean orbital volume of the population is 26.81 ± 0.59 $cm^3$ with the volume being significantly larger in males. The cross sectional study selected 54 patients aged between 23 and 82 years who underwent MRI study. Apart from the established measurements, the study also defined effective orbital volume which is termed as the difference between eyeball and orbital volumes. The effective orbital volume was significantly in association with anthropometric measurements such as patient height in both males and females.

Orbital dimensions in the past days could be estimated using direct skull measurements (Kaur, Yadav, & Singh, 2012). This method has been effectively used in the recent past and could yield dimensions of the orbit, orbital depth and index.

These measurements would then be used to estimate orbital volume. In other instances, a moldable model such as silicone could be fitted into the orbits of skulls and then subjected to volumetric analysis (Shyu *et al.*, 2015).This method was however limited to use of cadavers and skulls at the anatomy laboratory and museums (Mekala *et al*., 2015; Munguti *et al*., 2012).

Anibor & Ighodae (2016) in Delta State University, Nigeria used skull x-rays to obtain orbital rim dimensions and orbital index. However the limitation of radiography is the fact that it is 2D and cannot yield the depth measurement. Thus the volume cannot be acquired. The advent and improvement of imaging modalities that can give 3D reconstructed images such as the CT scan and MRI has enabled easy analysis to obtain orbital dimensions and volume(Acer *et al*, 2011).

Khandekar (2016) in his study measuring the bony orbital volume of healthy Saudi Children at King Khalid Eye Specialist Hospital, Saudi Arabia that used 3D assisted semi-automated volume estimation. The sagittal, coronal and axial images are used to obtain the volume required. The orbit edges were marked using green color and the orbit marked with red as region of interest (ROI), the volume of the marked orbit was then obtained automatically using the 3D volume virtual reality tool available at the advantage window. This study retrospectively analyzed CT scans of 374 children aged 15 years and below in Saudi Arabia's King Khalid Eye Specialist Hospital. The volume of Saudi children was established as 19.1 $mm^3$ with 95% confidence interval. Software obtained volume can be obtained by tracing orbital contours and afterwards reconstructing them into 3D images. From these images, volume can be automatically obtained. This was done by Ahmed *et al*, (2019) in his study that evaluated orbital volume post orbital fracture restoration. It was a prospective census study of 20 patients with fracture orbit treated by surgery at the Plastic and Reconstructive surgery department in Al-Azhar University Hospital between October 2018 and October 2019.

Du *et al*, (2019) in a CT based study investigating measurements of orbital volume of Chinese adults aged 18- 81 years at Guangxi Medical University established the average volume of the orbit as 22 ± 2.2 $cm^3$ for males and 20 ± 1.5 $cm^3$ for females. The cross-sectional retrospective study selected patients with normal ophthalmic examinations and no orbital diseases or systemic diseases that can affect the size of orbital soft tissues such as thyroid disease, hypertension and diabetes. The CT scans were analyzed using Mimics 3D reconstruction software to trace the orbit and acquire the volume. The study also in detail measured orbital fat, intraorbital optic nerve and extraocular muscles volume. All the latter volumes measured including bony orbital volume were all significantly lower in females compared to males. The volumes also showed correlation with body mass index except the intraorbital nerve volume.

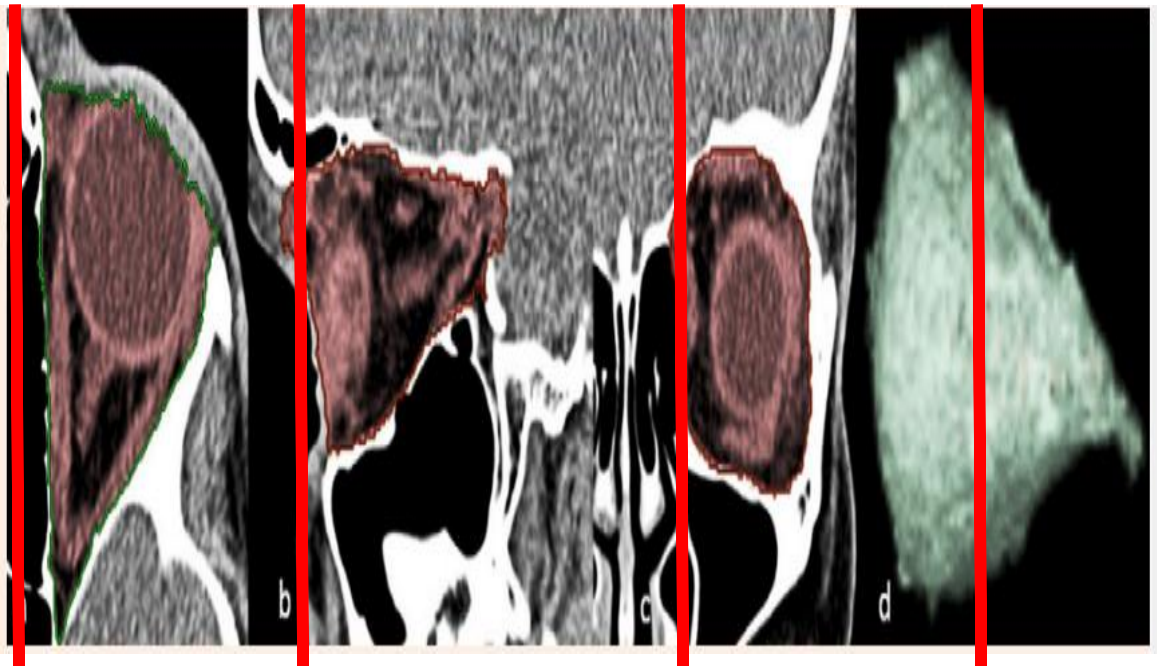



***Figure 14: 3D semi-automated volumetric methodology***
***a) Axial view b) Sagittal view c) Coronal sections d) Extracted orbit model***

*Adapted from Khandekar, (2016):Orbital volume measurement of Saudi Children using CT scan.*

### 2.3.2 Methodology of Orbital Volume Measurement

Over the course of time, researchers have come up with many methods of estimating orbital volume. In the nineteenth century, anatomists and anthropologists tried to estimate the orbital volume using several methods. In 1873, a French researcher named Gayat attempted to establish orbital volumes by filling them with tiny pellets made of lead then afterwards pouring them to a calibrated volumetric cylinder. This is perhaps the first documentation of the orbital volume ever done. He established the average of the 11 orbits of skulls he studied as 29 $cm^3$. Other researchers have also applied a similar methodology of orbital filling using dry sand, seeds and even water after sealing all the foramina using plasticine. The content was then poured to an empty calibrated flask for estimation as mentioned above (Sentucq *et al*., 2020).

Sarnat (1970) used elastic polymer casts to fill the orbits of rabbits and afterwards subjected the casts to volume calculation. This is considered the gold standard of determining orbital volume in skulls as it applies the Archimedean principle of volume determination. It states that the volume of water displaced by an immersed solid matter is equal to its volume. This is however possible only in skulls and cadavers and not in vivo. Advent of medical imaging modalities has made it possible to establish volumes of orbits among the living. The first imaging modality invented was the X-ray and it played the initial role in calculation of orbital volume. The first attempt of calculation of orbital volume was done in the 1960's .This was however inaccurate as it applied mathematical formulae of pyramid volume calculation as opposed to the irregular actual shape of the orbit with curvilinear shaped irregular walls (Sentucq *et al*., 2020).

The process of orbital volume determination became easier with the advent of Computed Tomography (CT) in 1972, it became possible to calculate volumes of irregular surfaced objects. Cooper (1985) is the first study that attempted to use CT to obtain orbital volume. It found out that there was a small discrepancy of CT obtained volumes and direct displacement methods on skulls of about 0.2 to 4%. Forbes *et al.*, (1985) went further and established the volume of orbital contents using pixel summation method. His method had a 7 -8 % discrepancy compared to displacement methods. With the arrival of computer software that enabled manipulation of images, it has been possible to calculate orbital volumes quite easily particularly with growing interest from maxillofacial surgeons, ophthalmologists and implant manufacturers (Sentucq *et al*., 2020).

Orbital volume is important in several clinical applications. It is used in current practice of craniofacial surgery to determine patient specific measurements which can be used for pre-surgical orbital reconstruction and manufacture of implants. It is important in predicting post-traumatic surgical enophthalmos where orbital volume plays a key role in its occurrence in conjunction with other factors such as orbital soft tissue loss and fat necrosis. Current imaging modalities that allow for 3D reconstruction of the orbit have made it easy to obtain orbital volumes. Several automatic and semiautomatic computer software are available for use. These softwares include Mimics, Osirix MD, iPlan, Analyze, Maxillo among others that are currently available in CT reporting softwares. They have been validated and shown to have acceptable intraobserver and interobserver variability (Jansen *et al*., 2016).

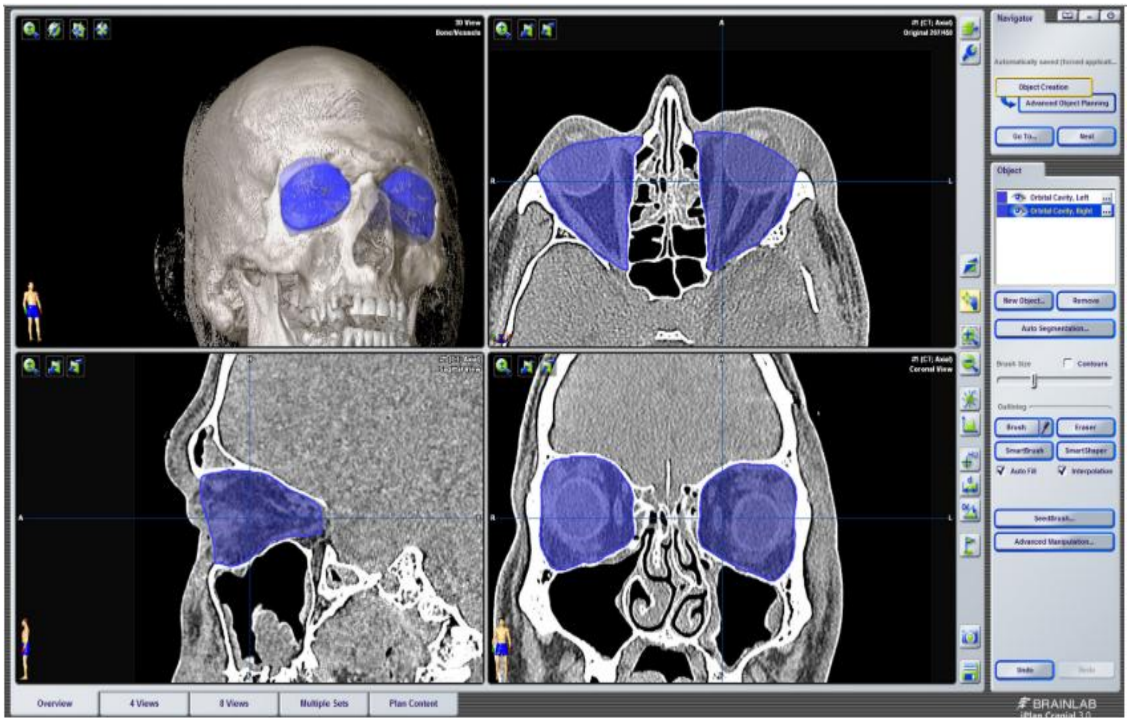



***Figure 15: Orbital wall margin tracing to determine volume***

*Adapted from Jansen et al., (2016)*

### 2.3.3 Orbital Dimensions

The orbital dimensions are important in many clinical applications and forensic medicine. The measurements are applied to determine gender in forensic examination of skulls particularly the orbital index. The orbital depth is also important in surgical procedures of the face and cranium (Munguti *et al.*, 2012, 2013). The depth of the orbit was determined by measuring the depths of the superior and inferior wall lengths with a Vernier caliper on crania at the National Museum of Kenya, Nairobi. The distance of the superior orbital wall was 5.4 cm for males and 5.2 cm for females. The distance of the inferior orbital wall was 5.5 cm for males and 5.4 cm for females. These were the depths recommended for safe surgery of the orbit (Munguti *et al.*, 2012).

Another study by Munguti *et al,* (2013) at the University of Nairobi, Kenya assessing measurements of 150 skulls at the National Museum of Kenya. The dimensions defined include the orbital height and breadth which when divided with each other yield orbital index. Orbital index is defined as the orbital height divided by orbital breadth. It is expressed as a percentage. Microseme or small index category is a percentage of 83 and less and is commonly associated with the black. Mesoseme or intermediate index orbit is a range of 83 – 89 and is associated with the European race. Megaseme or large index orbit is a percentage of 89 or above associated with yellow colored races. The Kenyan orbit was defined as mesoseme with average orbital indices of 83 for males and 84 for females.

Mekala *et al,* (2015) in a study measuring 200 skulls in Coimbatore Medical College, South India buttressed the vitality of reference orbital measurements for each population to maxillofacial surgeons, ophthalmologists and forensic experts. As such there is a need to establish orbital measurements. The Indian orbit was classified as microseme for both males and females with mean orbital indexes of 84.82 % and 85.22 % for the left and right orbits respectively. The average orbital height was 3.54 cm while the breadth was 4.18 cm.

An improvement to the above cadaveric studies have been done using imaging modalities such as X-rays and CT scans.  Anibor & Ighodae (2016) escalated the study in Delta State University, Abraka, Nigeria by obtaining orbital entrance height and breadth using orbital rays in patients with ages of 18 to 63 years. Average orbital height was 31.11 ± 0.56 cm on the right and 31.02 ± 0.29 cm on the left while the orbital widths measured 39.97 ± 0.37 cm and 39.61 ± 0.3 cm for right and left orbits respectively. The population's average index of the orbit fell within the microseme category. This modality has a limitation of being two dimensional hence the depth of the orbit cannot be assessed.

Khademi & Bhayat (2016), at Arak University of Medical Sciences, Iran further improved the study of orbital measurements by using CT scan to analyze measurements of the orbit. 120 patients with an age of 9 – 22 years were assessed and three measurements obtained, the orbital width, height and depth. The orbital width was defined as the length between anterior lacrimal crest medially and anterior edge of the zygomatic bone laterally culminating a mean of 2.85 ± 0.25 cm. The orbital height was termed as the length between the midpoints of orbital roof and floor giving a mean of 3.2 ± 0.16 cm. The depth on the other hand was defined as the distance linking the orbital rim plane and anterior edge of the optic canal. Mean depth obtained was 3.89 ± 0.4 cm.

## 2.4 The Eyeball

### 2.4.1 Anatomy of the Eyeball

The eyeball is defined as a globular structure embedded inside the orbital socket and connected to the brain by the optic nerve. It is the structure that is responsible for the process of vision. It has an external covering that comprises three layers - outer fibrous, middle vascular and inner pigmented and nervous layer. The outer fibrous forms the sclera and cornea, the middle vascular is the uveal tissues that encompass the choroid, iris and ciliary body while the inner pigmented and nervous layer contains the retina (Samar, 2019; Snell, 1998).

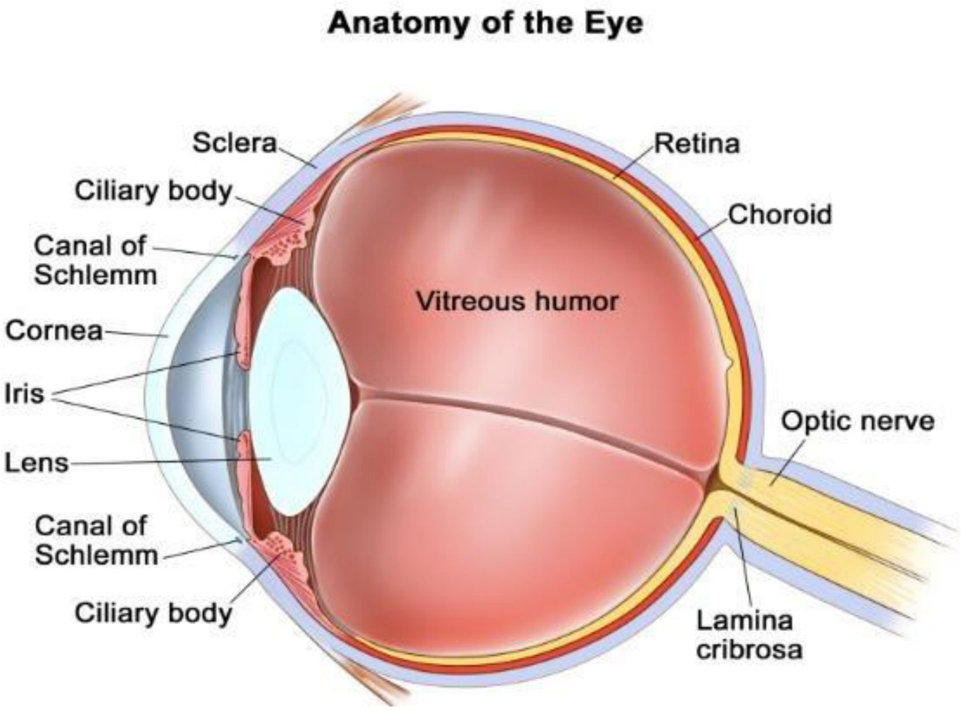



***Figure 16: Eyeball coronal view showing different structures***

***Adapted from Atlas of human Anatomy, 5th Edition (Netter, 2010)***

**The Sclera**

It is the fibrous external coat around the eyeball. With its density and strength, it serves to protect the eyeball contents from desiccation and physical damage. The anterior part is transparent accounting for about 1/6th of the circumference while the posterior aspect which accounts for 5/6th is opaque. Where the two parts of the sclera join is called the limbus (Snell, 1998).

**Cornea**

This is the external-most and transparent covering of the globe that plays a key role in refraction of light into the lens. It is made up of five layers – epithelium, Bowman's, stroma, Descemet's membrane and the endothelium (Samar, 2019).

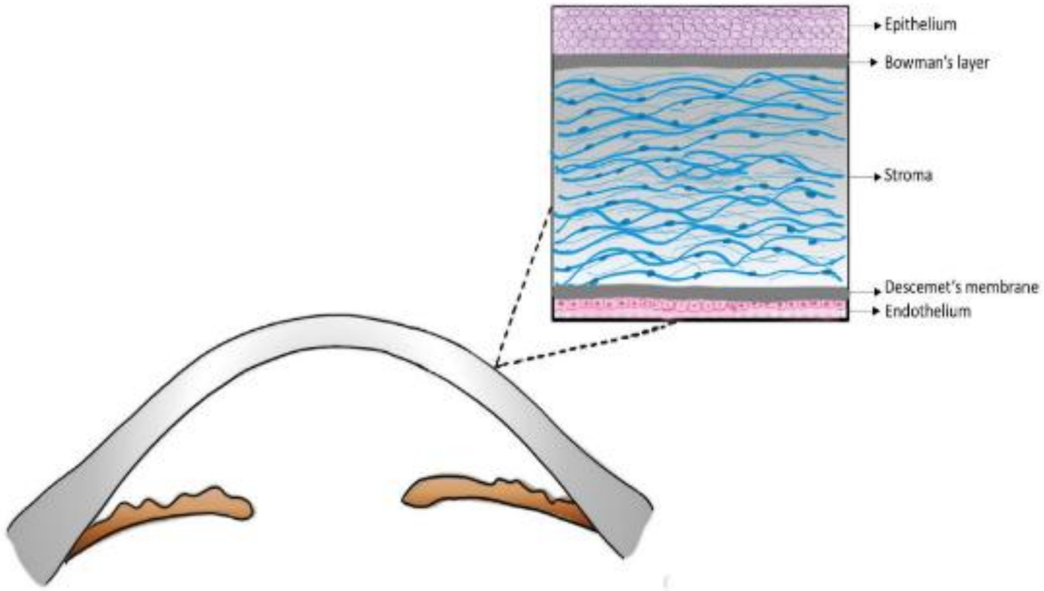



***Figure 17: Cross-section of cornea showing its five layers***

***Adapted from Essentials of Ophthalmology, 7th Edition (Samar, 2019)***

The cornea is avascular, has no lymphatic drainage but enjoys rich nerve supply from the trigeminal nerve, ophthalmic division (Zhang, 2020).

**The Uveal tissue**

The purpose of this layer is to provide nutrition to the various eye structures. It encompasses the iris anteriorly, ciliary body and far posteriorly the choroid. The iris gives the color of the eye depending on the amount of melanin. It helps control the quantity of light rays entering the eye. The ciliary body plays the function of producing aqueous humor and helps in accommodation. The choroid on the other end supplies nutrients and oxygen to the retina outer layers (Samar, 2019).

**Retina**

This is the most posterior layer of the globe coat. It extends anteriorly from the ora serrata to the optic disc on the posterior aspect. An imaginary equator circular line at the exit of vortex veins divided it into the peripheral retina and posterior pole.

The optic disc is a circular area where nerve fibers coalesce and form the optic nerve. The optic cup is a depression seen within the disc that is considered physiological and is where the central retinal artery and vein pass through.

The Ora serrata makes up the anterior margin of the retina which adheres firmly to the vitreous and choroid.

The Macula lutea is located at the posterior pole lateral to the optic disc. It harbors the fovea centralis, foveolar and the foveal avascular zone (Samar, 2019).

