THE PREVALENCE OF ANATOMICAL VARIATIONS IN THE INTRAORBITAL PART OF THE OPHTHALMIC ARTERY AND ITS BRANCHES IN CADAVERS

by

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DECLARATION

I, Kentse Sana Mpolokeng declare that the master's research dissertation that I herewith submit at the University of the Free State is my independent work and that I have not previously submitted it for a qualification at another institution of higher education.

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SUMMARY

The human orbit contains various important structures that may show variations relating to their anatomy. This study focused on the intraorbital part of the ophthalmic artery in a South African cadaver sample in the Free State (UFS) and Western Cape provinces (UCT).

Meyer pioneered the study of the ophthalmic artery as far back as 1887, with a main focus on its branches and their variations. Very limited investigation has been carried out in this field and available literature has little information on this. Currently no published data exists on the South African population with regard to intraorbital variations within the ophthalmic artery and its branches.

Original research was conducted to address the problem of the lack of data. Dissections of the eyes were done to investigate and document the possible variations of the intraorbital part of the ophthalmic artery and its branches.

The aim of the study was to determine the prevalence of anatomical variations in the intraorbital part of the ophthalmic artery and its branches in a cadaver sample. The results of the study will be of value to surgical interventionists treating patients with vascular diseases within the orbital region and also to the ophthalmology students studying the orbital vascular anatomy.

A total number of 59 cadavers were utilised, and 118 eyes were dissected under the lighted magnifier and observed for variations. The sample consisted of 23 cadavers (46 eyes) from the Department of Basic Medical Sciences of the University of the Free State, and 36 cadavers (72 eyes) from the Department of Human Biology of the University of Cape Town. Sixteen types of variations were observed and documented.

The ophthalmic artery crossed below the optic nerve in the left eye in 7.63% of cadavers at both institutions. No ophthalmic artery crossed below the optic nerve in the right eye in the UCT group, whereas 17.39% in the UFS group crossed below the optic nerve. Statistical analyses determined the frequencies of the variations. In certain individuals there were more than one type of variation which is in agreement with published literature. The majority of variations in branching patterns occurred bilaterally and in most cases, the variation in the left eye differed from the variation in the right eye. Males showed a higher frequency of variations.

These findings may well contribute to clinical application in ophthalmology and radiology while it will also inform anatomy students studying the blood supply to the eye and surrounding structures.

Keywords: Ophthalmic artery, optic nerve, variation, cadaver, UFS (University of the Free State), UCT (University of Cape Town), intraorbital, human orbit, dissections.

OPSOMMING

Die voorkoms van anatomiese variasies in die intraorbitale deel van die oftalmiese arteria en sy vertakkings in kadawers

Die menslike oog bevat verskeie belangrike strukture wat moontlik variasies kan toon wat verband hou met hul anatomie. Hierdie studie fokus op die intraorbitale deel van die oftalmiese arterie in 'n Suid-Afrikaanse kadawersteekproef in die Vrystaat (UV) en die Wes-Kaapse (UCT) provinsies.

Meyer was alreeds in 1887 die voorloper van studies van die oftalmiese arterie en het veral gefokus op die vertakkings en hul variasies. Slegs beperkte ondersoeke op hierdie terrein is gedoen en beskikbare literatuur bevat min inligting oor die onderwerp. Tans is daar geen gepubliseerde data beskikbaar oor die Suid-Afrikaanse bevolking met betrekking tot intraorbitale variasies binne die oftalmiese arterie en sy vertakkings nie.

Oorspronklike navorsing is gedoen om die probleem van die gebrek aan data aan te spreek. Disseksies van die oog is uitgevoer om die moontlike variasies van die intraorbitale deel van die oftalmiese arterie en sy vertakkings te ondersoek en te dokumenteer.

Die doel van die studie was om die voorkoms van anatomiese variasies in die intraorbitale deel van die oftalmiese arterie en sy vertakkings in 'n kadawersteekproef te bepaal. Die resultate van die studie sal waardevol wees vir chirurge wat intervensies doen op pasiënte met vaskulêre siektetoestande binne die orbit en ook vir oftalmologiestudente wat die anatomie van die orbit bestudeer.