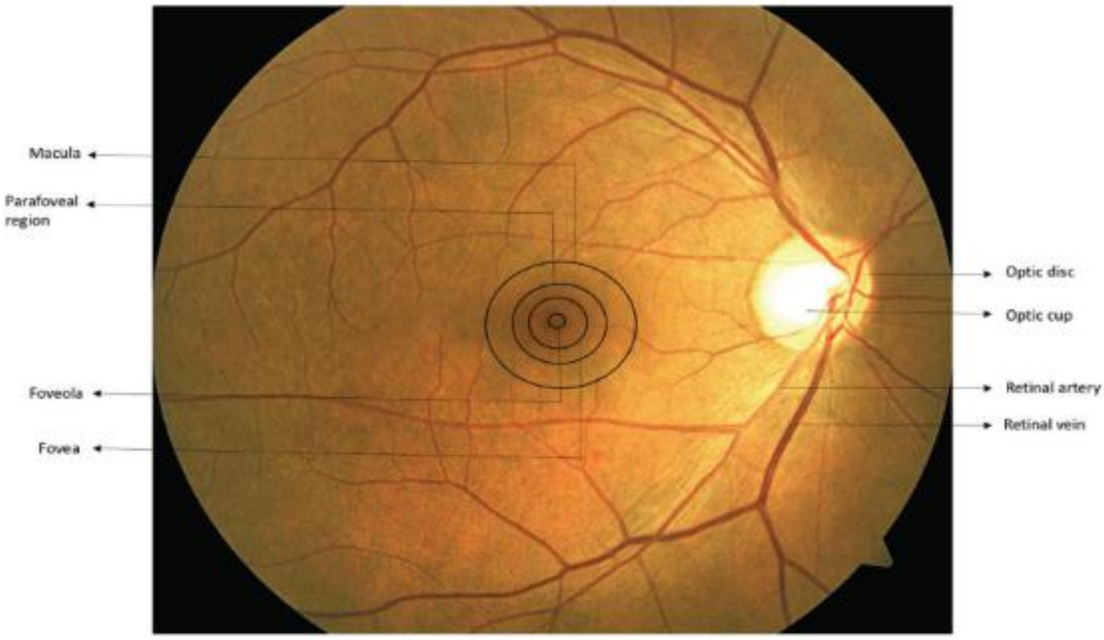



***Figure 18: Fundus posterior pole showing landmarks.***

***Adapted from Essentials of Ophthalmology, 7<sup>th</sup> Edition (Samar, 2019)***

The retina histologically is composed of 10 layers: the internal limiting membrane, nerve fiber layer, ganglion cell layer, inner plexiform layer, inner nuclear layer, outer plexiform layer, outer nuclear, external limiting membrane, photoreceptor later and retinal pigment epithelium. It receives blood supply from the central retinal artery, which branches off from the ophthalmic artery. The central retinal artery divides into four branches – superonasal, superotemporal, inferonasal and inferotemporal. Retinal veins follow the pattern of arteries and drain into the superior ophthalmic vein or directly to the cavernous sinus. Inner six layers are nourished by the central retinal artery while the outer four layers are supplied by the choroidal vessels (Irsch *et al*., 2009; Samar, 2019).

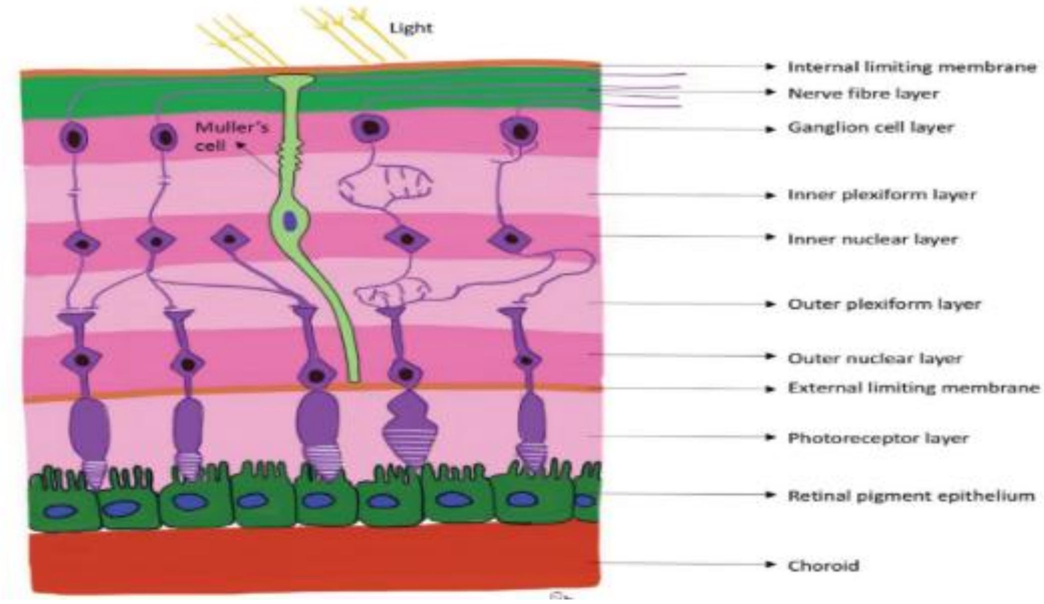



***Figure 19: Layers of the retina.***

***Adapted from Essentials of Ophthalmology, 7th Edition (Samar, 2019)***

**Chambers and Segments of the Eyeball**

The eyeball is subdivided into anterior and posterior segments by the lens. Anterior to the lens is the anterior segment occupied by the aqueous humor while posterior to the lens is the posterior segment occupied by the vitreous humor. Both of these segments help in refraction and absorption of light (Dutton & Waldrop, 2011).

The anterior segment is further subdivided into anterior and posterior chambers. The boundary of the anterior chamber ventrally is the cornea and sclera while the dorsal boundary is the ciliary body and iris (Dutton & Waldrop, 2011).

The posterior chamber is located dorsal to the anterior boundary of the anterior chamber and is bounded dorsally by the anterior surface of the lens (Netter, 2010).

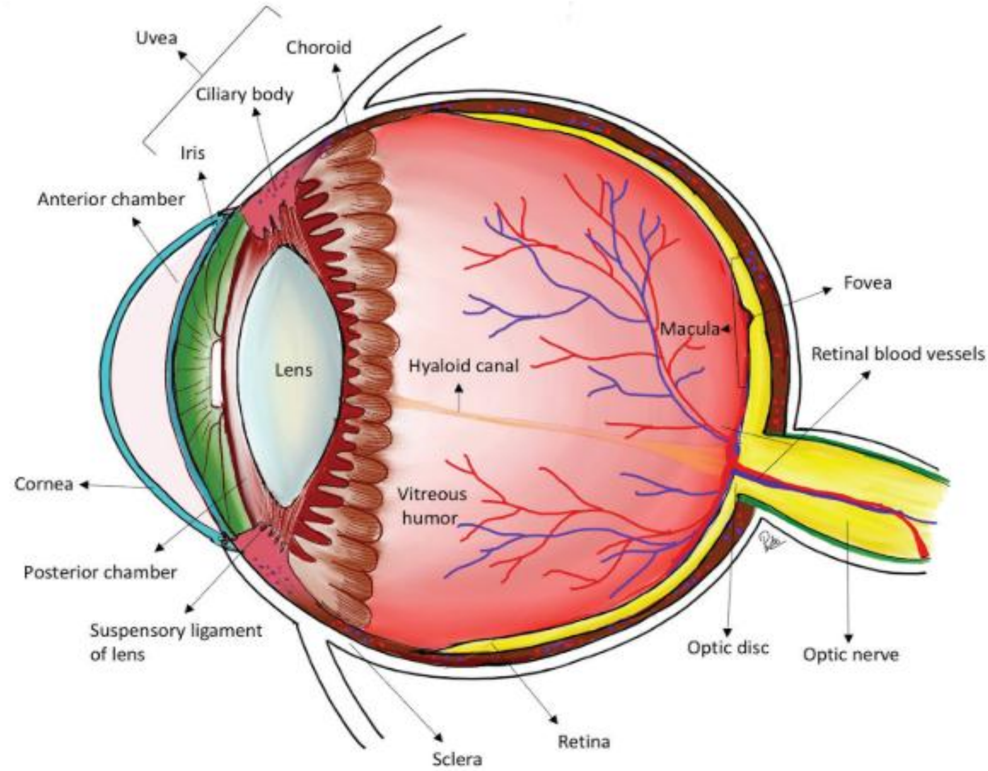



***Figure 20: Chambers of the eye and components.***

***Adapted from Essentials of Ophthalmology, 7th Edition (Samar, 2019)***

## 2.5 The Eyeball Volume

### 2.5.1 The Eyeball Volume Measurements among various ethnicities

The eyeball takes about 7.2 $cm^3$ of the orbital volume and has an average diameter of 24 mm. An eyeball of a patient with myopia will be larger as compared to one with hyperopia (Dutton & Waldrop, 2011). Variance among the different ethnicities has been noted in several studies and as such, measurements for every population should be established (Ibinaiye *et al*, 2014).

Igbinedion & Ogbeide (2013) did a measurement study of ocular volume using CT scan in Edo state, Nigeria. The study established that the average volume of the eyeball for both eyes was $5.23 \pm 1.8$ $cm^3$. It was a retrospective study that aimed to provide a reference for the African population. 200 consecutive patients with established normal vision who had undertaken CT scanning of the orbit were selected. The dimensions of the orbit, anteroposterior diameter and transverse diameters were averaged and used to calculate the volume. It was assumed that the orbit is a sphere and thus the formulae of calculating the volume of a sphere was used.

Ibinaiye *et al* (2014) did a study estimating the eyeball volume using MRI in Zaria, Nigeria. A cross section study of 100 patients aged 1 month to 77 years consecutively sampled at the hospital’s MRI department was done. To obtain the eye volume, it was assumed to be a sphere and calculations were undertaken using the formulae of a sphere. The mean eye volume of the male measured $6.86 \pm 0.98$ $cm^3$ and $6.97 \pm 0.86$ $cm^3$ on the right and left respectively while that of the females measured $6.75 \pm 1.01$ $cm^3$ and $6.74 \pm 0.95$ $cm^3$ on the right and left respectively. The volume was larger in males compared to females but not significant statistically. The volume was established to increase gradually with age until the age of 40 years where a decline was noted for both genders.

Acer *et al,* (2011) did a combined study to establish eyeball and orbital volumes of Turkish patients aged between 35 and 45 years using the point counting method of CT analysis. It established that the eyeball volume of the Turkish population was 7.45 ± 1.19 $cm^3$ for males and 7.32 ± 0.74 $cm^3$ for females. The methodology applied was termed as quick and efficient for assessing orbit and eyeball volumes. Özer *et al,* (2016) also conducted a study in Istanbul, Turkey to establish measurements namely the diameter and length of optic nerve, orbital rim dimensions (height and width), eyeball axial length and volume in relation to age and gender that were aimed at giving reference values for clinical and surgical importance. CT orbits of 198 individuals with age range of 5 – 74 years were analyzed using Osirix software that automatically yielded the eyeball volume measurements. The eyeball volume of the male right orbit was 6.6 ± 0.8 $cm^3$ while that of the female right orbit was 6.38 ± 0.79 $cm^3$ with no statistical difference being noted between genders and laterality.

Heymsfield *et al,* (2016) scaled up the research of the eyeball at Pennington Biomedical Research Center, Los Angeles, USA by relating it with body weight, height, Body Mass Index (BMI) and brain mass. The study enrolled 80 subjects entailing 44 women from various races – Caucasian, African American and others. It used MRI to analyze and obtain orbital volumes. The average volume of the orbit was 6.35 ± 0.69 $cm^3$ in men and 6.26 ± 0.53 $cm^3$ in women. There was no correlation of ocular volume with genders, weight or any component organ such as the brain. The study recommended further studies on different races and ages to explore the differences.

Bontzos *et al,* (2019) at Heraklion University Hospital in Greece obtained eyeball volume of 54 Caucasian origin while aiming to obtain the effective orbital volumes. Effective orbital volume was defined as the difference obtained when orbital and eyeball volumes were subtracted from each other. The obtained difference had an association with axial length of the eye. The eyeball volume obtained using 3D MRI was approximately 7.83 ± 2.27 $cm^3$. The obtained results were termed as important in orbital surgery, be it in trauma or decompression in cases of Grave's orbital disease.

Surekha *et al,* (2020) in a recent study in Kuppam, India also assessed the normal ocular volume by use of MRI. The study applied a prospective cohort design that sampled 425 subjects, 233 males and 1992 females with an age range of 2 months to 88 years. The volume of the eyeball was obtained using the mathematical formulae of a sphere using the diameter as the average of the two axial diameters – anteroposterior and transverse. The obtained mean ocular volume was 6.06 $cm^3$ for the male right eye and 5.83 $cm^3$ for the female right eye with no statistical difference noted with laterality. The study noted that the male eyeball was slightly larger compared to females.

### 2.5.2 Methodology of measuring the eyeball volume

The eyeball takes a spherical shape which has made calculation of its volume quite easy for earlier studies. The mathematical formulae of calculating volume of a sphere is used.

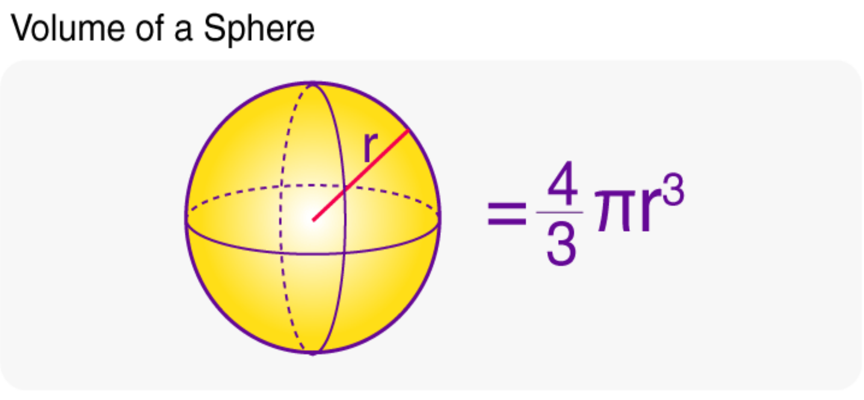



***Figure 21: Formula for calculating volume of a sphere***

*Adapted from Byju's mathematical formulae.*

Where: *r* is the radius.

Л is 3.142

This is the method that has been widely applied by many studies investigating the volume of the eyeball. The diameters of the eyeball are measured and averaged to give the diameter then further divided by two to give the radius. Igbinedion & Ibinaye (2014) applied this formula while calculating volumes of eyeballs of Nigerians in Edo state using CT scans. The anteroposterior diameter and transverse diameter were averaged to give the diameter and further divided by two to give the radius as follows:

Eyeball Volume = [(Anteroposterior diameter +Transverse Diameter/2)/2]$^3$× (4/3Л)

The same formula has also been applied by Ogbeide, (2007) in Nigeria while using ultrasound to establish ocular volumes, Ibinaye *et al.,* (2014) and Surekha *et al.,* (2020) using Magnetic Resonance Imaging.

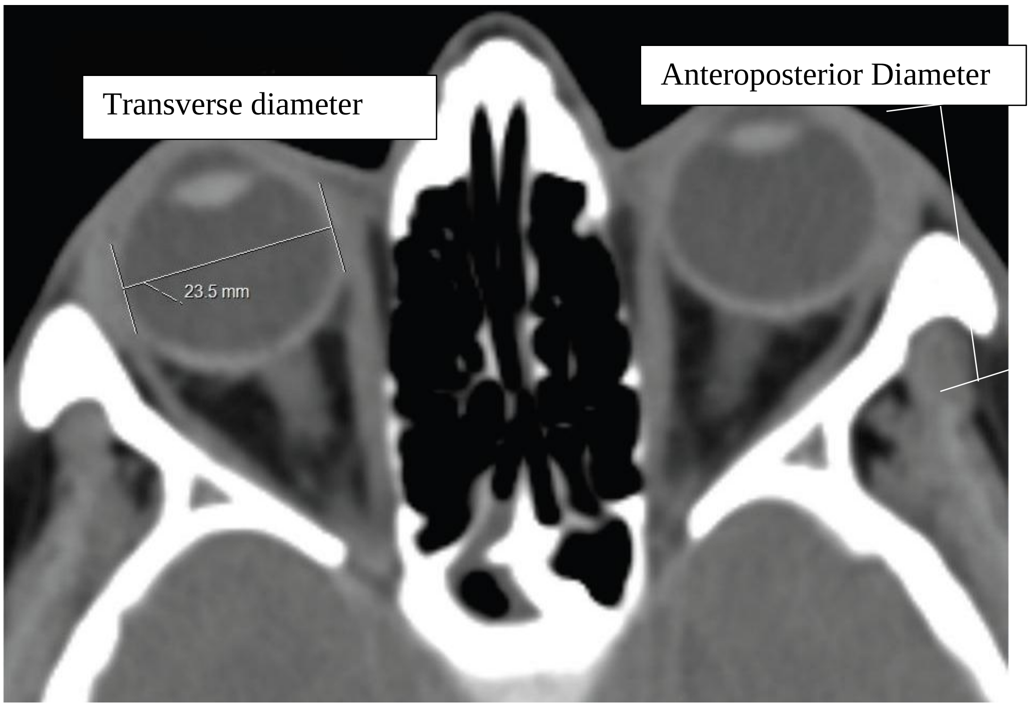



***Figure 22: Transverse orbital CT scan showing axial and transverse diameters of the eyeball.***

***Adapted from Igbinedion & Ogbeide (2013)***

The shortcoming of this methodology however arises from the fact that it assumes uniformity of the radius in the entire globe. Studies on diameters of the eyeball have shown that it is not a perfect sphere and that one diameter is usually larger than the other (Bekerman *et al,* 2011). This begs for a more accurate methodology that takes to account the above error. Heymsfield *et al.*, (2016) used a computer software named AnalyzeTM to establish the volume of eyeballs. The image was scrolled first to the widest portion of the lens and then four images above and four images below were subjected to grid stereology technique. This automatically yielded the eyeball volume. The same technique was applied by Acer *et al.,* (2016) using Osirix software where the margins of the eyeball were drawn in all slices then subjected to the volume rendering program option. The technique yielded the eyeball volume automatically with acceptable intra-observer and inter-observer precision. This is the current applicable method used in determination of volume owing to its accuracy and ease of performing it (Acer et al., 2011).

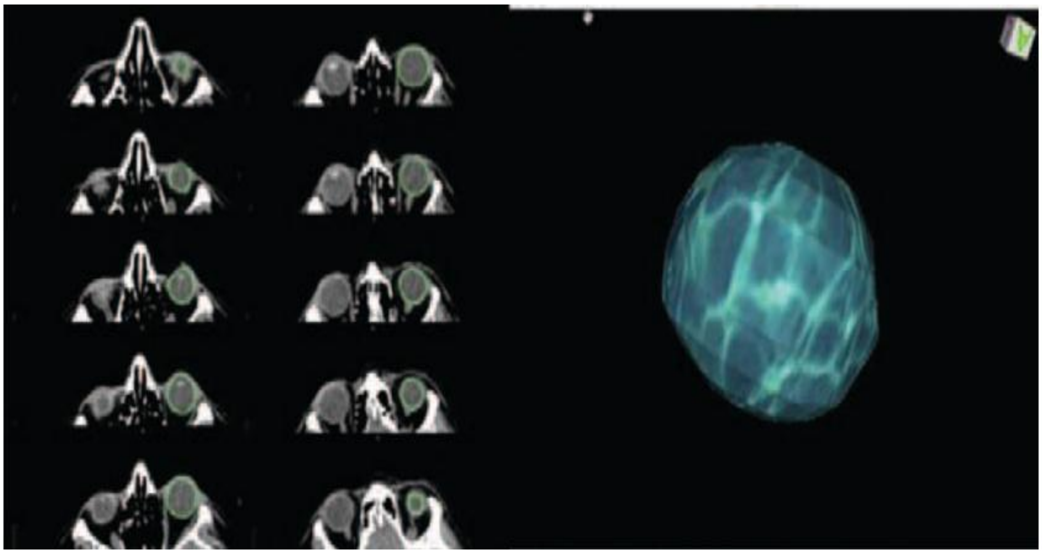


***Figure 23: Eyeball volume determination.***
***A shows tracing of eyeball margins, B shows the extracted eyeball model.***

*Adapted from Acer et al., (2011)*

### 2.5.3 Eyeball Dimensions

The eyeball given its spherical shape has three diameters: the anteroposterior axial, sagittal and transverse diameters (Bontzos *et al*., 2019). All the diameters are estimated accurately from the outermost to the opposite outermost layers of the eyeball. This was defined to be from the sclera to sclera or from cornea to the sclera (Bekerman *et al*., 2014). Igbinedion and Ogbeide (2013) established normal ocular volume that could be used as a reference for Africans by using reconstructed CT scans.

Ultrasound obtained eyeball measurements for the Nigerian population was found to have a mean diameter of 2.17 ± 0.2 cm. This is according to a study by Ogbeide (2007) which aimed at establishing the perceived normal eyeball volumes and diameters of the African population. It was a cross sectional study with a sample of 198 healthy patients in Nigeria. The study also aimed to establish how the findings correlated with gender and age as well as to compare them with other documented measurements around the world.

Bekerman *et al,* (2011) measurements of the eyeball were 2.42 cm, 2.37 cm and 2.2 cm to 2.5 cm in transverse/side to side, sagittal/vertical and axial/ anteroposterior respectively. This was a prospective cohort study that analyzed CT scans of 250 adults with ages of 18 - 93 years whose eyes were examined and termed healthy at Assaf Harofeh Medical Center, Tel Aviv University, Zerifin, Israel. It found that there was no correlation between the size of the eyeball and both age and gender of subjects. The axial diameter was noted to change with myopia and hypermetropia.

Ozer *et al,* (2016) in the Turkish based study evaluating several ophthalmic dimensions including optic nerve, orbital rim and eyeball. The axial length was the measurement that was mainly assessed and its mean established as 2.29 ± 0.11 cm and 2.28 ± 0.6 cm for the right and left respectively. Bontzos *et al,* (2019) conducted in Greece established the axial diameter as 2.69 ± 0.45 cm. Surekha *et al,* (2020) in his study of the Indian eyeball also measured the dimensions of the eyeball although he laid emphasis on the transverse and axial lengths, they measured 2.28 ± 0.11 cm and 2.24 ± 0.09 cm respectively. In all these studies there was no correlation of the size of orbit with age, gender and laterality.

### 2.6 Orbital and Eyeball Volume variance with various Population Parameters of age, gender and ethnicity.

The dimensions of the orbit and eyeball vary with age, gender and ethnicity. The orbit widens as age increases until a certain age where there is no increase. This is synonymous with the ocular volume which also increases with age up to a certain age after which it regresses in volume. The age given by many studies when the eyeball volume starts to regress in 40 years for both genders (Igbinedion & Ogbeide, 2013; Weaver *et al*., 2010).

#### 2.6.1 Orbital volume variance with gender

Orbital volume varies with gender. Many studies that have been done depict that the male orbit is larger than the female. The pattern of growth particularly during the adolescent period also differs. The male orbit rapidly grows achieving the adult size earlier as compared to the female orbit (Khandekar, 2016).

Shyu *et al,* (2015) on his cross- sectional study of 20 Taiwanese 3D CT scans found out that the mean orbital volume for males was larger compared to females. The mean orbital volume for left and right orbits was 24.3 ± 1.51 $cm^3$ and 24.7 ± 1.17 $cm^3$ in males and 21.0 ± 1.21 $cm^3$ and 21.1 ± 1.30 $cm^3$ in female subjects. The same finding was realized by Du *et al*, (2019) and Bontzos *et al*, (2019) who found out that the male orbit was significantly larger compared to female.

Mekala *et al,* (2015) in his skull geometric morphometric study on 200 skulls in South India found out that the orbital dimensions were larger in males than females. The orbital height ranged at 3.3-4.2 cm in males and 3.0-3.9 cm in females. The orbital breadth ranged at 3.7-4.9 cm in males and 3.5-5 cm in females. Singh *et al*, (2017) in a retrospective survey study on 60 orbital CT scans for 30 adult patients found out that males have significantly larger orbits compared to females. The aim of the study was to evaluate and compare depth and distances from various points of the orbital rim to the fissures and foramina of the orbital apex between genders of the local Malaysian population.

Khandekar (2016) in his study intended to measure the orbital volume with CT in healthy eyes in Saudi children found out that the orbital volume increased with age with it being larger in males as compared to females. It also found out that the growth spurt of the orbit varied with gender. The size of the orbit reached 95 % of adult size by 13 years in males and 17 years in females.

Acer *et al,* (2011) in a cross-sectional study using 31 Turkish subjects estimating the orbital and eyeball volumes using the Cavalieri principle noted that the average orbital volume was larger in males compared to females. The average orbital volume for the right orbit for females was $18.47 \pm 2.52$ $cm^3$ while that of males was $22.35 \pm 3.05$ $cm^3$. That of the left orbit was $18.16 \pm 2.52$ $cm^3$ for females and $22.71 \pm 2.80$ $cm^3$ for males.

**2.6.2 Orbital volume variance with Age**

The size of the orbit varies with age. It has also been demonstrated that the orbit achieves almost 95% of its maximum size by the age of 20 years. It then gradually grows achieving its maximum size at the age of about 40 years The female orbit however starts to decrease in volume after the age of 60 years while the male orbital volume is maintained (Furuta, 2000).

Ugradar & Lambros (2019) compared the size of orbit of patients in their $7^{th}$ decade and $2^{nd}$ decade and depicted that the orbital volume of those in the $7^{th}$ decade was larger than those in the $2^{nd}$ decade confirming another fact that the orbit grows throughout adulthood. This showed that the orbit does not cease to grow in early adulthood but likely at middle age of between 30 and 50 years.

Futura (2006) elicited the fact that orbital volume increased rapidly up to 15 years in males and 11 years in females achieving its 95 %. Smith *et al*., (2022) established that the orbit increased by 2 % annually after the $2^{nd}$ year of life up to eighteen years and this was also synonymous with findings of Chen *et al,* (2006) in China who found out that the volume of orbit increased rapidly in childhood up to the $20^{th}$ year after which it grew gradually up to 40 years after which it regresses in volume. The same happens with other components of the orbit including the eyeball, orbital fat, muscles and the lacrimal gland (Yoo *et al.,* 2013).

The size and volume of the orbit was shown to change with aging (Kahn & Shaw, 2008). This was a study that aimed to explain how the bony orbit contributes towards the aging process of the face. There was noted increase in dimensions in early adulthood with orbital aperture measurements showing different patterns of growth leading to recession of the orbital rim. These changes were noted to be more significant in females particularly in towards old age of more than 60 years. These bony changes were coupled with intra-orbital and extra-orbital soft tissue changes which in totality account for facial aesthetic changes that come with aging.

### 2.6.3 Eyeball volume variance with gender

The dimensions of the eyeball vary with gender. Acer *et al*, (2011) in a cross-sectional study using 31 Turkish subjects estimating the orbital and eyeball volumes using the Cavalieri principle noted that there was no significant volume difference in the ocular volume for the two genders. The ocular volume of the right side in females had a mean of 7.45 ± 1.19 $cm^3$ while that of males was 7.32 ± 0.74 $cm^3$. The average ocular volume of the left side was 7.45 ± 1.25 $cm^3$ for females and 7.61 ± 1.04 $cm^3$ for males.

Igbinedion and Ogbeide (2013) in their study aiming to measure the normal ocular volume using CT scan established that the mean ocular volume of males was slightly larger than that of females. The average male eyeball measured 5.33 $cm^3$ on the right and 5.22 $cm^3$ on the left. The average female eyeball volume on the other hand measured 5.33 $cm^3$ and 5.24 $cm^3$ for the right and left eyeball respectively. This shows that the sizes among the two genders show no significant difference.

Ibinaye *et al,* (2014) used Magnetic Resonance Imaging to estimate the eyeball volume of Nigerians in the Zaria region. It found out that the eyeball volume of the male gender was slightly larger than that of the female gender. The mean eyeball volumes of males was 6.75 $cm^3$ and 6.74 $cm^3$ for the right and left eyeball respectively while those of females were 6.61 $cm^3$ and 6.52 $cm^3$ for the right and left respectively. This similarly showed that the size of the male gender was larger but with no statistical significance.

Surekha *et al,* (2022) conducted a study in India aiming to establish the normal eyeball volume of subjects of that population using Magnetic Resonance Imaging. Consecutive sampling was used to identify 425 subjects aged between 5 months and 88 years. The right eyeball measured 6.06 $cm^3$ and 5.83 $cm^3$ for males and females respectively. The showed that the males had a slightly larger eyeball volume as compared to females but with so statistical significance.

**2.6.4 Eyeball volume variance with age**

The eyeball volume varies with age. Its size gradually increases during childhood years reaching its maximum at about 18 years. The eyeball volume achieves half of its adult volume within 12 – 16 months. Development then continues gradually up to the age of 14 years where it achieves its 95 % of volume. The axial length however continues up to the age of 18 years giving an impression that if the axial length elongates later than the latter age (Zadnick, 2008). In adulthood, the eyeball maintains its volume up to the age of 40 years when it starts to regress in volume, probably explaining visual acuity impairment that ensues at the latter age and old age (Ibinaiye *et al*., 2014).

Kim *et al,* (2016) in his study aimed at establishing age related differences among Korean adults established the axial. There was significant association of older age and shorter axial length as well as anterior chamber depth. The axial length elongates later in adulthood, it may lead to myopia, and if it halts elongating earlier than the age it may lead to hyperopia.

Ogbeide (2007) in a study assessing normal diameters of the eyeball and volume in the African population found out that the eyeball diameter slowly increased with age in both genders. The curve was steeper in males than females. The highest diameters were noted in the older age group for both genders. However, the eyeball volume was noted to reduce at old age, especially in females. This was attributed to hormonal and metabolic changes that occurred at old age.

**2.6.5 Orbital volume variance with Ethnicity**

The dimensions of the orbit vary with various population differences. It varies with ethnicity of the subjects (Munguti *et al.*, 2013). Orbital dimensions of the different populations have been demonstrated. Botwe *et al,* (2017) in his study evaluating the orbital index among Ghanaians concluded that the Ghanaian orbit falls in the microseme category. The mean orbital index was 81.22 ± 4.22. Anibor & Ighodae (2016) in his study on orbital index of adult Binis in Edo state Nigeria concluded that the population also falls under the microseme category with a population mean orbital index of 78.54 ± 5.6.

Munguti *et al,* (2013) in a skull geometric study of skulls at the Nairobi National Museum, Kenya found that the orbital index of Kenyans was 82.57 and 83.48 for male and female respectively. This places them under the borderline of microseme and mesoseme categories.

A study in the South Indian population using dry skulls by Mekala *et al,* (2015) found out that the orbital index of the population was mesoseme with an orbital index of 84.62 ± 8.21 and 85.46 ± 5.93 for male and females respectively. Kaur *et al,* (2012) in a similar study but targeting the North Indian population found out that the populations' mean orbital index is 81.65 which makes them microsemes. These findings depict the difference in the orbital breadth and height measurements among the different populations under scrutiny.

Acer *et al* (2011) in his study estimating eyeball and orbital volume applying the Cavalieri principle in Turkey found out that mean orbital volume for males was 22.35 ± 3.05 $cm^3$ and 22.71 ± 2.8 $cm^3$ for the right and left side respectively, while that of females was 18.47 ± 2.52 $cm^3$ and 18.16 ± 2.52 $cm^3$ for the right and left side respectively. The orbital volume of male Taiwanese on the other side was 24.7 ± 1.17 $cm^3$ and 24.3 ± 1.51 $cm^3$ for right and left sides respectively, while that of the female Taiwanese was 21.1 ± 1.3 $cm^3$ and 21.0 ± 1.21 $cm^3$ for the right and left side respectively (Shyu *et al*., 2015). The mean orbital volume of the Greek as depicted by Bontzos *et al,* (2019 ) in his cross-sectional study to establish the Effective Ocular Volume using MRI was 26.81 ± 0.59 $cm^3$. These differences in volume also shows that the orbital volume varies among ethnicities and populations.

On the examination of the mean eyeball volume, Acer *et al*, (2011) established measurements for Turkish males as 7.32 ± 0.74 $cm^3$ and 7.61 ± 1.04 $cm^3$ for the right and left sides respectively, while that of female Turks was 7.45 ± 1.19 $cm^3$ and 7.45 ± 1.25 $cm^3$ for the right and left sides respectively. Bontzos *et al,* (2019) found out the mean eyeball volume of the Greek was 7.83 ± 2.27 $cm^3$. Another study in an African setting done by Igbinedion & Ogbeide, (2013) in Edo, Nigeria found out that the mean ocular volume was 5.28 ± 1.16 $cm^3$. This depicts the clear variation in ocular volume with different ethnicities with the African eyeball being the smallest in volume.

**2.7 Utility of the Orbital and Eyeball volumes**

Orbital and eyeball dimensions are important in many aspects relating to medical and non-medical aspects of the orbit and the eye (Weaver et al., 2010). Munguti *et al,* (2012) in a skull geometric morphometric study in Nairobi National Museum Kenya highlighted the fact that it is important to know the dimensions of the orbit as they are crucial in surgical and cosmetic procedures. In his conclusion, it was found out that the orbits of the Kenyans were deeper than the Caucasians and therefore increases the risk of injury to the optic nerve as deep dissection has to be done. For this reason it was recommended that longer dissection probes may be needed for the Kenyan orbit during ophthalmic surgeries within the orbit to avoid iatrogenic injuries.

Orbital and ocular volumes help in calculation of the effective orbital volume, the difference between the eyeball and orbital volumes (Bontzos *et al*., 2019). This is important in conditions which affect the ocular and orbital volumes such as graves disorder. These volumes are also important in orbital restoration surgeries, especially in orbital fractures.

Weaver *et al,* (2010) highlighted in his study on CT based three dimensional measurement of orbit and eye that the normal variation of the parameters is vital in modeling and design of eye protection equipment. The study emphasized on the fact that an in-depth understanding of orbital structural variations is important in prediction of eye injury. This will in turn help in the design of better eye protective equipment such as helmets, goggles and facial guards in sport.

Mekala *et al,* (2015) in a measurement study on South Indian dry skulls highlighted the importance of orbital dimensions in forensic studies. This may include post-mortem identification, determining gender, assessing evolutionary trends as well as ethnicity. The same is alluded to by Munguti *et al*, (2013) in their study on gender differences in cranial and orbital indices for the black Kenyan population. Although the study did not depict a significant difference in orbital indices between the different genders, other studies such as the one done by Singh *et al*, (2017) using CT scan to analyze orbital measurements have shown that the male orbit is significantly larger than for females. Sentucq *et al.*, (2020) highlighted three important roles of having orbital volumes; prediction of post-traumatic enophthalmos, planning of orbital surgical interventions and measurement of orbital volume as an essential tool for orbital practice. One of the complications of trauma to the orbit is enophthalmos that ensues after reconstructive surgery. A major contributor of enophthalmos is when the post-surgical orbital volume is larger than the initial volume resulting in expansion of orbital volume. Other factors that contribute to enophthalmos include orbital fat necrosis and soft tissue volume loss as result of trauma and surgery. Studies have shown that cases of enophthalmos recorded an expansion of orbital volume by about 1 $cm^3$. The volume of the traumatized and reconstructed orbit was compared with the presumed normal orbit and ratio obtained. There was noted direct correlation between the ratio obtained and enophthalmos in cases of orbital fractures (Whitehouse *et al.*, 1994; Suguira *et al.*, 2017).

Orbital volumetry offers good orbital analysis in 3D which gives detail needed for pre-operative planning. The current recommended surgical practice advises that implants or grafts should be made according to customs of the patient. This helps in reducing incidences of post-surgical complications such as enophthalmos and dystopia. Laser-melted implants and bent meshes that are specific to the patient have served to reduce postsurgical enophthalmos. The unaffected side is usually used to make the implant for the affected side (Sentucq *et al.*, 2020).

Bontzos *et al.,* (2019) also emphasized on the importance of the space left in the orbit after accounting for space occupied by the eyeball. It is named Effective Orbital Volume (EOV). It is calculated by subtracting the eyeball volume from the orbital volume. It is important in maxillofacial and ophthalmology practice. The quantification is needed in orbital surgery to decompress soft tissues due to Grave's orbitopathy, restoration of orbital volume in orbital fractures and cosmetic reconstructive procedures. The ratio of the orbital contents has to be maintained to ensure that there is no enophthalmos or exophthalmos which is desired for facial aesthetics. The primary purpose of the face is for aesthetics.

# CHAPTER THREE

## 3.0 METHODOLOGY

### 3.1 Study Site

The study was carried out in the Radiology Directorate of Moi teaching and Referral Hospital. The CT scans were acquired and analyzed at the Radiology department while participants were screened by the principal investigator. They were then examined using the prescribed screening tool. Moi Teaching and Referral Hospital is the second largest National Referral Hospital in Kenya, located in Eldoret town, Uasin-Gishu County. It has an inpatient bed capacity of 991 and serves Western Kenya, Eastern Uganda and South Sudan. It serves an average of 1200 inpatients and 1500 outpatients every single day. About 1500 patients undergo CT scan every month in the facility with 40% of these being head scans. It is for this reason that the study was carried out here owing to the diverse nature of the patients and thus could be presumed to be representative of the East African region (MTRH Records, 2020).

### 3.2 Study Design

A cross-sectional study was conducted for a period of one year between 1$^{st}$ September, 2021 and 31$^{st}$ August, 2022.

### 3.3 Study Population

The study population entailed all adult patients sent to the Radiology department with an indication for a head CT scan from the outpatient and inpatient departments for the various indications.

## 3.4 Eligibility Criteria

### 3.4.1 Inclusion Criteria

a. Adult patient whose ophthalmic history was normal as per the screening tool.
b. Adult patient who had been examined and ophthalmologic examination findings established as normal. Some sections of the examination chart were exempted for elderly patients who could not obey instruction.

### 3.4.2 Exclusion Criteria

a. Patients with history of any ophthalmic surgery.
b. Patients with a history of orbital trauma.
c. Patients with history of opthalmopathies such as diabetes, hypertension and thyrotoxicosis.
d. Patients discovered to have orbit-ocular lesions on review of CT scan images.
e. Poor quality CT images.

## 3.5 Sample size and Sampling Procedure

### 3.5.1 Sample Size

The study aimed to estimate the orbital and eyeball volumes from the study population. A study done by Acer *et al*, (2011) among 31 Turkish subjects estimating the eyeball and orbital volumes found the standard deviation in orbital volume to be 5.46 $cm^3$. This study set to estimate the average orbital volume within 0.5 $cm^3$ of true average volume with 95% confidence. The number of participants required is estimated using the formula below as proposed by Naduvilath *et al*, (2000) for estimating sample size for ophthalmology studies.

$$n = \frac{[Z_{1-\alpha/2} \times SD]^2}{d}$$

Where,

n = minimum sample size required

$Z^2_{1-\alpha/2}$= Critical value for standard normal distribution at α-level of significance (α=0.05, $Z_{1-\alpha/2}$=1.96).

SD = 5.56 that is, estimated population standard deviation from study done by Acer *et al*, (2011).

d = precision (d=0.25)

Using the above equation,

$$n = \frac{[1.96 \times 5.56]^2}{0.25} = 475$$

### 3.5.2 Sampling Procedure

Systematic random sampling was used to select the study participants. 1796 head CT scans are done within a period of 1 year at the selected Philips CT room (MTRH records, 2020). The interval was calculated as $\frac{1796}{458} = 3.92$. Hence every 3rd patient who met the eligibility criteria was recruited into the study. The first participant was selected by choosing the first third patient sent for head CT scan.

## 3.6 Study Procedure

### 3.6.1 Participant Recruitment

Patients who were sent for CT scan head in the Radiology and Imaging department were first screened using a screening tool that entailed ophthalmic history and examination. A verbal consent was sought before screening. Those who had normal findings on the screening tool were enrolled into the study. A written consent was administered to enable the participants to choose whether to participate in the study or not.

### 3.6.2 Procedure for eye examination

The principal investigator screened the participants by taking history and performing an ophthalmic examination. Ophthalmic history included finding out whether the patient wore spectacles, establish refractive errors of those who wore spectacles, any existent eye condition, history of injury to the eye, history of surgery of the eye and whether they suffered from three medical conditions – hypertension, hyperthyroidism and diabetes. These conditions namely hypertension and hyperthyroidism can affect the size and position of the eyeball causing proptosis or exophthalmos. Diabetes can cause reduced size of the eyeball (Khademi & Bayat, 2016)

Ophthalmic examination included general examination of the eyelids for scars, asymmetry and any squint. Visual acuity was then conducted on every eye using the Snellen chart placed six meters from the patient. Extraocular muscle movement was also conducted.

CT scans were then acquired using the Philips 64 slice CT scan machine at the MTRH radiology department. Local CT protocol for examination and view of the orbit (Appendix VI) was used.

### 3.6.3 Procedure for analyzing CT images

Images were saved in a compact disc and well labeled with the assigned study number. Thereafter they were opened and reconstructed to 2D and 3D images to allow measurement of the orbital and ocular dimensions using the Hospital's PaxeraUltima software Worklist version 7.2.0.0, Viewer version 6.0.0.1.

### 3.6.3.1 Orbital dimension determination

For the bony orbit, the height, breadth and depth were measured using the PaxeraUltima software (Bone window; window parameters: WW 2000, WL 500; accuracy: 1 pixel). Measurements of the breadth and height were done using coronal images scrolled to the orbital rim. The depth was measured at the axial plane cutting through the optic canal. The length of a line drawn perpendicular to a line joining the medial and lateral orbital rims to the anterior end of the optic canal. This is supported by a study done by Khademi & Bayat, (2016) where the depth of the orbit was defined as the distance between orbital rim plane and entrance of optic canal using horizontal plane.

The measurements obtained are as follows:

(i) Breadth: longest distance between lateral and medial orbital rims

(ii) Height: longest distance between lower and upper orbital rims

(iii) Depth: line drawn fronto-orbital rim edges plane to the optic canal anterior most end. This will form the height of the cone formed.

All these measurements were tabulated in the questionnaire.

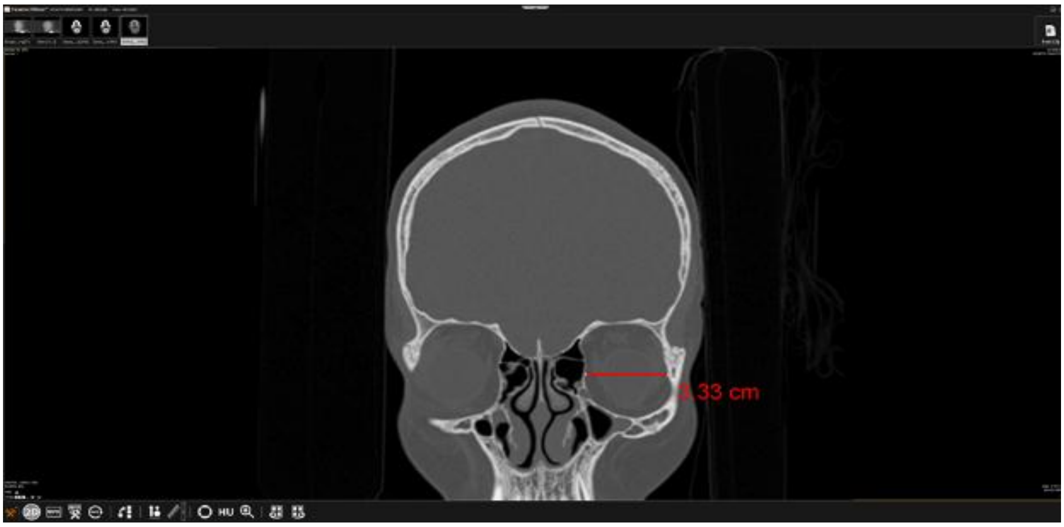


***Figure 24: Coronal view of the orbits showing left orbit breadth.***

*(Researcher, 2022)*


***Figure 25: Coronal view of orbits showing left height measurement.***

***(Researcher, 2022)***


***Figure 26: Coronal view of the orbits showing right orbit height and breadth measurements***

***(Researcher, 2022)***

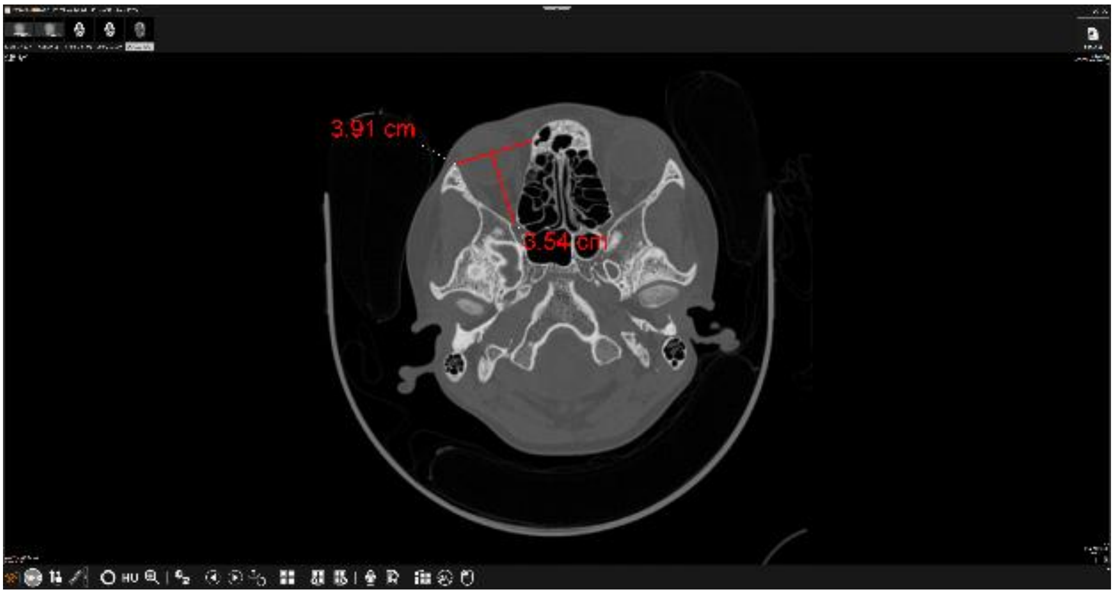



***Figure 27: Right Orbital axial CT scan showing depth***

***(Researcher, 2022)***

### 3.6.3.2 Orbital volume determination

Volume estimation of the orbit was done using a special software for manual segmentation volumetric analysis, Eclipse version 16.1 at the Radiotherapy Department. It is a software usually used for planning of radiotherapy beam administration and can also assist in determining volumes of traced structures. This method is considered the gold standard in obtaining volume in non-cadaveric and clinical circumstances such as during pre-surgical orbital volume analysis (Jansen *et al*,2016).The saved disc was loaded to the computer where pre-radiation planning of patient dose administration is done. It was then opened using the Eclipse software. The orbits were then rendered to a "contouring" process which entails tracing of the orbital margins from the floor to the roof. Adaptive mode was used which is able to automatically trace the margins of the orbit as opposed to static mode where the margins of the orbit are manually traced. The brush tool was used to correctly align the margin-line that traced beyond the required orbital bony margin. The next process was "interpolation" where the drawn lines are automatically merged.