In totaal is 59 kadawers bestudeer en 118 oë is gedissekteer onder 'n verligte vergrootglas, en die variasies is waargeneem. Die steekproef het bestaan uit 23 kadawers (46 oë) van die Departement Basiese Mediese Wetenskappe van die Universiteit van die Vrystaat (UV) en 36 kadawers (72 oë) van die Departement van Mensbiologie van die Universiteit van Kaapstad (UCT). Sestien tipes variasies is waargeneem en gedokumenteer.

Die oftalmiese arterie van die linkeroog het in 7.63% van kadawers van beide instansies die optiese senuwee onder gekruis. Geen oftalmiese arterie het onder die optiese senuwee in die regteroog gekruis in die UCT groep nie, terwyl dit in 17.39% van die UV groep voorgekom het. Statistiese analises het die frekwensie van die variasies bepaal. By sommige individue was daar meer as een tipe variasie, wat in ooreenstemming is met bevindinge in gepubliseerde literatuur. Die meerderheid variasies in vertakkingspatrone het bilateraal plaasgevind en in die meerderheid gevalle het die variasie in die linkeroog verskil van die variasie in die regteroog. Manlike persone het ’n groter frekwensie van variasie vertoon.

Hierdie bevindinge mag inderdaad bydra tot kliniese aanwending in oftalmologie en radiologie terwyl dit ook anatomiestudente wat die bloedtoevoer tot die oog en omliggende strukture bestudeer van inligting voorsien.

Sleutelwoorde: Oftalmiese arterie, optiese senuwee, variasie, kadawer, UV (Universiteit van die Vrystaat), UCT (Universiteit van Kaapstad), intraorbitaal, menslike orbit, disseksies.

LIST OF ABBREVIATIONS

Abbreviations of artery names used in the study

ACA	Anterior choroidal artery
AEA	Anterior ethmoidal artery
CRA	Central retinal artery
DNA	Dorsal nasal artery
DOA	Dorsal ophthalmic artery
DS	Dural Sheath
ECA	External carotid artery
I	Inferior
ICA	Internal carotid artery
LA	Lacrimal artery
LPCA	Long posterior ciliary artery
MA	Meningeal artery
MBChB	Medicinae Baccalaureus, Baccalaureus Chirurgiae
MMA	Middle meningeal artery
MPA	Medial palpebral arteries
MPCA	Medial palpebral ciliary artery
N	Nasal
OA	Ophthalmic artery
OAC	Ophthalmic artery chemotherapy
Orb. Per.	Orbital Periosteum
OC	Optic Canal
ON	Optic nerve
PDOA	Primitive dorsal ophthalmic artery
PEA	Posterior ethmoidal artery
PPS	Point of Penetration of the dural Sheath.

Pr DOA	Primitive dorsal ophthalmic artery
Pr VOA	Primitive ventral ophthalmic artery
PVOA	Primitive ventral ophthalmic artery
S	Superior
SA	Stapedial artery
SAS	Statistical analysis software
SOA	Supraorbital artery
SOF	Supraorbital fissure
SPCA	Short posterior ciliary artery
STA	Supratrochlear artery
T	Temporal
TR	Tendinous ring
VOA	Ventral ophthalmic artery
UCT	University of Cape Town
UFS	University of the Free State

THE PREVALENCE OF ANATOMICAL VARIATIONS IN THE INTRAORBITAL PART OF THE OPHTHALMIC ARTERY AND ITS BRANCHES IN CADAVERS

CHAPTER 1

ORIENTATION TO THE STUDY

1.1. INTRODUCTION

The variations in the ophthalmic artery (OA) and its branches were first described by Meyer in 1887 (Hayreh, 1962c:212). Hayreh (1962c:212) further noted that little information regarding the branches and their anomalies was available in literature but more recent anatomical studies have described the OA in more detail, resulting in valuable data on its embryology and anatomy (Carmona, Castellanos, Catalina-Herrera & Jiménez-Castellanos, 1995:139). As far back as the early 1960's, Hayreh and Dass (1962b), and more recently Hayreh in 2006 and Remington in 2012, reported that the artery shows great variability not only in its course and relationships, but also in the sites of its origin and number of its collateral branches, as illustrated in Figure 1.1.