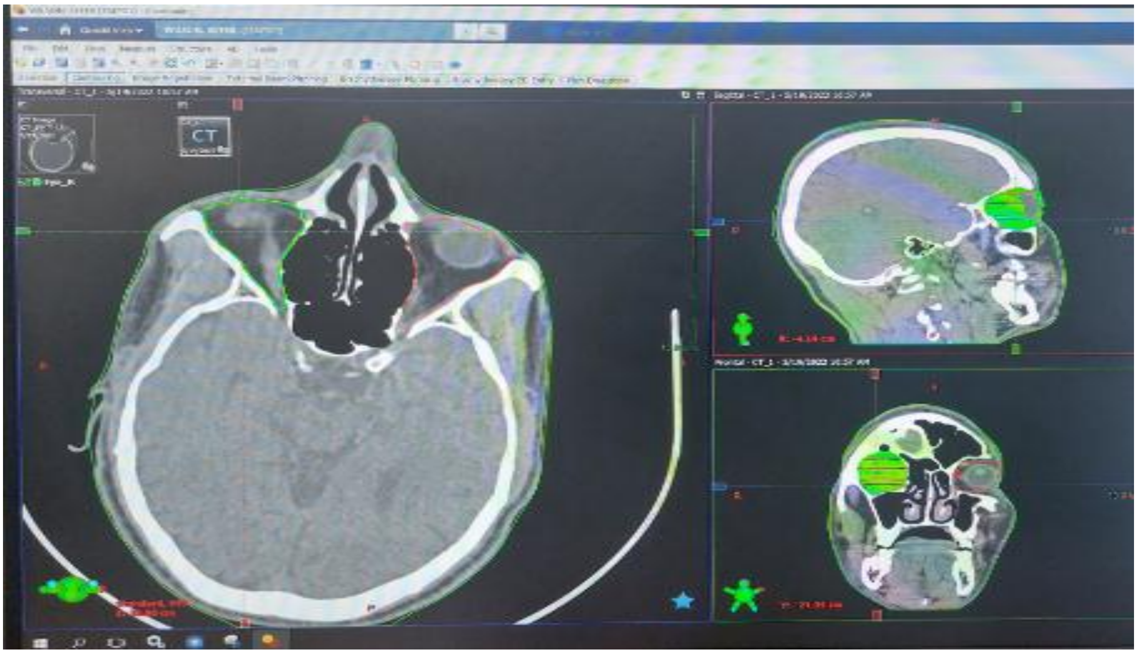


***Figure 28: Axial CT scan showing contouring process for the right orbit.***

*(Researcher 2022)*

The next process was subjecting the interpolated area to a process named "External Beam Planning" which automatically created a 3D sketch of the orbit.

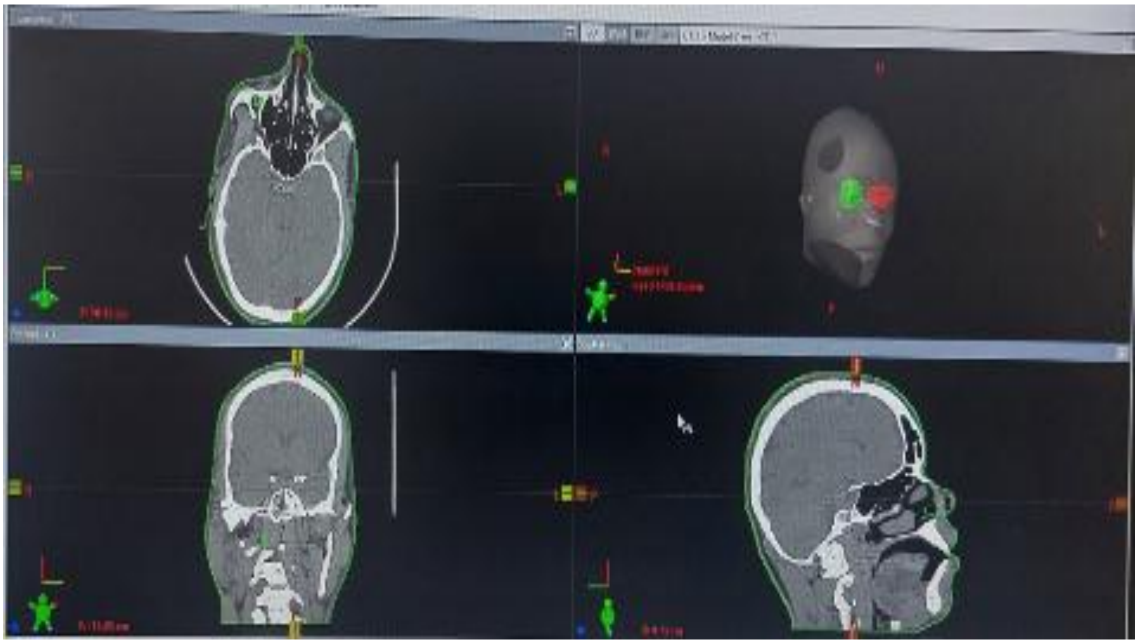


***Figure 29: External Beam Planning 3D reconstructed orbits***

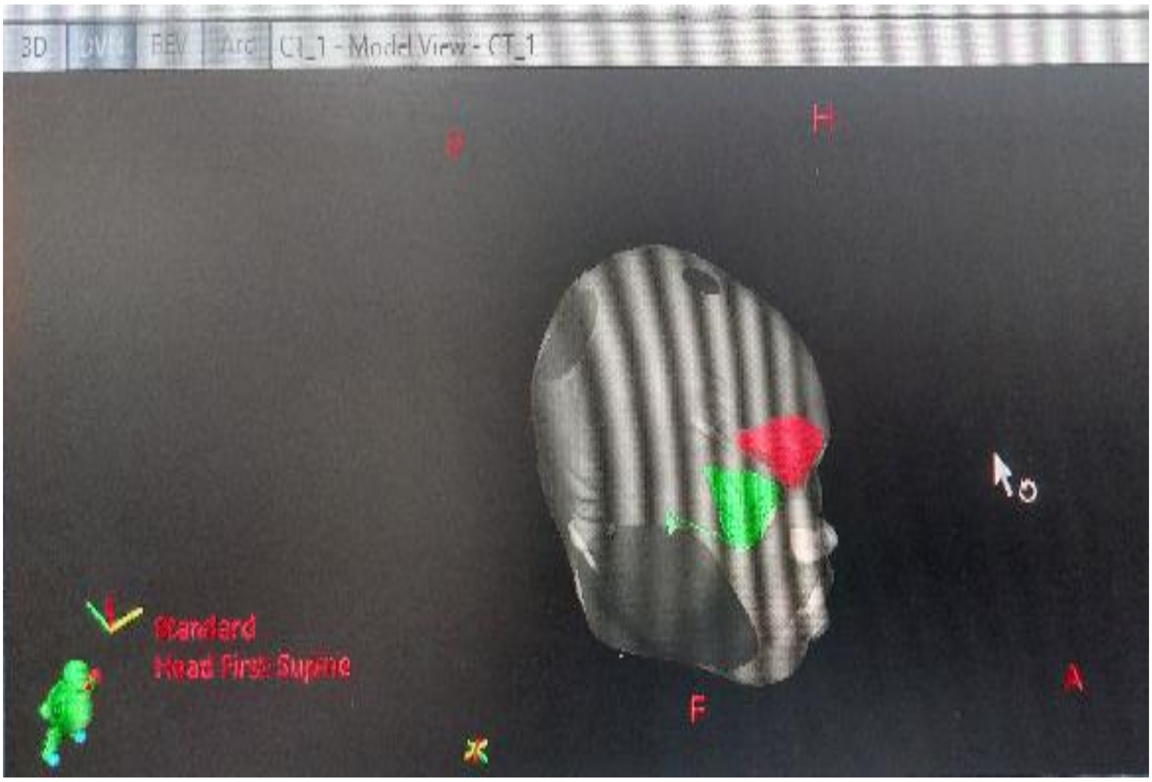



***Figure 30: 3D model view of the orbits***

*(Researcher 2022)*

The final process was clicking on the area of interest on the listed structures which automatically gives the volume.

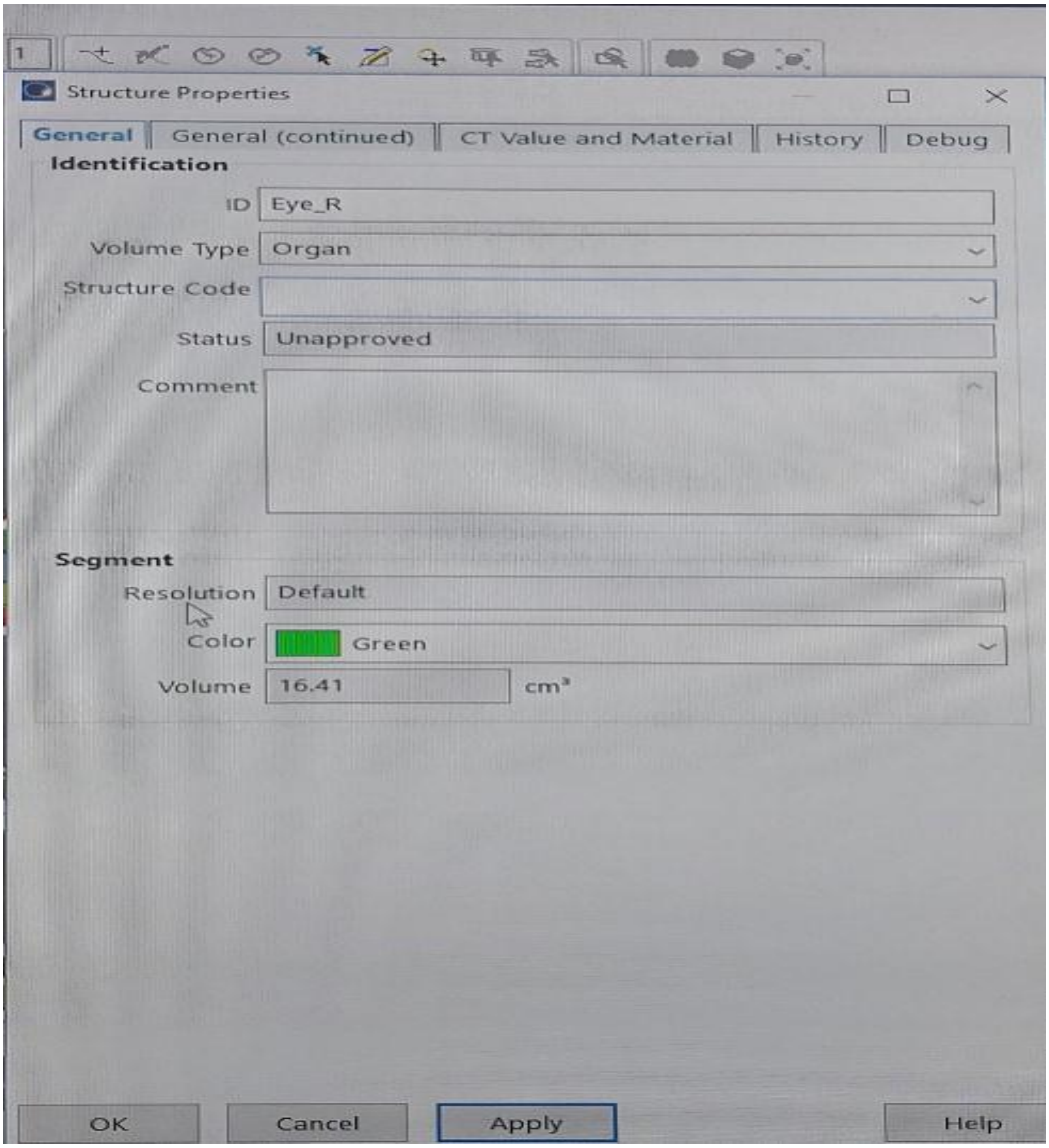



***Figure 31: Automatically generated volume of orbit.***

*(Researcher, 2022)*

### 3.6.3.3 Eyeball dimension determination

For the eyeball, the transverse, axial anteroposterior diameter and sagittal diameters were measured using the PaxeraUltima software (spine window; window parameters: WW 60, WL 360; accuracy: 1 pixel). All measurements were estimated using similar window parameters, brightness and contrast. The three diameters were measured at widest diameter at the level where the lens, optic nerve and insertions of medial and lateral recti muscles are visualized. The diameters are as follows:

(i) Sagittal diameter – widest diameter from distal sclera to proximal sclera

(ii) Transverse diameters - widest diameter from lateral sclera to medial sclera

(iii)Axial anteroposterior (AP) diameter - from sclera to cornea.


***Figure 32: Coronal view of the orbits showing right eyeball sagittal measurement. (Researcher, 2022)***

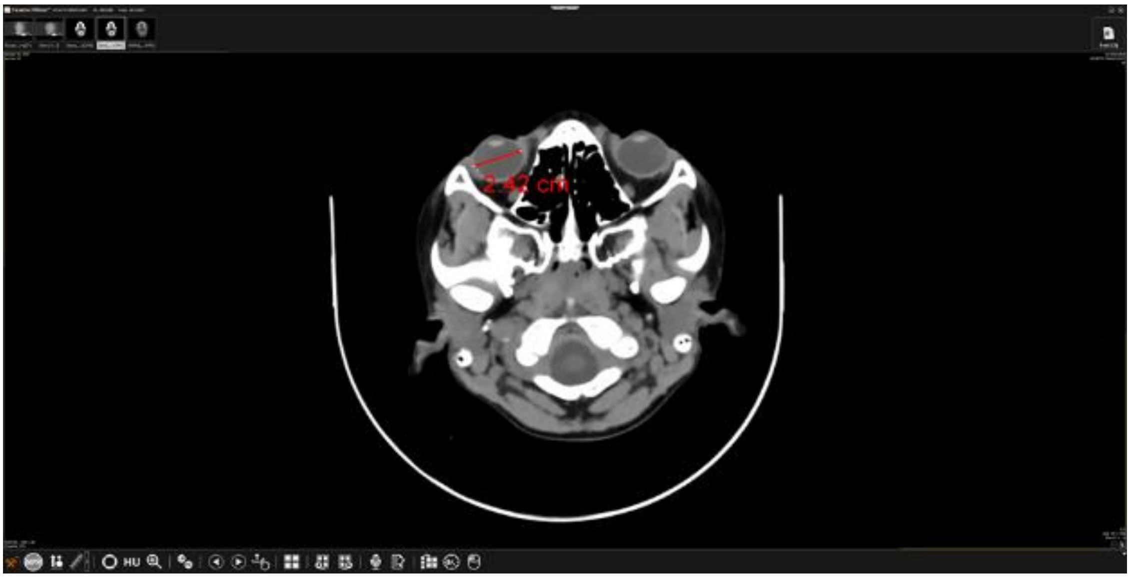



***Figure 33: Axial view of the orbits showing right eyeball transverse measurement***

***(Researcher, 2022)***

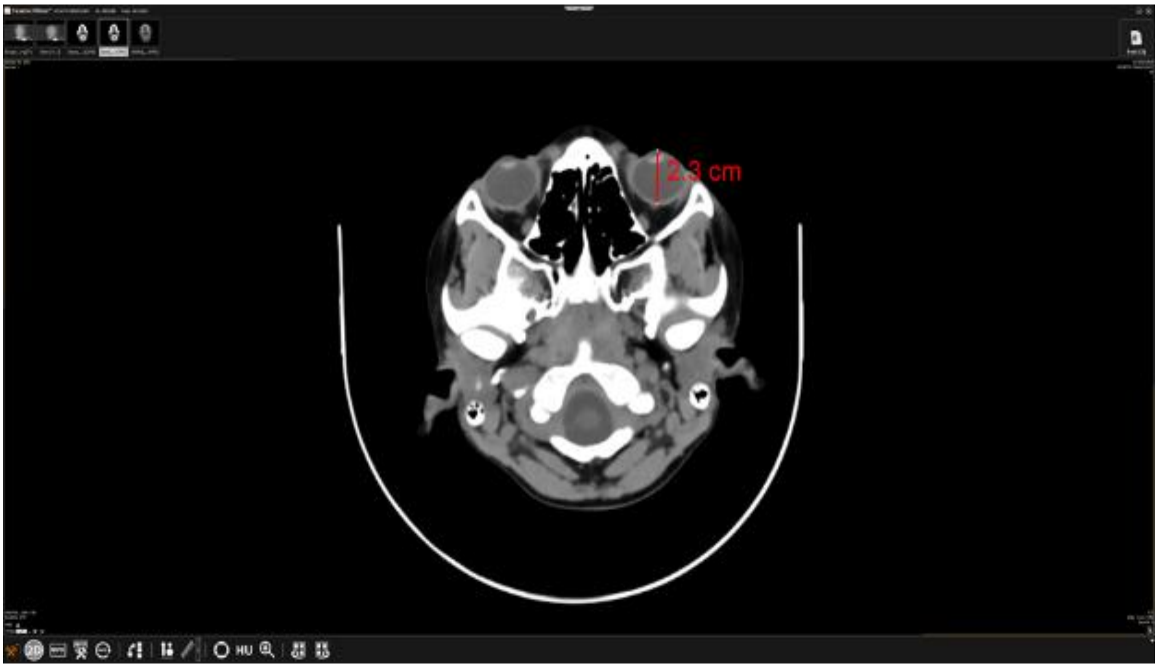



***Figure 34: Axial view of the orbits showing left eyeball anteroposterior measurement.***

***(Researcher, 2022)***

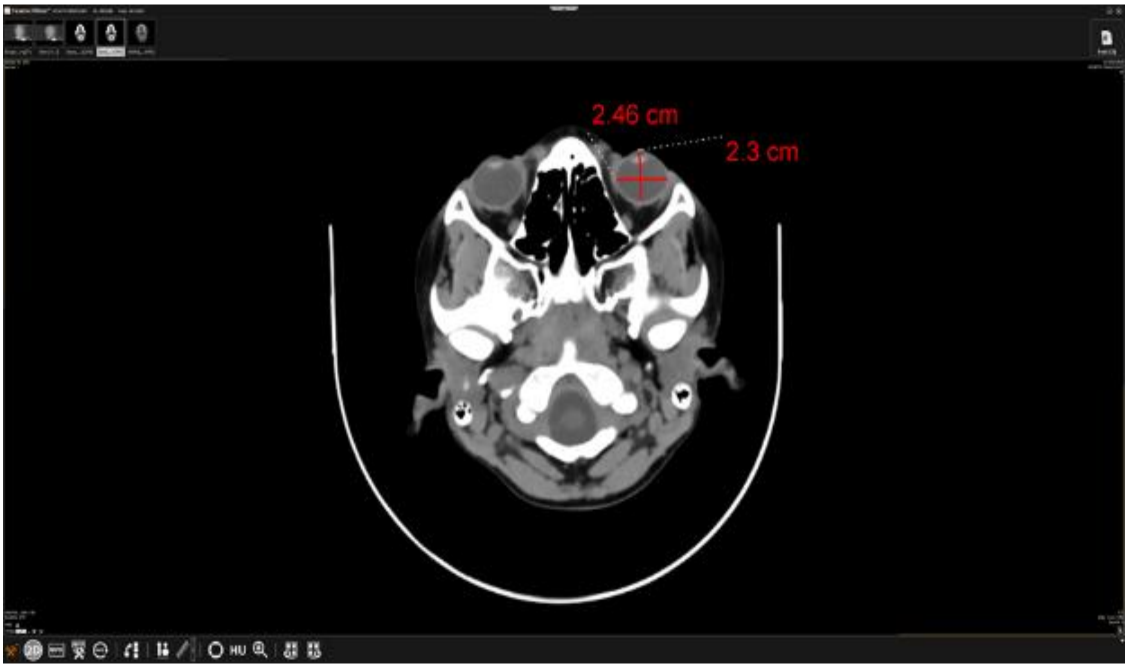



***Figure 35: Axial view of the orbits showing left eyeball anteroposterior and transverse measurement.***

***(Researcher, 2022)***

### 3.6.3.4 Eyeball Volume determination

Volume measurement of the eyeball was also done using Radiotherapy planning software, Eclipse Version 16.1 at the Radiotherapy planning room. Tracing of the eyeball using "contouring" mode was done in the axial plane from the upper to lower pole in the axial plane. This was followed by "interpolation" and subjection to "External Beam Planning" which yielded the 3D model of the eyeball and its volume. The figures obtained were then recorded on the questionnaire.

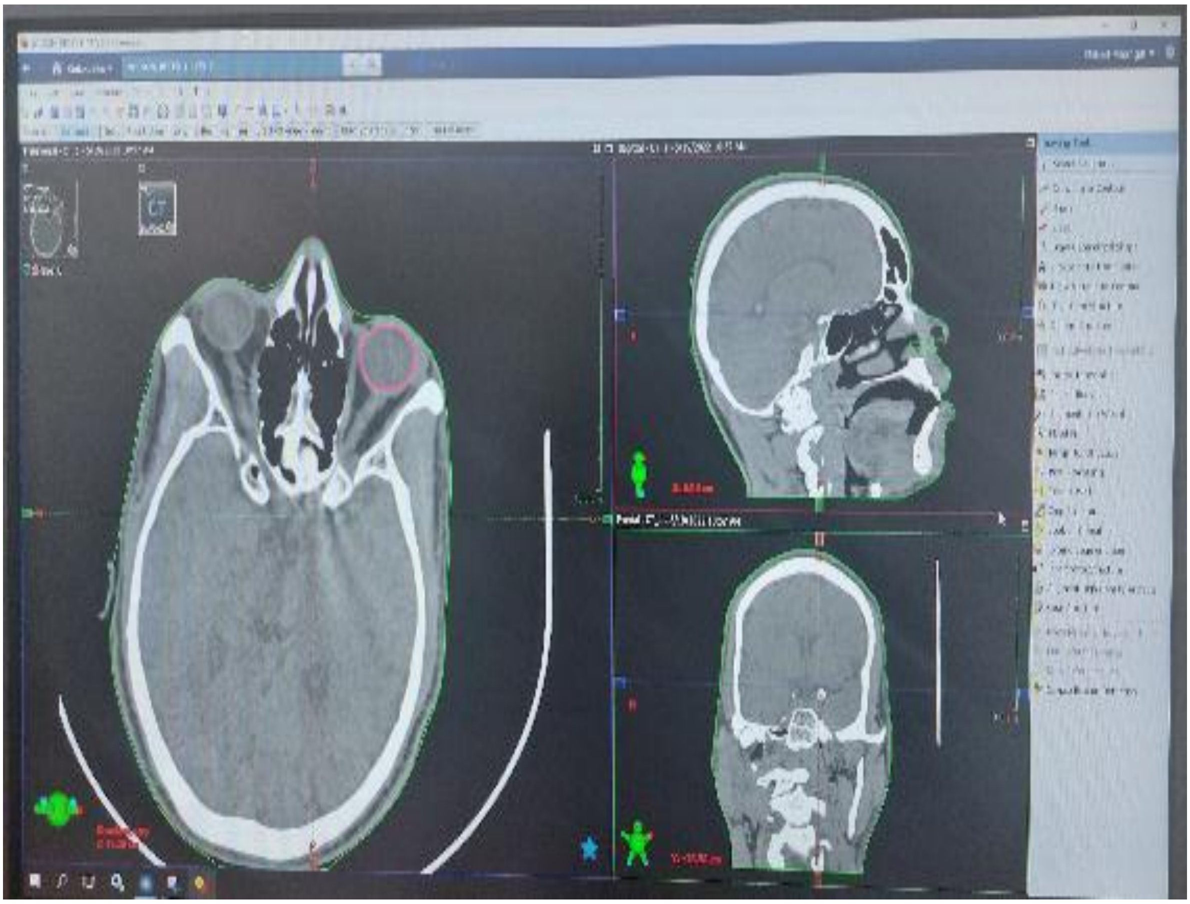


***Figure 36: Contour tracing of the left eyeball***
*(Researcher, 2022)*

*Figure 37: Contouring process showing traced left eyeball*

*(Researcher, 2022)*

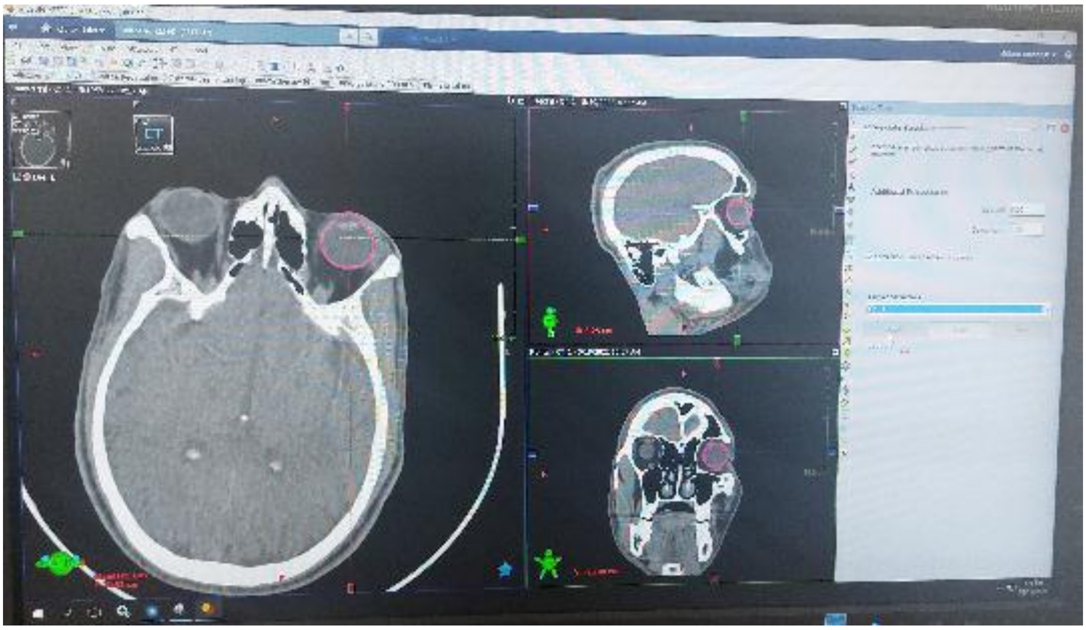


*Figure 38: Interpolation of the left eyeball*

*(Researcher, 2022)*

***Figure 39: Generated eyeball volume.***

*(Researcher, 2022)*

### 3.7 Data Collection Instrument

The instrument of data collection was a structured questionnaire. The questionnaire was organized in three sections. The first section collected biodata of participants. The second part aimed to collect data on the measurements of the orbit while the third section aimed to record measurements of the eyeball.

Information was coded into a password protected database and thereafter questionnaires kept under lock and key in a safe cabinet within the department of Radiology. The information was kept confidential and encrypted access was granted to the investigator and supervisor only. Serial numbers were of help in protecting participants' identity.

### 3.7.1 Pilot Testing

Pilot testing is a pretest study done using a small sample with similar characteristics with the sample population (Saunders *et al.,* 2009). The number of participants in the pretest is desired to be ten percent of the sample size of the main study (Orodho, 2005). Therefore, 48 participants were selected at the Directorate of radiology, Moi Teaching and Referral Hospital, Eldoret. Collected data was analyzed to determine the reliability and feasibility of the study.

### 3.7.2 Validity of the Research Instrument

The questionnaire was interrogated by university supervisors. Parameters used in determining achievability of objectives and content validity were established as done by other scholars.

### 3.7.3 Reliability of the Research Instrument

A pilot study was done to find out the internal consistency of the research instrument. This helped in removing ambiguities from the questionnaire as a result of poor structure. This pilot study used 48 questionnaires that were filled at MTRH radiology department. Data acquired was coded into SPSS after which Cronbach alpha coefficient was calculated. Cronbach alpha should be above 0.6 for the research instrument to be declared as reliable (Nunally and Bernsterin, 1994).

## 3.8 Data Management

### 3.8.1 Data Collection

Data was collected between 1st September, 2021 and 31st August, 2022.

CT scan images were then analyzed to obtain measurements and volumes of the orbit and eyeball. The same were recorded on the questionnaire. This data was then fed into a computer database, only accessible to the investigator and supervisors.

### 3.8.2 Quality Control

Patients were screened by the investigator to ensure that they have no pre-existing ophthalmic condition that may affect the orbital and ocular dimensions. All CT scans were acquired using the MTRH Radiology protocol for the orbit. Images acquired were reviewed by the investigator and verified by the consultant radiologist to ascertain that ocular and orbital structures are normal before dimensions are acquired.

### 3.8.3 Data Analysis

Data analysis will be done in four stages; data clean up, data reduction, differentiation and explanation, and coding. Data clean-up was done by editing, tabulation and coding to detect errors. Coding and keying into a computer were then done on an excel sheet. Appropriate codes were created for different variables and verified for possible erroneous entries before the stage of analysis. The research adopted a quantitative technique as prescribed by Creswell, (2011).

The data recorded on patient demographics and measurements were first of all recorded in an excel spreadsheet (Microsoft Corp., USA) before being recorded onto an analytic database, Statistical Package for Social Sciences (SPSS 22, IBM Corp, New York, USA). Data was assessed by the principal investigator with the assistance of a biostatistician. Data collection forms kept in a safe and lockable cabinet to ensure safety and confidentiality. The database in use was backed up in a safe online cloud to avert any loss of data.

Data was analyzed using the Statistical Package for Social Sciences (SPSS 22, IBM Corp, NY, USA) software. Data was tried for normal Gaussian distribution by plotting a histogram. The mean, standard deviation and range was calculated for orbital and ocular volumes. Data that was obtained for both orbits shall be compared.

The variation of ocular and orbital volume for age groups (18-29; 30-39; 40-49; 50-59; 60-69; 70-79; 80-89; 90-99 years) and gender (male; female) was analyzed as well. The association of variables was evaluated using Chi square test using 95% confidence interval. The level of significance for all analysis was put at $P < 0.05$.

Pearson correlation coefficient helped in establishing relationships between dependent variables (orbital volume and eyeball volumes) and independent variables with a confidence of 95%. The model for the various hypothesis is as follows:

$Y_n = \beta_0 + \beta_n X_n + \varepsilon$

Where, $Y_n$ = Orbital/ Eyeball volumes.

n = Denotes Independent variables.

$\beta_0$ = Constant Term or Intercept

$\beta n X n$ = Denotes the product of β coefficients and their various independent variables

ε = is a stochastic random error term

Its analysis found out the extent and direction of influence between dependent and independent variables. The values obtained from dependent and independent variables were keyed and computed to get the correlation coefficient which should lie between -1 and +1. Where values indicate various levels of linear relationship as follows: $r = -1$ ( perfect negative relationship); $r = -0.7$ (strong negative relationship); $r = -0.5$ (moderate negative relationship); $r = -0.3$ (weak negative relationship); r =0 (no linear relationship); $r= +0.3$ (weak positive relationship); $r= +0.5$ (moderate positive relationship); $r = +0.7$ (strong positive relationship); $r = +1$ (perfect positive relationship).

### 3.8.4 Dissemination of Information

The results of the study were presented to the Hospital's management and the University's departments of Radiology and Imaging, Ophthalmology, Maxillofacial surgery and Plastic and Reconstructive Surgery as well as the Resource Center. They were also available for publication at a respectable journal of medicine for referencing and in studies and management of patients.

## 3.9 Ethical Considerations

Approval was sought from Moi University and Moi Teaching and Referral Hospital Institutional Research and Ethics Committee (MTRH/MU-IREC) with the approval number, 0003944 and Chief Executive Officer of Moi Teaching and Referral Hospital. Approval was also sought from National Commission for Science, Technology & Innovation (NACOSTI) with the reference number, 751814. All participants were given information about the study and how the investigator went about the study – assessment and the procedure. The benefits, risks and complications of the procedure were also explained. The patients were to be enrolled to the study strictly on a voluntary basis. No incentives or inducements were offered and confidentiality maintained throughout the study.

## 3.10 Study Time Frame

The study was carried out over a period of one year, beginning 1$^{st}$ **September, 2021** to **31$^{st}$ August, 2022.**

### 3.11 Study Recruitment Schema

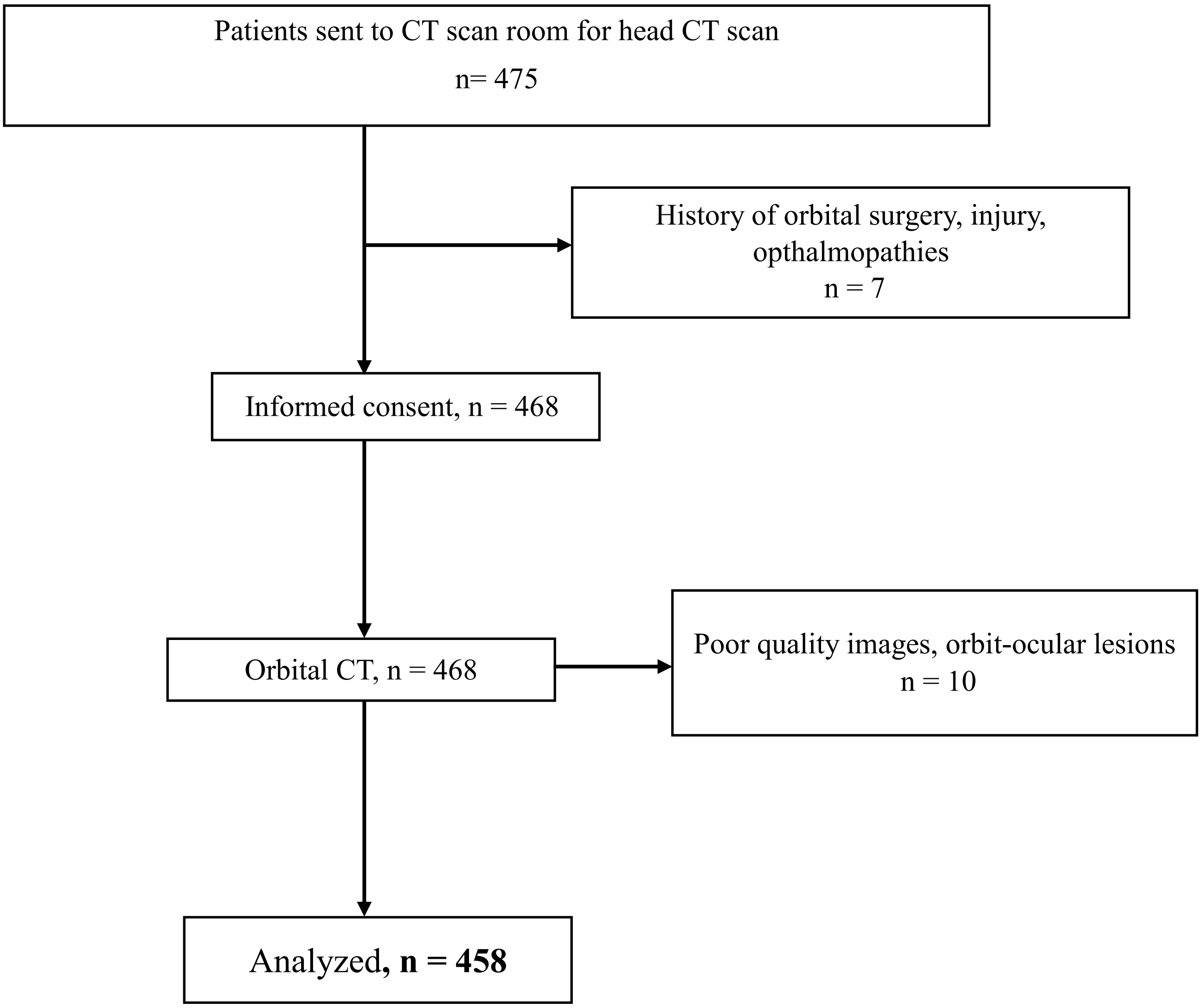



***Figure 40: Recruitment Schema***

# CHAPTER FOUR

## FINDINGS

### 4.1 Introduction

The findings are based on 458 patients who visited the radiology department of MTRH with an indication for a head CT scan from the outpatient or inpatient departments for the various indications.

### 4.2 Demographic characteristics

***Table 1: Age and gender distribution***

| Age category | Gender | | Total | Percentage |
|---|---|---|---|---|
| | **Males** | **Females** | | |
| **18 – 29** | 114 | 53 | 167 | 36.5 |
| **30 – 39** | 66 | 40 | 106 | 23.1 |
| **40 – 49** | 38 | 16 | 54 | 11.8 |
| **50 – 59** | 22 | 12 | 34 | 7.4 |
| **60 – 69** | 22 | 19 | 41 | 8.9 |
| **70 – 79** | 13 | 15 | 28 | 6.1 |
| **80 – 89** | 12 | 9 | 21 | 4.6 |
| **90 – 99** | 4 | 3 | 7 | 1.5 |
| Total | **291** | **167** | **458** | **100** |
| Percentage | **63.5** | **36.5** | | |

The age of patients ranged from 18 to 98 years with a mean of 41.1 ± 20 years and median age of 35 (IQR 25, 54). About a third (36.5%) of the patients were aged between 18 and 29 years followed by those aged between 30 and 39 years (23.1%). Majority (63.5%) of patients were males.

**4.3 Objective one: To determine CT Orbital Volumes at MTRH**

***Table 2: Mean orbital measurements for the right and left eyes in relation to age of the male subjects in centimeters***

| **Age (years)** | **Frequency (n)** | **Eye laterality** | **Breadth** | **Height** | **Depth** |
|---|---|---|---|---|---|
| 18 – 29 | 114(39.2%) | Right | 3.46 ± 027 | 3.53 ± 0.26 | 3.95 ± 0.40 |
| | | Left | 3.47 ± 0.25 | 3.56 ± 0.26 | 3.94 ± 0.41 |
| 30 – 39 | 66(22.7%) | Right | 3.55 ± 0.27 | 3.39 ± 0.36 | 3.93 ± 0.40 |
| | | Left | 3.52 ± 0.30 | 3.40 ± 0.37 | 3.90 ± 0.39 |
| 40 – 49 | 38(13.1%) | Right | 3.56 ± 0.22 | 3.52 ± 0.30 | 3.85 ± 0.48 |
| | | Left | 3.55 ± 0.27 | 3.50 ± 0.30 | 3.83 ± 0.50 |
| 50 – 59 | 22(7.6%) | Right | 3.70 ± 0.24 | 3.47 ± 0.24 | 3.95 ± 0.17 |
| | | Left | 3.67 ± 0.23 | 3.46 ± 0.24 | 3.97 ± 0.18 |
| 60 – 69 | 22(7.6%) | Right | 3.57 ± 0.27 | 3.49 ± 0.40 | 4.02 ± 0.41 |
| | | Left | 3.57 ± 0.26 | 3.52 ± 0.38 | 4.02 ± 0.41 |
| 70 – 79 | 13(4.5%) | Right | 3.84 ± 0.17 | 3.62 ± 0.22 | 4.07 ± 0.32 |
| | | Left | 3.81 ± 0.21 | 3.63 ± 0.22 | 3.98 ± 0.31 |
| 80 – 89 | 12(4.1%) | Right | 3.35 ± 0.34 | 3.41 ± 0.18 | 3.59 ± 0.56 |
| | | Left | 3.35 ± 0.38 | 3.38 ± 0.18 | 3.66 ± 0.55 |
| 90 – 99 | 4(1.4%) | Right | 3.81 ± 0.27 | 3.49 ± 0.24 | 3.14 ± 0.92 |
| | | Left | 3.77 ± 0.21 | 3.46 ± 0.17 | 3.02 ± 1.18 |
| Total | 291 | Right | 3.54 ± 0.28 | 3.49 ± 0.30 | 3.92 ± 0.43 |
| | | Left | 3.53 ± 0.28 | 3.50 ± 0.30 | 3.90 ± 0.44 |

The mean overall right eye breadth measurement for male patients was 3.54 ± 0.28 cm while the left mean breadth measurement was 3.53 ± 0.28 cm. Both left and right breadth measurement seemed to increase with age. On average, the right height measurement for male patients was 3.49 ± 0.30 cm and 3.50 ± 0.30 cm for male left orbital height measurement. The overall left orbital depth of male patient averaged 3.90 ± 0.44 cm and the right side had a mean of 3.92 ± 0.43 cm. Age group 70 – 79 years seemed to have higher measurements for breadth and height while the 60 – 69 age group had the highest overall measurements for depth of orbit.

***Table 3: Mean orbital measurements for the right and left eyes in relation to age for female subjects in centimeters***

| **Age (years)** | **Eye laterality** | **Frequency (n)** | **Breadth** | **Height** | **Depth** |
|---|---|---|---|---|---|
| 18 – 29 | Right | 53 (31.7%) | 3.38 ± 0.30 | 3.36 ± 0.35 | 3.88 ± 0.50 |
| | Left | | 3.37 ± 0.25 | 3.41 ± 0.30 | 3.83 ± 0.61 |
| 30 – 39 | Right | 40 (23.9%) | 3.44 ± 0.22 | 3.44 ± 0.22 | 3.94 ± 0.30 |
| | Left | | 3.43 ± 0.22 | 3.44 ± 0.21 | 3.93 ± 0.27 |
| 40 – 49 | Right | 16 (9.6%) | 3.49 ± 0.34 | 3.51 ± 0.19 | 4.00 ± 0.28 |
| | Left | | 3.49 ± 0.32 | 3.50 ± 0.18 | 3.99 ± 0.30 |
| 50 – 59 | Right | 12 (7.2%) | 3.73 ± 0.19 | 3.45 ± 0.21 | 3.97 ± 0.26 |
| | Left | | 3.70 ± 0.21 | 3.42 ± 0.26 | 3.93 ± 0.24 |
| 60 – 69 | Right | 19 (11.4%) | 3.63 ± 0.56 | 3.63 ± 0.32 | 3.85 ± 0.53 |
| | Left | | 3.51 ± 0.33 | 3.58 ± 0.26 | 3.85 ± 0.49 |
| 70 – 79 | Right | 15 (9.0%) | 3.48 ± 0.25 | 3.31 ± 0.31 | 3.67 ± 0.57 |
| | Left | | 3.45 ± 0.25 | 3.31 ± 0.29 | 3.75 ± 0.59 |
| 80 – 89 | Right | 9 (5.4%) | 3.44 ± 0.36 | 3.32 ± 0.18 | 3.41 ± 0.97 |
| | Left | | 3.46 ± 0.48 | 3.33 ± 0.15 | 3.43 ± 1.00 |
| 90 – 99 | Right | 3 (1.8%) | 3.49 ± 0.40 | 3.54 ± 0.26 | 4.10 ± 0.43 |
| | Left | | 3.52 ± 0.38 | 3.64 ± 0.26 | 4.08 ± 0.38 |
| Total | Right | 167 | 3.47 ± 0.33 | 3.43 ± 0.29 | 3.87 ± 0.48 |
| | Left | | 3.45 ± 0.28 | 3.43 ± 0.26 | 3.86 ± 0.51 |

The overall average measurements for female right eye breadth was 3.47 ± 0.33 cm while the left side had a breadth measurement of 3.45 ± 0.28 cm. On average, the right height measurement for female patients was 3.43 ± 0.29 cm and the left side had 3.43 ± 0.26 cm. The overall left orbital depth of the female patient averaged 3.86 ± 0.51 cm and the right side had a mean of 3.87 ± 0.48 cm. Age group 18 – 29 years seemed to have the lowest average measurements for breadth.