Embryological development plays a major role in the later development of the vascular system through all the notable stages (Alvarez, Rodesch, Garcia-Monaco and Lasjaunias 1990:294).

Three stages of influence in the developmental history of the vascular system were reported by Hayreh and Dass (1962b:182) as had been postulated by Roux in 1878 namely:

i) Initially entirely dependent on genetic factors,
ii) A transitional stage in which hereditary formation is gradually supplemented by adaptational factors, and
iii) The influence of haemodynamic factors.

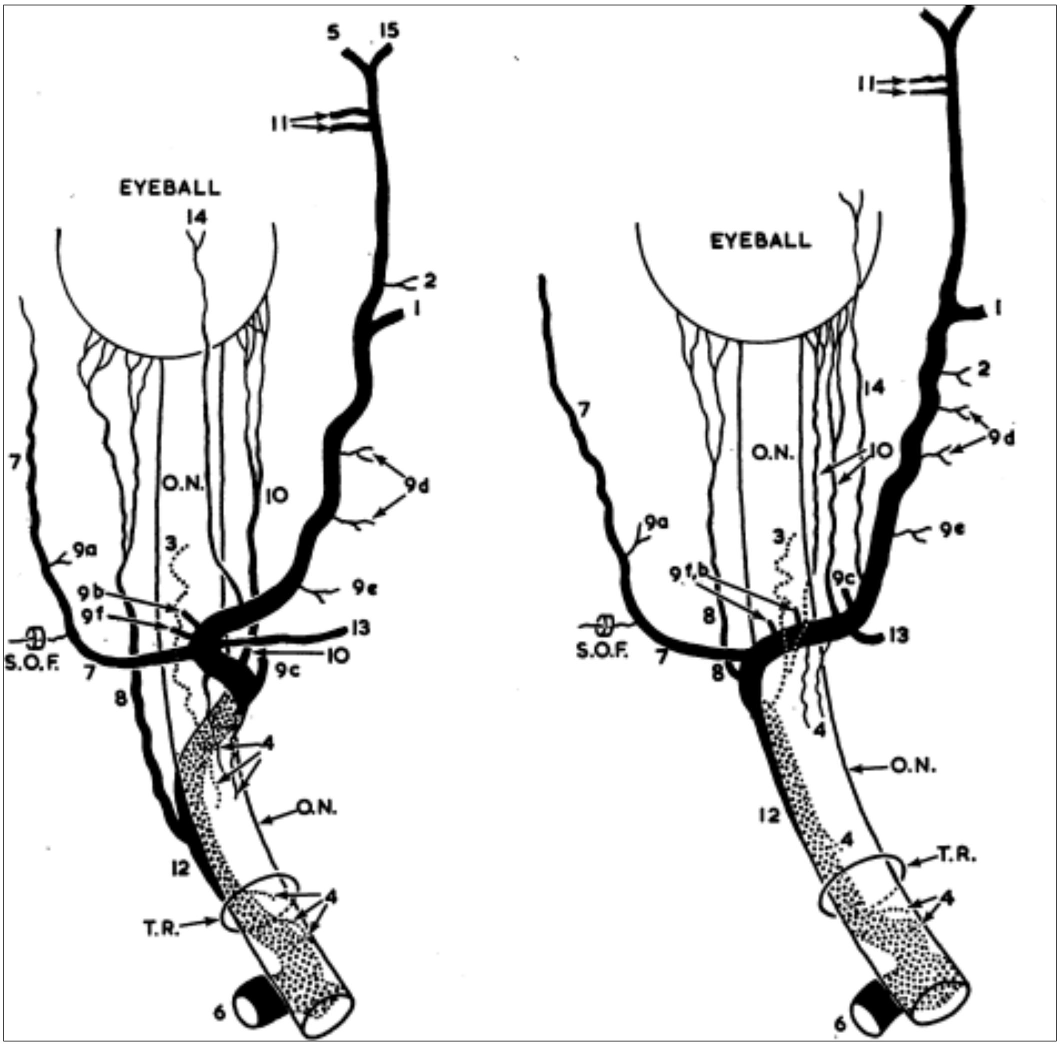

Figure 1.1: **The pattern of the branches of the ophthalmic artery when it crosses under the optic nerve (left) and the pattern of the branches of the ophthalmic artery when it crosses over the optic nerve (right) as described by Meyer in 1887**. **Adapted from Hayreh (1962c**:**215). ON= Optic Nerve, SOF= Superior Orbital Fissure, TR= Tendinous Ring.**