***Table 4: Mean orbital volume for both eyes in relation to age and gender of the study subjects in cubed centimeters (cm³)***

| Age (years) | Gender | Frequency (n) | Eye laterality | |
|---|---|---|---|---|
| | | | **Right** | **Left** |
| 18 – 29 | Male | 114 | 21.94 ± 2.55 | 22.03 ± 2.46 |
| | Female | 53 | 20.90 ± 2.55 | 20.95 ± 2.88 |
| 30 – 39 | Male | 66 | 22.69 ± 2.71 | 22.59 ± 2.58 |
| | Female | 40 | 21.75 ± 2.86 | 21.69 ± 2.88 |
| 40 – 49 | Male | 38 | 23.05 ± 2.94 | 23.27 ± 3.05 |
| | Female | 16 | 21.14 ± 2.26 | 21.33 ± 2.03 |
| 50 – 59 | Male | 22 | 22.59 ± 4.08 | 22.73 ± 4.31 |
| | Female | 12 | 22.85 ± 2.22 | 23.19 ± 2.53 |
| 60 – 69 | Male | 22 | 22.35 ± 2.75 | 22.62 ± 2.80 |
| | Female | 19 | 23.29 ± 2.80 | 23.31 ± 2.82 |
| 70 – 79 | Male | 13 | 24.32 ± 3.28 | 24.32 ± 3.68 |
| | Female | 15 | 20.89 ± 2.67 | 20.57 ± 2.87 |
| 80 – 89 | Male | 12 | 22.96 ± 2.67 | 22.95 ± 2.62 |
| | Female | 9 | 20.87 ± 3.42 | 20.76 ± 3.79 |
| 90 – 99 | Male | 4 | 24.98 ± 2.60 | 25.46 ± 2.24 |
| | Female | 3 | 16.98 ± 0.04 | 17.02 ± 0.04 |
| Total | Male | 291 | 22.53 ± 2.87 | 22.61 ± 3.08 |
| | Female | 167 | 21.46 ± 2.80 | 21.48 ± 2.93 |

On average males had slightly larger right eye orbital volume that measured 22.53 ± 2.87 $cm^3$ compared to that of females which measured 21.46 ± 2.80 $cm^3$. Same to the left eye, where the male had a mean orbital volume of 22.61 ± 3.08 $cm^3$ compared to females who had a mean orbital volume of 21.48 ± 2.93 $cm^3$. There was no clear trend on average orbital volume by age group. The range of orbital volumes was 12.94 – 30.79 $cm^3$ for males and 13.42 – 30.74 $cm^3$ for females.

### 4.4 Objective two: To establish CT eyeball volumes at MTRH

***Table 5: Mean eyeball diameter for the right and left eyes in relation to age of the male subjects in centimeters***

| Age (years) | Frequency (n) | Eye laterality | AP diameter | Sagittal diameter | Transverse diameter |
|---|---|---|---|---|---|
| 18 – 29 | 114(39.2%) | Right | 2.46 ± 0.19 | 2.52 ± 0.26 | 2.50 ± 0.22 |
| | | Left | 2.45 ± 0.17 | 2.51 ± 0.25 | 2.54 ± 0.45 |
| 30 – 39 | 66(22.7%) | Right | 2.45 ± 0.14 | 2.47 ± 0.22 | 2.49 ± 0.17 |
| | | Left | 2.43 ± 0.14 | 2.50 ± 0.22 | 2.49 ± 0.18 |
| 40 – 49 | 38(13.1%) | Right | 2.43 ± 0.15 | 2.41 ± 0.16 | 2.49 ± 0.10 |
| | | Left | 2.43 ± 0.16 | 2.41 ± 0.15 | 2.49 ± 0.09 |
| 50 – 59 | 22(7.6%) | Right | 2.48 ± 0.11 | 2.46 ± 0.10 | 2.50 ± 0.08 |
| | | Left | 2.48 ± 0.11 | 2.47 ± 0.11 | 2.49 ± 0.08 |
| 60 – 69 | 22(7.6%) | Right | 2.40 ± 0.10 | 2.45 ± 0.15 | 2.42 ± 0.08 |
| | | Left | 2.43 ± 0.13 | 2.44 ± 0.18 | 2.42 ± 0.10 |
| 70 – 79 | 13(4.5%) | Right | 2.50 ± 0.14 | 2.50 ± 0.13 | 2.52 ± 0.14 |
| | | Left | 2.52 ± 0.12 | 2.51 ± 0.11 | 2.60 ± 0.27 |
| 80 – 89 | 12(4.1%) | Right | 2.40 ± 0.14 | 2.51 ± 0.16 | 2.48 ± 0.14 |
| | | Left | 2.42 ± 0.21 | 2.48 ± 0.15 | 2.45 ± 0.11 |
| 90 – 99 | 4(1.4%) | Right | 2.42 ± 0.19 | 2.49 ± 0.17 | 2.39 ± 0.21 |
| | | Left | 2.33 ± 0.20 | 2.39 ± 0.27 | 2.43 ± 0.18 |
| Total | 291 | Right | 2.45 ± 0.16 | 2.48 ± 0.21 | 2.49 ± 0.17 |
| | | Left | 2.45 ± 0.16 | 2.48 ± 0.21 | 2.51 ± 0.31 |

Overall, male anteroposterior (AP) diameter had a slightly lower average measurement for both right and left eye compared to sagittal and transverse diameter. However, the majority of male AP diameter, sagittal diameter and transverse diameter measurements had measurements ranging between 2.4 and 2.5 cm.

***Table 6: Mean eyeball diameter for the right and left eyes in relation to age of the female subjects in centimeters***

| **Age (years)** | **Eye laterality** | **Frequency (n)** | **AP diameter** | **Sagittal diameter** | **Transverse diameter** |
|---|---|---|---|---|---|
| 18 – 29 | Right | 53 (31.7%) | 2.36 ± 0.14 | 2.39 ± 0.15 | 2.42 ± 0.13 |
| | Left | | 2.34 ± 0.14 | 2.40 ± 0.19 | 2.42 ± 0.14 |
| 30 – 39 | Right | 40 (23.9%) | 2.38 ± 0.15 | 2.39 ± 0.12 | 2.44 ± 0.13 |
| | Left | | 2.40 ± 0.16 | 2.38 ± 0.12 | 2.44 ± 0.14 |
| 40 – 49 | Right | 16 (9.6%) | 2.41 ± 0.10 | 2.44 ± 0.13 | 2.47 ± 0.10 |
| | Left | | 2.41 ± 0.09 | 2.43 ± 0.15 | 2.55 ± 0.24 |
| 50 – 59 | Right | 12 (7.2%) | 2.49 ± 0.09 | 2.41 ± 0.12 | 2.46 ± 0.15 |
| | Left | | 2.45 ± 0.11 | 2.41 ± 0.11 | 2.47 ± 0.12 |
| 60 – 69 | Right | 19 (11.4%) | 2.42 ± 0.15 | 2.41 ± 0.12 | 2.47 ± 0.15 |
| | Left | | 2.42 ± 0.14 | 2.44 ± 0.13 | 2.46 ± 0.14 |
| 70 – 79 | Right | 15 (9.0%) | 2.33 ± 0.08 | 2.32 ± 0.15 | 2.37 ± 0.06 |
| | Left | | 2.33 ± 0.09 | 2.32 ± 0.16 | 2.38 ± 0.07 |
| 80 – 89 | Right | 9 (5.4%) | 2.33 ± 0.13 | 2.30 ± 0.15 | 2.43 ± 0.19 |
| | Left | | 2.35 ± 0.15 | 2.43 ± 0.36 | 2.43 ± 0.17 |
| 90 – 99 | Right | 3 (1.8%) | 2.41 ± 0.13 | 2.4 ± 0.23 | 2.57 ± 0.14 |
| | Left | | 2.40 ± 0.15 | 2.42 ± 0.20 | 2.57 ± 0.16 |
| Total | Right | 167 | 2.38 ±0.13 | 2.39 ± 0.14 | 2.44 ± 0.13 |
| | Left | | 2.38 ±0.14 | 2.40 ± 0.17 | 2.45 ± 0.15 |

The female anteroposterior, sagittal and transverse diameters had equal average measurement for both right and left eye averaging 2.4 cm. In addition, there was no clear incremental or decreasing trend in measurement over the age groups. The age group of 70 – 79 years had the lowest average eyeball diameter.

***Table 7: Mean eyeball volume in cm³ for both eyes in relation to age for both genders***

| **Age (years)** | **Gender** | **Frequency (n)** | **Eye laterality** | |
|---|---|---|---|---|
| | | | **Right** | **Left** |
| 18 – 29 | Male | 114 | 5.61 ± 0.88 | 5.56 ± 0.93 |
| | Female | 53 | 5.59 ± 1.11 | 5.46 ± 1.05 |
| 30 – 39 | Male | 66 | 5.28 ± 0.95 | 5.30 ± 0.90 |
| | Female | 40 | 5.27 ± 0.96 | 5.25 ± 0.96 |
| 40 – 49 | Male | 38 | 5.38 ± 0.89 | 5.35 ± 0.89 |
| | Female | 16 | 5.53 ± 1.18 | 5.54 ± 1.00 |
| 50 – 59 | Male | 22 | 5.24 ± 0.68 | 5.17 ± 0.68 |
| | Female | 12 | 5.52 ± 1.51 | 5.24 ± 1.50 |
| 60 – 69 | Male | 22 | 5.41 ± 0.97 | 5.40 ± 0.85 |
| | Female | 19 | 6.05 ± 1.38 | 5.86 ± 1.25 |
| 70 – 79 | Male | 13 | 5.57 ± 1.01 | 5.50 ± 0.81 |
| | Female | 15 | 5.01 ± 1.27 | 4.94 ± 1.07 |
| 80 – 89 | Male | 12 | 5.77 ± 1.24 | 5.59 ± 1.07 |
| | Female | 9 | 4.87 ± 0.92 | 4.83 ± 0.88 |
| 90 – 99 | Male | 4 | 5.26 ± 0.95 | 5.28 ± 0.83 |
| | Female | 3 | 6.92 ± 0.03 | 6.57 ± 0.22 |
| Total | Male | 291 | 5.46 ± 0.92 | 5.43 ± 0.89 |
| | Female | 167 | 5.49 ± 1.18 | 5.39 ± 1.10 |

The average right eyeball volume for female patients was larger measuring 5.49 ± 1.18 $cm^3$ compared to that of males which measured 5.46 ± 0.92 $cm^3$. Left eyeball mean volume for males measured 5.43 ± 0.89 $cm^3$ which was slightly larger than that of females which measured 5.39 ± 1.10 $cm^3$. The range of eyeball volume was 2.63 – 8.41 $cm^3$ for males and 2.2 – 8.58 $cm^3$ for females.

### 4.5 Objective three: To assess how Orbital and Eyeball volumes relate with age and gender at MTRH

*Table 8: Orbital volume in cm³ by gender, and laterality*

| Variable | Laterality | Category | Mean (SD) | Range | Statistic value | p-value |
|---|---|---|---|---|---|---|
| Gender | Right | Male | 22.53 (2.87) | 13.07 – 30.67 | $3.839^t$ | <0.001 |
| | | Female | 21.46 (2.80) | 14.98 – 30.74 | | |
| | Left | Male | 22.61 (2.87) | 12.94 – 30.79 | $4.008^t$ | <0.001 |
| | | Female | 21.48 (2.93) | 13.42 – 30.60 | | |
| Laterality | | Right | 22.14 (2.89) | 13.07 – 30.74 | $-0.298^t$ | 0.766 |
| | | Left | 22.20 (2.94) | 12.94 – 30.79 | | |

$^t$*t*-test

#### 4.5.1 Relation of orbital volumes and gender

On average, the male patients had a larger orbital volume of both eyes. It measured 22.53 ±2.87 cm³ on the right and 22.61 ±2.87 cm³ on the left compared to females whose mean volume measured 21.46 ±2.80 cm³ and 21.48 ±2.93 cm³ on the right and left sides respectively. This difference in means was statistically significant (p<0.001) for both eyes. However, there was no difference in orbital volume in regards to laterality of the eye (p=0.766).

### 4.5.2 Relation of orbital volumes and age

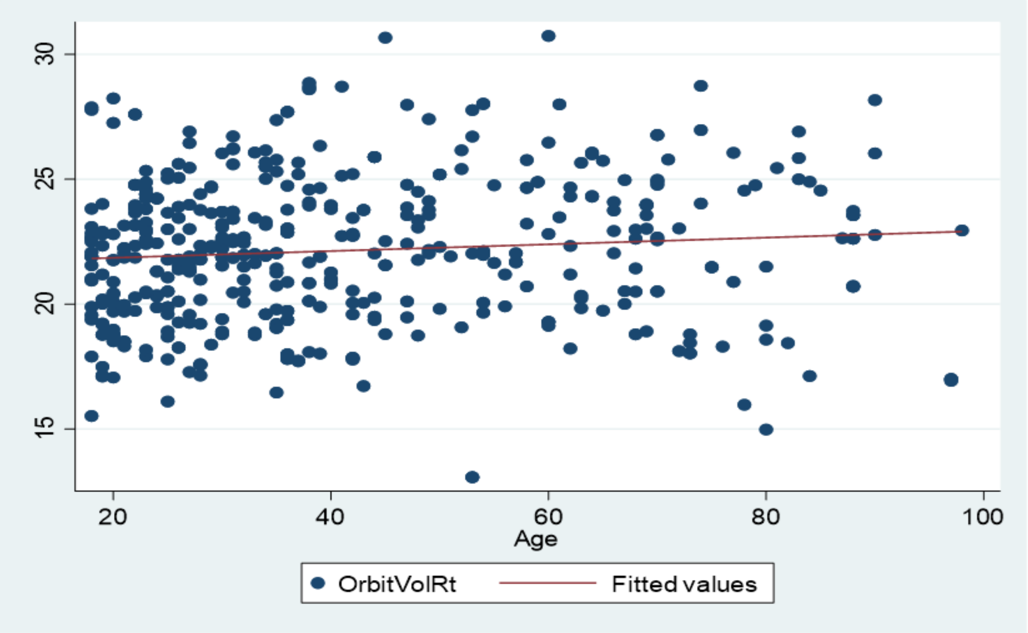



***Figure 41: Scatter graph for age and right orbital volume***

There was a positive correlation between age and right orbital volume though not statistically significant (r=0.0932, p=0.046). An increase in age was associated with an increase in the right orbital volume.

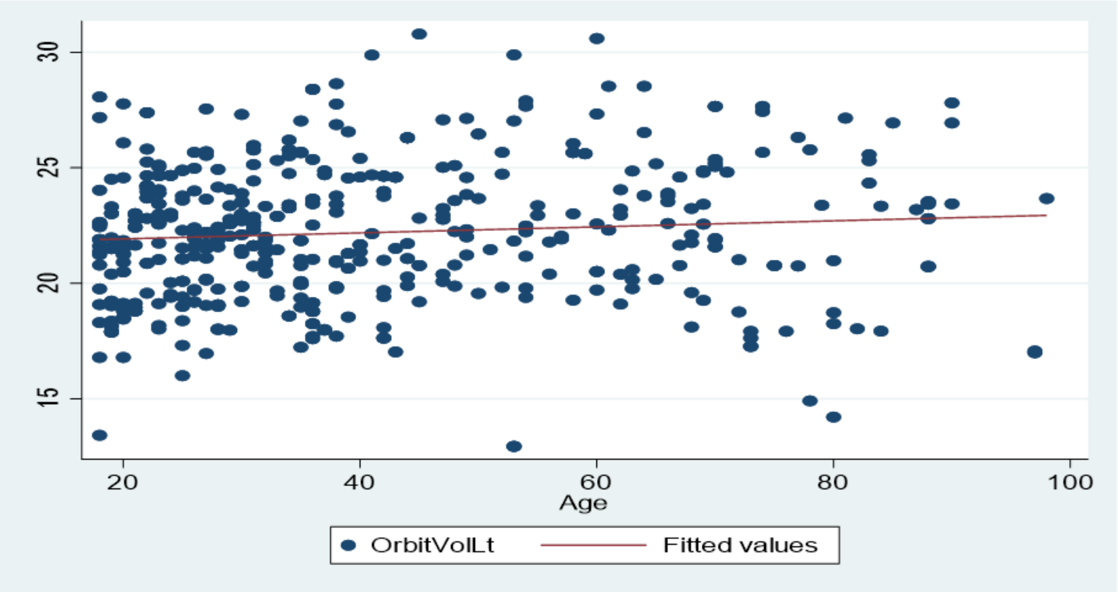



***Figure 42: Scatter graph for age and left orbital volume***

There was a positive correlation between age and left orbital volume though not significant (r=0.089, p<0.057). An increase in age was associated with an increase in the left orbital volume.

***Table 9: Eyeball volume in cm³ by age, gender, and laterality***

| **Variable** | **Laterality** | **Category** | **Mean (SD)** | **Range** | **Statistic value** | **p-value** |
|---|---|---|---|---|---|---|
| Gender | Right | Male | 5.46 (0.92) | 3.58 – 8.41 | | |
| | | Female | 5.49 (1.18) | 2.3 – 8.58 | -0.251[t] | 0.802 |
| | Left | Male | 5.43 (0.89) | 2.63 – 8.32 | | |
| | | Female | 5.39 (1.10) | 2.2 – 8.07 | 0.458[t] | 0.647 |
| Laterality | | Right | 5.47 (1.02) | 2.3 – 8.58 | | |
| | | Left | 5.41 (0.97) | 2.2 – 8.32 | 0.881[t] | 0.379 |

[t] *t*-test

### 4.5.3 Relation of eyeball volumes and gender

On average, the male patients had a slightly lower eyeball volume of right eye measuring 5.46 ± 0.92 cm³ compared to that of females which measured 5.49 ± 1.18 cm³. The difference was however not significant (p=0.802). The average male left eyeball volume was slightly larger measuring 5.43 ± 0.89 cm³ compared to that of females which measured 5.39 ± 1.10 cm³. The difference was also not statistically significant (p=0.647). The difference in eyeball volume was not statistically different with laterality of the eye (p=0.379).

### 4.5.4 Relation of eyeball volumes and age

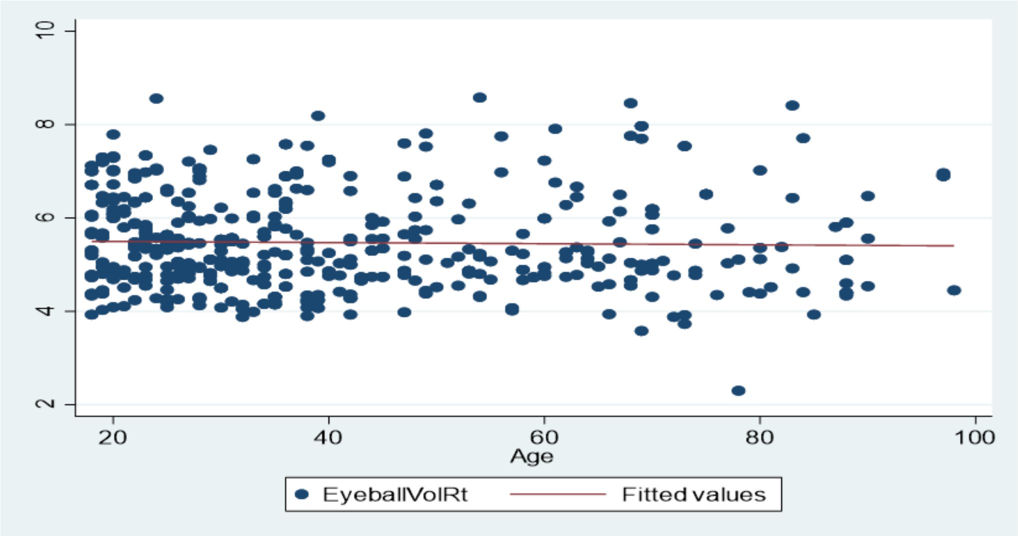



***Figure 43: Scatter graph for age and right eyeball volume***

There was a weak negative correlation between age and right eyeball volume (r=-0.024, p=0.612). An increase in age was associated with a decrease in the right eyeball volume.

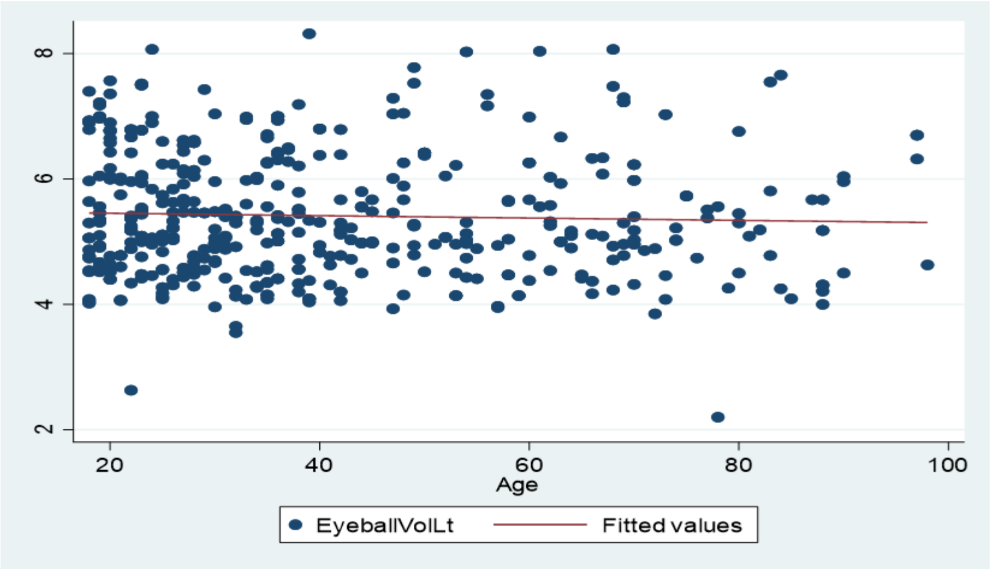



***Figure 44: Scatter graph for age and left eyeball volume***

There was a weak negative correlation between age and left eyeball volume (r=-0.039, p=0.405). An increase in age was associated with a decrease in the left eyeball volume.

# CHAPTER FIVE

## 5.0 DISCUSSION

### 5.1 Demographics

The distribution of gender in the 458 participants of the study was majorly male, comprising 63.5 %. This compares to studies where there was male preponderance in the study including Igbinedion & Ogbeide (2013) in Benin University Teaching Hospital, Nigeria where 61 % of participants were male, Shyu *et al*, (2015) in Chang Gung University Taiwan which had 50% males and a Middle East study by Khandekar (2016) which had 53% males. This could be attributed to probability and chance.

The age group with the largest number of patients was 18- 29 years contributing to 36.5 % followed by the 30-39 age group accounting to 23.1 %. This agreed with Igbinedion (2007) where the 20-29 years age group had the most number of participants. This is the largest population group in both the highlighted countries where youths account for the biggest fraction of the population (Bryceson *et al*., 2012).

### 5.2 Orbital Volumes at MTRH

#### 5.2.2 Orbital Measurements

The orbital dimensions measured in this study are orbital breadth, height and depth. The mean orbital breadth for males was 3.54 ± 0.28 cm on the right orbit and 3.53 ± 0.28 cm on the left. The overall average measurements for the female orbital breadth were smaller measuring 3.47 ± 0.33 cm on the right orbit and 3.45 ± 0.28 cm on the left. These breadth measurements were slightly lesser compared to Anibor & Ighodae (2016) measurements of the Nigerian orbit which had a mean orbital breadth of 4.00 ± 0.04 for the right eye and 3.96 ± 0.03 cm for the left. The findings were also lower compared to a study of South Indian orbits where the mean of male was 4.29 ± 0.27 cm while that of females was 4.0 ± 0.24 cm (Mekala *et al*., 2015). The South Indian orbit recorded a larger breadth measurement probably because measurements were obtained by measuring skulls. The findings were also slightly lower compared to Weaver *at al*., (2010) which established that the mean orbital breadth of patients in North Carolina USA was 3.69 ± 1.6 cm. It was however significantly higher compared to findings of Khademi & Bayat (2016) which found out that the mean orbital breadth of Iranians was 2.85 ± 0.24 cm. The differences can be explained by the difference in ethnicity among subjects in the various studies. The method applied in acquisition of the measurements can also give rise to difference, some studies involved direct measurement on skulls while others used images acquired through plain radiography and CT scanning.

The mean orbital height in this study for males was 3.49 ± 0.30 cm for the right orbit and 3.50 ± 0.30 cm for the left. The measurements were lesser for females at 3.43 ±0.29 cm for the right and 3.43 ± 0.26 cm for the left. The height measurements are slightly smaller compared to South Indian orbits that measured 3.62 ± 0.23 cm for the male and 3.45 ± 0.2 cm for the female (Mekala et al., 2015). The findings are however larger compared to the Nigerian orbital height measurement of 3.11 ± 0.06 cm for the right orbit and 3.10 ± 0.03 cm for the left (Anibor & Ighodae, 2016). The orbital height is also larger compared to Khademi & Bhayat (2016) that established Iranian orbital height as having a mean of 3.2 ± 0.2 cm and Weaver *et al*, (2010) that established North Carolina USA orbital height measurement as 3.2 ± 1.6 cm.

The mean orbital depth for the male orbit established in this study was 3.92 ± 0.43 cm for the right and 3.90 ± 0.44 cm for the left. The mean depth measurement for females is almost similar to the male, on the right being 3.87 ± 0.48 cm and 3.86 ± 0.51 cm on the left. The study findings of depth compare well with Khademi & Bhayat (2016) which established the depth of the Iranian orbit as 3.88 ± 0.4 cm applying the same CT technique and methodology. The slight difference is because of the dissimilarity in ethnicity of participants. These findings however contrast to Kenyan measurements established by Munguti *et al,* (2012) which established the depth of the orbital walls as 5.29 ± 0.29 cm for the right superior wall. The difference arose because of methodology, Munguti *et al,* (2012) study measured the length of the orbital walls as opposed to the current study that measured the midline orbital depth from the orbital rim plane to the anterior end of the optic canal.

### 5.2.2 Orbital Volumes at MTRH

Orbital volumes were obtained using a radiotherapy Eclipse software Version 16.1 tool that automatically yielded the volume upon tracing the orbital wall contours. The study found out that the overall mean volume of the male right orbit was 22.53 ± 2.87 $cm^3$ while the left was 22.61 ± 3.08 $cm^3$. The measurements were slightly less for the female orbit measuring 21.46 ± 2.8 $cm^3$ on the right and 21.48 ± 2.93 $cm^3$ on the left with statistical significance (p value = <0.001). These values compared well with dimensions reported in previous studies by Acer *et al*, (2011), Shyu *et al*, (2015), Du *et al*, (2019) and Jeong *et al*, (2021).

Acer *et al*, (2011) established the mean volume of the Turkish orbit as 18.47 ± 2.52 $cm^3$ for the female right orbit and 22.35 ± 3.05 $cm^3$ for the male right orbit. The male measurements compare well with the findings of the study while the female measurements show that the Kenyan female orbit is larger. The reason for this is that in the study, an adult population with an age range of 35-45 years was chosen as opposed to this study that obtained a range of 18- 98 years. The study also used 31 subjects which is a smaller number compared to the large number of 458 subjects in this study.

Shyu *et al,* (2015) in the study of the Taiwanese orbit using the reliable 3D calculation established that the male right orbit had an average volume of 24.3 ± 1.51 $cm^3$ while the female right one was 21.0 ± 1.21 $cm^3$. The female orbit compares well with the current study while the male Taiwanese orbit has larger volume. This can be attributed to the smaller number of subjects in the study, 20 aged 16-57 years as compared to the current study with 458 subjects. It could also mean that the Taiwanese orbit is larger compared to the Kenyan orbit.

It compares well also with Du *et al*, (2019) who established the volume of the Chinese orbit as 22.0 ± 2.2 $cm^3$ for males and 20.0 ± 1.5 $cm^3$ for females. The findings have a similar picture with the current study for both genders for adults. This can be attributed to the fact that the sample size of the study consisted of adults with a wide age range of 18-81 years, almost similar to the current study's range. Hence it can be said that there's no difference between measurements of the Kenyan orbit and the Chinese.

Jeong *et al*, (2021) established the volume of orbits for both African Americans and Caucasians as having means of 22.38 $cm^3$ and 23.22 $cm^3$ respectively. The Caucasian orbit was established as slightly larger than that of an African American. This study compares well with the current study particularly for the African Americans who are of a similar race with the subjects in this study. The Caucasian orbit is however slightly bigger compared to the current study's findings. This validates the fact that the orbit differs in size with ethnicity and environment (Munguti *et al*., 2013).

The study however contrasts with the findings of Bontzos *et al*, (2019) that established the Greek orbit volume as having a larger mean of 26.81 ± 0.59 cm³. This is a significantly larger volume as compared to the current study. The study however used a smaller sample of 54 adults aged between 23 and 82 years. The measurements of the study can also be attributed to a forthrightly larger orbit of the Greek population as compared to the current study's Kenyan population. Studies have shown that there is a difference in orbit size among various ethnicities (Munguti *et al*., 2013; Shyu *et al*, 2015).

***Table 10: Orbital volumes of various ethnicities reported on literature***

| Author | Orbital Volume (cm³) | Ethnicity /Continent | Imaging Modality | Notes |
|---|---|---|---|---|
| **Acer *et al.*, (2011)** | Male: 21.17 ±3.12<br>Female: 18.47 ±2.52 | Turkish/Europe | Computed Tomography | Used point counting method<br><br>Included 40 adults aged 35-45 years |
| **Shyu *et al.*, (2015)** | Male: 24.3 ±1.51<br>Female: 21.1 ±1.21 | Taiwanese/Asia | Computed Tomography | Used 3D Osirix software.<br><br>20 adults aged 16-57 years. |
| **Du *et al*, (2019)** | Male: 22 ±2.2<br>Female: 20.0 ±1.5 | Chinese/Asia | Computed Tomography | Used 3D Mimics software.<br><br>103 Chinese adults aged 19-81 years. |
| **Bontzos *et al.*, (2019)** | Mean orbital volume 26.81 ± 0.59 | Greek/Europe | Magnetic Resonance Imaging | Used open source imaging processing software 3D Slicer<br><br>54 Caucasian adults aged 23-82 years. |
| **Jeong *et al.*, (2021)** | **African Americans**<br>Males: 23.92<br>Females:20.83<br>Overall: 22.38<br><br>**Caucasians**<br>Males :24.17<br>Females: 22.28<br>Overall: 23.22 | American/North America | Computed Tomography | Used Osirix 3D software<br><br>60 adults aged 22-78 years. |
| Rotich, (2023) | **Males: 22.57 ± 2.98**<br>**Females: 21.47 ± 2.87** | **Kenyan/Africa** | **Computed Tomography** | **Used 3D Eclipse Software**<br><br>**458 subjects aged 1-98 years.** |

## 5.3 Eyeball Volumes at MTRH

### 5.3.1 Eyeball Measurements

The three measurements of the eyeball acquired were transverse, sagittal and anteroposterior diameters. They did not show a significant difference among the recorded figures. The mean diameters of the eye were 2.48 ± 0.2 cm for the males and 2.42 ± 0.2 cm for females. These measurements were slightly larger compared to Ogbeide, (2007) that found that the average diameter of the eyeball of a sample in Nigeria is 2.14 ± 0.04 cm. The slight difference may have arisen because the imaging modality used was ultrasonography or the size of the eyeball is smaller for the population studied in Nigeria compared to the population studied in Kenya. It compares well with an Israeli study that established the transverse, sagittal and axial dimensions of the eyeball as 2.43 cm, 2.37 cm and 2.34 cm respectively (Bekerman et al., 2014a). This study used the same imaging modality, CT scan hence could explain the similarity of the findings. It also compares well with Wiseman *et al.*, (2022) study in Edinburg, United Kingdom that established the axial eyeball length as 2.41 ± 0.1 cm. The study however used Magnetic Resonance Imaging (MRI) as the imaging modality.

### 5.3.2 Eyeball Volumes

The overall eyeball volume was 5.44 ± 0.91 $cm^3$ for females and 5.41 ± 1.14 $cm^3$ for males. These measurements compared well to Igbinedion & Ogbeide, (2013) at University of Benin Teaching Hospital, Benin, Edo, Nigeria that established the ocular mean volume of both eyes as 5.24 ±1.77 $cm^3$. The eyeball volumes did not differ significantly with laterality or gender. The similarity is attributable to the same African ethnicity of the subjects and possibly the use of the same modality of imaging

– CT scan. A wide range of subjects aged between 3 and 84 years was also chosen, which is similar to the current study.

The mean eyeball measurement is however smaller compared to Acer *et al*, (2011) at Erciyes University, Turkey that found the mean eyeball volumes of males and females as 7.47 $cm^3$ and 7.45 $cm^3$ respectively, Bontzos *et al*, (2019) at Heraklion University, Greece that found out the volume of eyeballs as 7.83 ± 2.27 $cm^3$, and Heymsfield *et al.*, (2016) at Baton Biomedical Research Center, Los Angeles, USA that established the eye volume as 6.35 $cm^3$ and 6.26 $cm^3$ for males and females respectively. This difference can be attributed to the Caucasian race adult nature of the participants selected for the study. The findings were also smaller compared to Ibinaye *et al*, (2014) at Ahmadu Bello University Teaching Hospital, Nigeria that determined the eyeball volume of males and females as 6.86 $cm^3$ and 6.75 $cm^3$ respectively. This slight difference is a result of the variance in regional ethnicity of the subjects and methodology used in the study. MRI modality was used and volume calculated from eyeball measurements using the mathematical formulae of a sphere - Volume = $^4/_3\pi r^3$.

***Table 11: Eyeball volumes of various ethnicities reported on literature***

| Author | Eyeball Volume ($cm^3$) | Ethnicity /Continent | Imaging Modality | Notes |
|---|---|---|---|---|
| **Acer *et al.*, (2011)** | Male: 7.32 ± 0.74<br>Female: 7.45 ± 1.19 | Turkish/Europe | Computed Tomography | Used point counting method<br><br>Included 40 adults aged 35-45 years |
| **Igbinedion & Ogbeide (2013)** | Mean Eyeball Volume: 5.28 ± 1.8<br>Male: 5.29<br>Female: 5.34 | Nigerian/Africa | Computed Tomography | Calculated volume using sphere formula method.<br><br>Included 200 adults aged 3 - 84 years. |
| **Ibinaye *et al.*, (2014)** | Male: 6.86±0.98<br>Female: 6.75 ± 1.01 | Nigeria/Africa | Magnetic Resonance Imaging (MRI) | Calculated volume using sphere formula method.<br><br>120 adults aged 1 month-77 years. |
| **Heymsfield *et al*, (2019)** | Male: 6.35<br>Female: 6.26 | American/America | Computed Tomography | Used a Stereology tool to trace eyeballs and obtain volume.<br><br>80 adults aged 20-35 years. |
| **Bontzos *et al.*, (2019)** | Mean: 7.83 ± 2.27 | Greek/Europe | Magnetic Resonance Imaging (MRI) | Used Osirix 3D software<br><br>54 Caucasian adults aged 23-82 years. |
| **Surekha *et al*, (2020)** | Male: 6.06<br>Females: 5.83 | Indian/Asia | Magnetic Resonance Imaging (MRI) | Calculated volume using sphere formula method.<br><br>425 patients aged 5 months to 88 years. |
| Rotich, (2023) | **Males: 5.41 ± 0.93**<br>**Females: 5.44 ± 1.14** | **Kenyan/Africa** | **Computed Tomography** | **Used 3D Eclipse Software**<br><br>**458 subjects aged 1-98 years.** |

## 5.4 Relation of orbital and eyeball volumes with age and gender at MTRH

### 5.4.1 Relation of Orbital Volumes and age

There was a positive correlation between age and orbital volume. An increase in age was associated with an increase in the volume of orbit with age. The orbital volume maintained an increasing upward trend up to old age in males. This compares well with Ugradar & Lambros (2019) at the University of California, USA that established that the orbital volume of elderly males aged 60 – 75 years were larger compared to those aged 18 - 30 years. It also agreed with Furuta (2000) at Fukushima Medical University, Japan that the male orbit increased rapidly up to the age of 15 years reaching 0.95 of adult size. Afterwards it grew gradually in size and had the likelihood of increasing in volume after the age of 40.

For females, the orbital volume was also noted to increase with age. The age with the largest orbital averaged volume is 60-69 years and afterwards a decreasing volume was noted with the older age groups. The average orbital volume of the 90 -99 years age group measured 16.93 $cm^3$. This compares to Chen (2006) who found out that the female orbit increases with age until the age of 40 after which there is minimal change and noted reduction in orbital volume at old age. This was attributed to possible hormonal changes that occur in females after menopause (Bontzos *et al*., 2019; Özer *et al.*, 2016).

There was however no clear trend on the average orbital volume by age group for both genders. This can be attributed to the fact that the orbit achieves 95% of its volume within the first two decades of life. The remaining 5% is attained slowly into adulthood up to the age of 40 years (Furuta, 2000; Smith *et al*., 2022). Therefore, no significant change was noted after the first two decade cohorts.

### 5.4.2 Relation of Orbital Volumes and gender

The male orbit had a significantly larger mean with a p value of $<0.001$. This is in agreement with studies by Furuta *et al*, (2000) at Fukushima Medical University, Japan that established that the male orbital volume was significantly larger as compared to the female orbit with measurements of 23.6 ± 2.0 $cm^3$ and of 20.9 ± 1.3 $cm^3$ for males and females respectively, Acer *et al*, (2011) in Turkey who found out the male orbit as significantly larger as compared to females measuring of 22.35 ± 3.1 $cm^3$ and 18.47 ± 2.5 $cm^3$ respectively, Bontzos *et al*, (2019) Heraklion, Greece that found the male orbit significantly larger than males as well with measurements of males and females as of 27.62 ± 0.38 $cm^3$ and of 25.34 ± 0.31 $cm^3$ respectively and Du *et al*, (2019) in Guangxi Medical University, China that found that the male orbit was significantly larger that the female measuring of 22 ± 2.2 $cm^3$ and of 20 ± 1.5 $cm^3$ respectively. This was attributed to hormonal difference among the two genders that are thought to influence bony growth (Özer *et al*., 2016).

### 5.4.3 Relation of Eyeball Volumes and age

There was negative correlation established between both right and left eyeball volumes with age. This compares well with Bekerman *et al* (2014) at Assaf Harofeh Medical Center, Tel Aviv University, Israel that established no significant difference in size of eyeball among different age groups in the adult population, Kim *et al.*, (2016) at Kangwon University Hospital, Korea that established no significant change in measurements of the eyeball in the adults selected aged between 20 – 94 years and Surekha *et al*, (2020) that similarly established no difference in age groups studied with the youngest and oldest at 5 months and 88 years of age respectively. This is attributed to the fact that the eyeball achieves its maximum dimensions and size at the age of about 18 years. After the age of 40 years, myopic and hyperopic changes as a result of change in axial length occur (Ibinaiye *et al*., 2014; Kim *et al*., 2016).

There was also noted associated decrease in eyeball volumes of both eyes in both genders with increase in age. This agrees with Igbenedion & Ogbeide (2012) at University of Benin Teaching Hospital, Nigeria that noted a reduction in eyeball volume after the age of 50 years and Ibinaye (2014) at University of Port Harcourt, Nigeria that established that the volume of eyeball started to reduce in size after the age of 40 years. This is associated with age degenerative changes that lead to shrinking of the eyeball. There was however no difference in volume reduction among the two genders.

**5.4.4 Relation of Eyeball Volumes and gender**

There was no statistically significant difference in the size of the eyeball with gender. The size of the right eye was slightly larger in females ($5.49 \pm 1.18$ $cm^3$) compared to males ($5.46 \pm 0.92$ $cm^3$). The left eyeball volume for females also had a slightly larger figure measuring $5.43 \pm 0.89$ $cm^3$ compared to males which measured $5.39 \pm 1.10$ $cm^3$. This is similar to findings of Acer *et al*, (2011) in Turkey, Bakerman *et al,* (2014) in Israel, Ozer *et al,* (2016) and Surekha *et al,* (2020) in India which established that there is no difference in eyeball volume with gender.

There was noted decrease in the size of the eyeball volume with increase in age for both genders that was however not quantified. This is agreement with Igbinedion & Ogbeide (2012), Ibinaye (2014) and Kim *et al*, (2016) which established that there was a decline in the size of the eyeball volume from the age of 40 years onwards.

## 5.5 Study Limitation

1. The findings of the study could not be used to represent the entire Kenyan population as patients selected were majorly from the Western region of Kenya. Other studies in other regions need to be done to get a true value of the Kenyan orbital and eyeball volumes.

# CHAPTER SIX

## 6.0 CONCLUSION AND RECOMMENDATION

### 6.1 Conclusion

1. The male orbital volume was larger with a mean of 22.57 ± 2.98 $cm^3$, while that of females had a mean of 21.47± 2.87 $cm^3$.
2. There was no difference in eyeball volume measurements among males and females measuring 5.41 ± 0.93 $cm^3$ and 5.44 ± 1.14 $cm^3$ respectively.
3. There is no significant difference in both eyeball and orbital volumes with age.

### 6.2 Recommendations

1. Differences in orbital volume with gender should be taken into consideration in orbital clinical practice and manufacture of oculoplastic implants.
2. With the noted difference, further studies need to be done to establish the pattern of volume growth and measurements of both the orbit and eyeball for the local pediatric population.

**REFERENCES**

Acer, N., Demir, M., Uçar, T., Pekmez, H., & Göktaş, A. (2011). Estimation of the eyeball and orbital volume using the cavalieri principle on computed tomography images. *Balkan Medical Journal*, *28*(2), 184–188. https://doi.org/10.5174/tutfd.2010.03473.3

Ahmed, A. S., El-banoby, T. M., & Shoaib, A. A. A. (2019). *Orbital Volume Evaluation post Orbital Fractures Restoration*. *77*(October), 5710–5717.

Alinasab, B., Beckman, M. O., Pansell, T., Abdi, S., Westermark, A. H., & Stjärne, P. (2011). Relative Difference in Orbital Volume as an Indication for Surgical Reconstruction in Isolated Orbital Floor Fractures. *Craniomaxillofacial Trauma & Reconstruction*, *4*(4), 203–211. https://doi.org/10.1055/s-0031-1286117

Anibor, E., & Ighodae, W. (2016). Orbital Index of Adult Binis in Edo State, Nigeria. *International Journal of Forensic Medical Investigation*, *2*(1), 17. https://doi.org/10.21816/ijfmi.v2i1.12

Bekerman, I., Gottlieb, P., & Vaiman, M. (2014). Variations in Eyeball Diameters of the Healthy Adults. *Journal of Ophthalmology*. https://doi.org/10.1155/2014/503645

Bekerman, I., Gottlieb, P., & Vaiman, M. (2014). Variations in Eyeball Diameters of the Healthy Adults. *Journal of Ophthalmology*, (*2014).*

Bontzos, G., Papadaki, E., Mazonakis, M., Maris, G. T., Kapsala, Z., Blazaki, S., … Detorakis, T. E. (2019). Quantification of effective orbital volume and its association with axial length of the eye. A 3D-MRI study. *Romanian Journal of Ophthalmology*, *63*(4), 360–366. https://doi.org/10.22336/rjo.2019.56

Botwe, B. O., Sule, D. S., & Ismael, A. M. (2017). *Radiologic evaluation of orbital index among Ghanaians using CT scan*. 4–9. https://doi.org/10.1186/s40101-017-0145-7

Bryceson, D. F., Njeru, L. K., Gichimu, B. M., Demographics, Y., Sumberg, J., Anyidoho, N. A., … Clejan, P. (2012). Regional Analysis of Youth Demographics: Kenya. *IDS Bulletin*, *2*(1999), 1–8. Retrieved from http://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/2257/FAC_Working_Paper_032.pdf?sequence=1%0Ahttp://onlinelibrary.wiley.com/doi/10.1111/j.1759-5436.2012.00374.x/full%0Ahttps://assets.publishing.service.gov.uk/media/5af9544740f0b622d7cc6e58/Ke

Dutton, J. J., & Waldrop, T. G. (2011). *Atlas of Clinical and Surgical Orbital Anatomy* (Second Edition). North Carolina: Elsevier Inc.

Furuta, M. (2000). Measurement of orbital volume by computed tomography - Especially on the growth of orbit -. *Journal of Japanese Ophthalmological Society*, *104*(10), 724–730. https://doi.org/10.1016/s0021-5155(00)00372-5

Ibinaiye, P. O., Maduforo, C. O., & Chinda, D. (2014). *Estimation of the Eyeball Volume on Magnetic Resonance Images in Zaria , Nigeria*. *1*(2), 82–85. https://doi.org/10.4103/2384-5147.136817

Igbinedion, B. O., & Ogbeide, O. U. (2013). Measurement of normal ocular volume by the use of computed tomography. *Nigerian Journal of Clinical Practice*, *16*(3), 315–319. https://doi.org/10.4103/1119-3077.113453

Irsch, K., Medicine, J. H., Guyton, D. L., & Medicine, J. H. (2009). *Anatomy of the Eyes*. (January), 10–16. https://doi.org/10.1007/978-0-387-73003-5

Jansen, J., Schreurs, R., Dubois, L., Maal, T. J. J., Gooris, P. J. J., & Becking, A. G. (2016). Orbital volume analysis: validation of a semi-automatic software segmentation method. *International Journal of Computer Assisted Radiology and Surgery*, *11*(1), 11–18. https://doi.org/10.1007/s11548-015-1254-6

Juma, W. C., Songole, R. S., Kinyanjui, D. W., & Ashraf, A. (2020). Risk Factors for Psychiatric Morbidity and Demographic Characteristics Among Patients with Facial Injury. *Journal of Anxiety & Depression*, *3*(1), 1–15. https://doi.org/10.46527/2582-3264.120

Kahn, D. M., & Shaw, R. B. (2008). Aging of the Bony Orbit: A Three-Dimensional Computed Tomographic Study. *Aesthetic Surgery Journal*, *28*(3), 258–264. https://doi.org/10.1016/j.asj.2008.02.007

Kaur, J., Yadav, S., & Singh, Z. (2012). Orbital dimensions□ A direct measurement study using dry skulls. *J. Acad. Indus. Res*, *1*(6), 293. Retrieved from www.answer.com/topic/megaseme.

Khademi, Z., & Bayat, P. (2016). Computed tomographic measurements of orbital entrance dimensions in relation to age and gender in a sample of healthy Iranian population. *Journal of Current Ophthalmology*, *28*(2), 81–84. https://doi.org/10.1016/j.joco.2016.03.002

Khandekar, R. (2016). Measurement of bony Orbital Volume with Computed Tomography (CT) in Healthy Eyes of Saudi Children. *Journal of Cancer Prevention & Current Research*, *6*(4). https://doi.org/10.15406/jcpcr.2016.06.00215

Kim, J. H., Kim, M., Lee, S. J., Han, S. B., Kong, Y. T., Yang, H. K., & Hyon, J. Y. (2016). Age-related differences in ocular biometry in adult Korean population. *BMC Ophthalmology*, *16*(1), 1–5. https://doi.org/10.1186/s12886-016-0328-8

Kokilam. (2010). *Dagnostic value of CT scan in orbital diseases with histopathological correlation*. (Branch III).

Manana, W. (2014). *An analysis of the pattern of orbital fractures at two referral teaching institutions in Nairobi by a dissertation submitted in partial fulfillment for the award of a master of dental surgery degree in oral and maxillofacial surgery*

Mekala, Shubha, & Rohini, D. (2015). Orbital Dimensions and Orbital Index: a Measurement Study on South Indian Dry Skulls. *International Journal of Anatomy and Research*, *3*(3), 1387–1391. https://doi.org/10.16965/ijar.2015.242

Munguti, J., Mandela, P., & Butt, F. (2012). Referencing orbital measures for surgical and cosmetic procedures. *Anatomy Journal of Africa*, *1*(1), 40-45–45.

Munguti, Mandela, & Butt. (2013). *Sex differences in the cranial and orbital indices for a black Kenyan population*. *International Journal of Medicine and Medical Sciences Vol. 5(2), pp. 81-84, February 2013*https://doi.org/10.5897/IJMMS12.134

Netter. (2010). *Atlas of human Anatomy*. *5*, 1–425.

Ogbeide, U. (2007). *Sonographic assessment of the normal eyeball diameters and volume in an African population by a dissertation submitted to the national postgraduate medical college of Nigeria. I*.

Özer, C. M., Öz, I. I., Şerifoglu, I., Büyükuysal, M. Ç., & Barut, Ç. (2016). Evaluation of eyeball and orbit in relation to gender and age. *Journal of Craniofacial Surgery*, *27*(8), E793–E800. https://doi.org/10.1097/SCS.0000000000003133

Samar, B. (2019). Basic anatomy of the eye, adnexa and visual pathways. In *Essentials of Ophthalmology* (Seventh, pp. 1–31).

Sentucq, C., Schlund, M., Bouet, B., Garms, M., Ferri, J., Jacques, T., & Nicol, R. (2020). Version of Record: https://www.sciencedirect.com/science/article/pii/S1748681520304575. *Science Direct*.

Shyu, V. B. H., Hsu, C. E., Chen, C. H., & Chen, C. T. (2015). 3D-assisted quantitative assessment of orbital volume using an open-source software platform in a Taiwanese population. *PLoS ONE*, *10*(3), 1–13. https://doi.org/10.1371/journal.pone.0119589

Smith, E. A., Halbach, C. S., Robertson, A. Z., Peterson, A. M., Harrison, A. R., Grünheid, T., … Mokhtarzadeh, A. (2022). Orbital volume changes during growth and development in human children assessed using cone beam computed tomography. *Head and Face Medicine*, *18*(1), 1–9. https://doi.org/10.1186/s13005-022-00310-9

Snell, R. (1998). *Clinical Anatomy of the Eye of the Eye* (Second).

Surekha, Naveen, Rajendra, Kiran, & Sai. (2020). Assessment of Normal Occular Volume Using Magnetic Resonance Imaging. *International Journal of Contemporary Medicine, Surgery and Radiology*, *5*(1), 2018–2020. https://doi.org/10.21276/ijcmsr.2020.5.1.59

Thaworanunta, S., & Shrestha, B. (2016). Orbital prosthesis fabrication: current challenges and future aspects. *Open Access Surgery*, 21. https://doi.org/10.2147/oas.s81435

Turvey, T. A., & Golden, B. A. (2012). Orbital Anatomy for the Surgeon. *Oral and Maxillofacial Surgery Clinics of North America*, *24*(4), 525–536. https://doi.org/10.1016/j.coms.2012.08.003

Weaver, A. A., Loftis, K. L., Tan, J. C., Duma, S. M., & Stitzel, J. D. (2010). CT based three-dimensional measurement of orbit and eye Anthropometry. *Investigative Ophthalmology and Visual Science*, *51*(10), 4892–4897.

Wiseman, S. J., Tatham, A. J., Meijboom, R., Terrera, G. M., Hamid, C., Doubal, F. N., … MacGillivray, T. (2022). Measuring axial length of the eye from magnetic resonance brain imaging. *BMC Ophthalmology*, *22*(1), 1–9. https://doi.org/10.1186/s12886-022-02289-y

Ye, J., Kook, K. H., & Lee, S. Y. (2006). *Evaluation of Computer-Based Volume Measurement and Porous Polyethylene Channel Implants in Reconstruction of Large Orbital Wall Fractures*. *M*, 509–513. https://doi.org/10.1167/iovs.05-0816

Zhang, J. (2020). *Eye Anatomy & Function*.

# APPENDICES

## Appendix I: Consent Form
**English Version**

**Investigator**: My name is Dr. Rotich Kelvin Cheruiyot, a qualified medical doctor registered with the Kenya Medical Practitioners and Dentist Council (KMPDC). I am currently undertaking my Master's degree in Radiology and Imaging at Moi University. I would appreciate it if you accept my request to recruit you into my study of the normal orbital and ocular volumes in relation to age and gender at MTRH radiology department.

**Purpose:** This study will aim to determine the normal adult orbital and ocular volumes in relation to age and gender at MTRH.

**Procedure:** Adult patients sent for head CT scan for various indications will be screened to rule out ophthalmologic conditions that affect size of orbit and eyeball. Demographic data will be acquired and then be sent for the head CT scan at MTRH, Eldoret. The scan will then be analyzed to obtain orbital and eyeball dimensions and recorded in a questionnaire. Data collection forms will be kept in safe lockable cabinets during the study period.

**Benefits:** The benefit of the study is limited to knowledge and research purposes. There is no direct gain for taking part in the study. Study subjects shall be accorded similar quality of service as non- study subjects.

**Risks:** No risk is anticipated as a result of the subject participating in the study.

**Confidentiality:** All information acquired from the study will be kept confidential and shall not be shared to any unauthorized entity.

**Right to Refuse:** All subjects are advised that participation is fully voluntary and have freedom to refuse to take part or pull out from the study at any time. This study will be approved by the Institutional Research and Ethics Committee (IREC) of Moi University/Moi Teaching and Referral Hospital.

Please sign to agree to take part in this study.

Patient/Guardian ………...…Investigator ………….…Date ........./……. / 202……

**Kiswahili Version**

**Mpelelezi:** Jina langu ni Daktari ROTICH Kelvin Cheruiyot. Mimi ni daktari aliyefuzu na kusajiliwa na Baraza la kudhibiti Madaktari nchini Kenya. Ninasomea shahada la uzamili kwenye Idara ya Radiologia na Taswira katika Chuo Kikuu cha Moi. Naomba nikusajili kwenye utafiti wangu unaoangalia ujazo wa kawaida wa macho na pango-jicho za wagonjwa ikitumia picha za CT katika Hospitali ya Rufaa ya Moi.

**Kusudi:** Utafiti huu utajaribu kubainisha ujazo wa kawaida wa jicho na ambapo jicho yakaa kwenye nyuso za wananchi waliofanyiwa CT scan katika Hospitali ya Rufaa ya Moi, Eldoret, Kenya.

**Utaratibu:** Wagonjwa walio katika hali njema watakaotumwa kufanyiwa CT scan ya kichwa kwa sababu zozote isipokuwa ugonjwa za macho watapimwa katika Idara ya Opththalmology kuhakikisha kwamba hawana magonjwa zinazoweza kubadilisha ujazo wa macho. Takwimu zao zitanakiliwa kwenye fomu kisha kufanyiwa CT scan katika hospitali ya MTRH. Picha zitakozonakiliwa zitatumika kupima ujazo wa macho na "pango-jicho". Vipimo vitanakiliwa kwenye fomu kisha kuwekwa vizuri katika kabati salama inayofungwa na kufuli.

**Faida:** Hakuna faida ya moja kwa moja atakayopewa yule mgonjwa atakayechaguliwa kwenye utafiti huu. Wagonjwa watakaoshiriki kwenye utafiti huu watapewa matibabu sawia na wagonjwa ambao hawatahusishwa.

**Usiri:** Habari zozote ambazo zitapatikana kwenye utafiti huu zitawekwa kwa siri inayofaa na hazitatolewa kwa mtu yeyote asiyehusika na utafiti huu.

**Haki ya Kukataa:** Kushiriki katika utafiti huu ni kwa hiari ya mtu binafsi. Kuna uhuru wa kukataa kushiriki au kujiondoa kwenye utafiti huu wakati wowote. Utafiti huu umepitishwa na Kamati ya Maadili (IREC) ya Chuo Kikuu cha Moi na Hospitali ya Rufaa ya Moi.

Tafadhali weka sahihi au alama kama umekubali kushiriki katika utafiti huu.

Mzazi / Mlezi: ....................... Mpelelezi: ....................... Tarehe: ........./……./202….

## Appendix II: Questionnaire for eyeball and orbital volume

Thank you for accepting to take in this study

I would like to ask questions that would help me in establishing the normal orbital and eyeball volumes as obtained using Computed Tomography (CT) at Moi Teaching and Referral Hospital (MTRH).

### SECTION A: DEMOGRAPHIC INFORMATION

Date ………………………. Study Number: …………………………….

Age ………………………..

Gender ……………………. Male ☐ Female ☐

County of Residence …………………………………

Occupation ……………………………………………

### SECTION B: ORBIT MEASUREMENTS AND VOLUME

| Breadth | | | Height | | | Depth, h | | | Volume | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Right** | **Left** | | **Right** | **Left** | | **Right** | **Left** | **Right** | **Left** |
| **Average breadth** | | | **Average height** | | | **Average depth, h** | | | | |

## SECTION C: EYEBALL MEASUREMENTS AND VOLUME

| **Anteroposterior (AP) diameter** | | | **Sagittal diameter** | | | **Transverse diameter** | | | **Volume** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Right** | **Left** | | **Right** | **Left** | | **Right** | **Left** | **Right** | **Left** |
| **Average AP diameter** | | | **Average sagittal diameter** | | | **Average Transverse diameter** | | | | |

***Thank you for your cooperation***

**Appendix III: Participant Screening Tool**

**SECTION A: OPHTHALMIC HISTORY**

Do you wear spectacles? Yes ☐ No ☐

If yes, which of the refractive errors do you have?

Short sightedness ☐ long sightedness ☐ don't know ☐

Do you suffer from any eye condition? Yes ☐ No ☐

If yes, which condition is it? …………………………………………………

Have you ever sustained injury to the eye? Yes ☐ No ☐

Have you undergone any surgical procedure of the eye? Yes ☐ No ☐

Do you suffer from any of the following conditions? Tick if yes

(i) Hypertension ☐
(ii) Hyperthyroidism ☐
(iii) Diabetes ☐

**SECTION B: OPHTHALMIC EXAMINATION FINDINGS**

**General Examination**

**Eyelids:** Any scars? Yes ☐ No ☐

Asymmetry? Yes ☐ No ☐

Squint? Yes ☐ No ☐

**Visual Acuity - using Snellen chart**

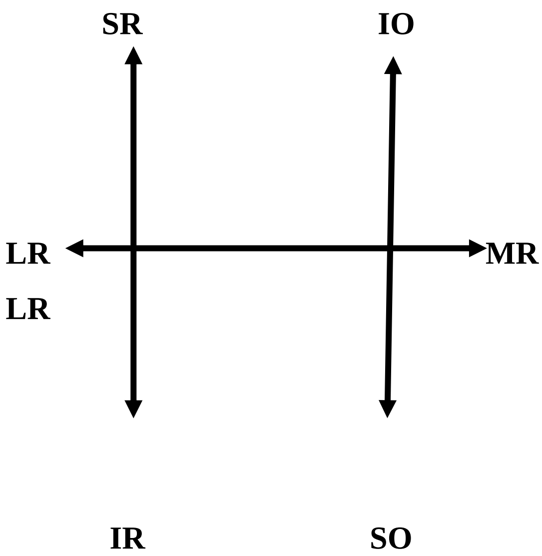
**Right Eye: 6/---------**

**Left Eye: 6/---------**

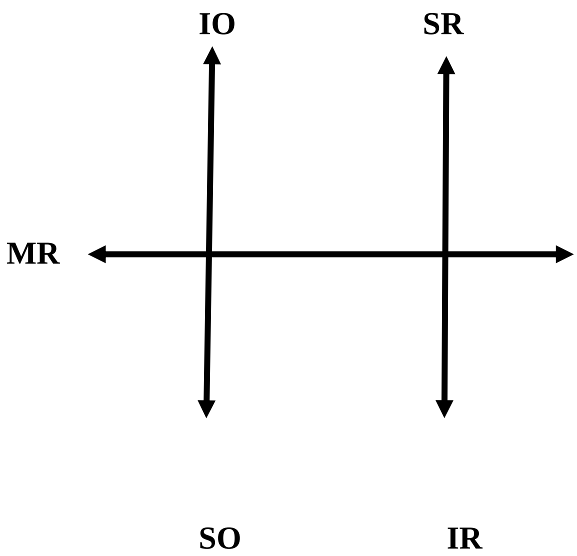
**Extraocular Muscle Movement**

Indicate with (-) in case of an underactive muscle, leave blank if normal.

**Right Eye**




**Left Eye**




**<u>KEY</u>**

SR – Superior Rectus

LR – Lateral Rectus

IR – Inferior Rectus

SO – Superior Oblique

IO – Inferior Oblique

**Appendix IV: Time Schedule**

| ***Activities*** | ***YEAR 2021*** | | ***2022*** | | ***2023*** |
|---|---|---|---|---|---|
| | ***January – March*** | ***April-August*** | ***January - August*** | ***December*** | ***January - October*** |
| Proposal Writing, Corrections, Submission, IREC approval and defense. | | | | | |
| Piloting Instruments and Data Collection | | | | | |
| Data Processing and Analysis | | | | | |
| Project Report Preparation and Submission | | | | | |
| Defense and final submission. | | | | | |

**Source: (*Researcher, 2021)***

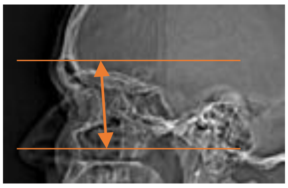
**Appendix V: Estimated Project Budget**

| ITEM | QUANTITY | UNIT PRICE | TOTAL |
|---|---|---|---|
| Laptop computer | 1 | 100,000 | **100,000** |
| Printing and binding services | | | **18,000** |
| Data collection costs | | | **50,000** |
| Compact discs storage of images plus writing | 500 | 20 | **10,000** |
| Internet services | | | **10,000** |
| Statistical consultation services | | | **50,000** |
| Miscellaneous | | | **25000** |
| **Total** | | | **263,000** |

## Appendix VI: Orbital CT Protocol

**MTRH ORBIT CT PROTOCOL (MTRH records, 2020)**

**Philips 64 Slice**

| | |
|---|---|
| Position | Supine head first |
| Topogram Direction | Caudocranial |
| Respiratory Phase | Any |
| Scan type | Helical |
| KV/mA/Rotation time (sec)<br>Pitch<br>Noise Index/ASir/Dose Reduction | 120/Smart mA 150-250/1.0<br>0.8<br>10.0/30/30% |
| Detector width x Rows | 128 x 0.6 mm |
| Slice thickness (mm) | 0.6 |
| Scan Start/End Locations<br><br>DFOV | Sinus: 1cm inferior from the maxilla /1cm superior from frontal sinus<br><br>25cm, decrease appropriately |
| Angulation of gantry | 20° |
| IV Contrast type/volume/rate/Delay | Omnipaque 300/80 mL/2.5 mL/sec/60 secs |
| 2D/3D Technique Used | DMPR 5mm x 5mm **axial orbital reformats** average mode, auto transferred to PACS<br>**Comments:** Recon 1 is a thin standard algorithm for DMPR. Recon 2 is the bone algorithm |
| Reconstructions and Reformation | Coronal and sagittal MPRs made in examination cards using raw data in bone and soft tissue kernels. If unable to place the patient in ideal position, make axial MPRs parallel to the optic nerve in bone and soft tissue kernels. If performed with and without IV contrast, create ALL reformats on both data sets—unenhanced and enhanced series. |

## Appendix VII: IREC Approval

**INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)**

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471//2/3

MOI UNIVERSITY
COLLEGE OF HEALTH SCIENCES
P.O. BOX 4606
ELDORET
Tel: 33471/2/3

Reference: IREC/2021/99

12th August, 2021

***Approval Number: 0003944***

Dr. Kelvin Cheruiyot Rotich,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
**ELDORET-KENYA.**

Dear Dr. Rotich,

**COMPUTED TOMOGRAPHY OBTAINED ORBITAL AND EYEBALL VOLUMES IN RELATION TO AGE AND SEX AT MOI TEACHING AND REFERRAL HOSPITAL**

This is to inform you that ***MTRH/MU-IREC*** has reviewed and approved your above research proposal. Your application approval number is ***FAN: 0003944.*** The approval period is **12th August, *2021- 11th August, 2022.***

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, Material Transfer Agreements (MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***MTRH/MU-IREC***.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***MTRH/MU-IREC*** within 72 hours of notification.
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***MTRH/MU-IREC*** within 72 hours.
v. Clearance for export of biological specimens must be obtained from ***MOH at the recommendation of NACOSTI*** for each batch of shipment.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to ***MTRH/MU-IREC.***

Prior to commencing your study; you will be required to obtain a research license from the National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and other relevant clearances from study sites including a written approval from the CEO-MTRH which is mandatory for studies to be undertaken within the jurisdiction of Moi Teaching & Referral Hospital (MTRH) and its satellites sites.

Sincerely,

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
12 AUG 2021
APPROVED
P.O. Box 4606-30100 ELDORET

**PROF. E. WERE**
**CHAIRMAN**
**INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| cc | CEO | - | MTRH | Dean | - | SOP | Dean | - | SOM |
| | Principal | - | CHS | Dean | - | SON | Dean | - | SOD |

## Appendix VIII: Hospital Approval

An ISO 9001:2015 Certified Hospital

**MOI TEACHING AND REFERRAL HOSPITAL**

Telephone :( +254)053-2033471/2/3/4
Mobile: 722-201277/0722-209795/0734-600461/0734-683361
Fax: 053-2061749
Email: ceo@mtrh.go.ke/directorsofficemtrh@gmail.com

Nandi Road
P.O. Box 3 – 30100
**ELDORET,** KENYA

**Ref:** ELD/MTRH/R&P/10/2/V.2/2010

13th August, 2021

Dr. Kelvin Cheruiyot Rotich
Moi University
School of Medicine
P.O. Box 4606-30100
**ELDORET-KENYA**

**COMPUTED TOMOGRAPHY OBTAINED ORBITAL AND EYEBALL VOLUMES IN RELATION TO AGE AND SEX AT MOI TEACHING AND REFERRAL HOSPITAL**

You have been authorised to conduct research within the jurisdiction of Moi Teaching and Referral Hospital (MTRH) and its satellites sites. You are required to strictly adhere to the regulations stated below in order to safeguard the safety and well-being of staff, patients and study participants seen at MTRH.

1 The study shall be under Moi Teaching and Referral Hospital regulation.
2 A copy of MTRH/MU-IREC approval shall be a prerequisite to conducting the study.
3 Studies intending to export human bio-specimens must provide a permit from MOH at the recommendation of NACOSTI for each shipment.
4 No data collection will be allowed without an approved consent form(s) to participants unless waiver of written consent has been granted by MTRH/MU-IREC.
5 Take note that **data** collected must be treated with due confidentiality and anonymity.

The continued permission to conduct research shall only be sustained subject to fulfilling all the requirements stated above.

13/08/2021

**DR. WILSON K. ARUASA, *EBS***
**CHIEF EXECUTIVE OFFICER**
**MOI TEACHING AND REFERRAL HOSPITAL**

MOI TEACHING AND REFERRAL HOSPITAL
CEO
APPROVED
13 AUG 2021
SIGN...............................
P. O. Box 3-30100, ELDORET

cc - Senior Director, Clinical Services
- Director, Nursing Services
- HOD, HRISM

*All correspondence should be addressed to the Chief Executive Officer*
*Visit our Website:* ***www.mtrh.go.ke***
TO BE THE LEADING MULTI-SPECIALTY HOSPITAL FOR HEALTHCARE, TRAINING AND RESEARCH IN AFRICA

## Appendix IX: NACOSTI certificate of approval

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **751814**

Date of Issue: **13/September/2021**

**RESEARCH LICENSE**

**This is to Certify that Dr.. Kelvin Cheruiyot Rotich of Moi University, has been licensed to conduct research in Uasin-Gishu on the topic: COMPUTED TOMOGRAPHY OBTAINED ORBITAL AND EYEBALL VOLUMES IN RELATION TO AGE AND SEX AT MOI TEACHING AND REFERRAL HOSPITAL for the period ending : 13/September/2022.**

License No: **NACOSTI/P/21/12905**

**751814**

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

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