Consequently, the various deviations in the course of the OA may be developmental in origin; the differentiation of this unusual vascular pattern from the diffuse vascular capillaries may be due to morphogenetic or mechanical influences (Hayreh and Dass, 1962b:182).

Stedman (2006:96) describes an anomaly as a birth defect caused by a structural abnormality or a marked deviation from the average or a norm. A variation by contrast is defined as a deviation in structure from the recognised norm or standard (Stedman, 2006:2090), while an abnormality is a feature or event that is not considered to be normal (Soanes, 2002:2).

Upon doing the literature review, it was discovered that a number of authors (Alvarez *et al*., 1990:296; Greene, 2011:3; Hayreh, 1962b:212; Saude, 1993:150) described the patterns of their findings in published literature on the OA with the terms “abnormality”, “anomaly” and “variation”. In the current study, the term that will be used throughout the dissertation is variation.

1.2. BACKGROUND TO THE RESEARCH PROBLEM

There is considerable anatomical variation in the terminal courses of the branches of the ophthalmic artery (Leestma, 2009:362). The rate of prevalence of these variations has not yet been determined for the South African population. This could be important for surgical or therapeutic interventions, as well as for radiologists who report on the results of angiograms.

The South African population consists of a variety of population groups as shown by the estimated South African statistics survey (2016:2). The groups comprising the population are classified as Blacks (80.7%), Coloured (8.8%), White (8.1%) and Indian/Asian (2.5%). The population history of each group will be discussed in more detail in Chapter 3.

New therapeutic modalities have redefined the importance of these studies as knowledge of the detailed anatomy of the OA is essential for pathophysiological and diagnostic approaches as well as for therapeutic modalities (chemotherapy and surgery) in the treatment of various diseases and intraocular tumours such as retinoblastoma (Kotsiomitis, Mazarakis, Michalinos, Troupis & Zogana, 2015:1).

1.3. PROBLEM STATEMENT

The human orbit contains various important structures that may show variations relating to their anatomy. This study focuses on the intraorbital part of the OA in South African cadavers in the Free State and Western Cape provinces. To address the problem of the lack of data, dissections of the orbit were done to investigate and document the possible variations of the intraorbital part of the OA and its branches. Both orbits were dissected and compared with each other to determine whether the findings that were observed existed bilaterally or unilaterally.

In order to address the problem stated, the following research questions were posed:

- Which variations are present in the OA and its branches in the orbits of human cadavers in the Department of Basic Medical Sciences, University of the Free State and the Department of Human Biology, University of Cape Town?
- Do these variations occur unilaterally or bilaterally?

- What is the frequency of the unilaterality or bilaterality?
- Are the variations observed in this study also influenced by sex?

1.4. OVERALL GOAL, AIM AND OBJECTIVES OF THE STUDY

The overall goal of the study was to investigate and document the possible variations of the intraorbital part of the ophthalmic artery and its branches by dissection in a set of cadavers, and by comparing the left and right orbits to determine if variations exist and whether they occur bilaterally or unilaterally.

1.4.1. Aim of the study

The aim of the study is to investigate the intraorbital variations of the arterial blood supply in a cadaver sample and to compare the two sides in each cadaver.

1.4.2. The objectives of the study

The objectives of the study are:

- To perform dissections of cadaver eyes and document the variations of the OA by means of a data sheet, photography and annotated schematic presentations.
- To compare the two sides to see if the variations of the OA exist bilaterally or unilaterally, including whether one side is more commonly affected than the other. This will be documented by means of data sheets, photography and annotated schematic presentations.
- The sex of the cadavers was noted on the data sheet for the determination of prevalence and to compare the findings of the dissection between male and female cadavers.
- The population group was also recorded.

1.5. DEMARCATION OF THE FIELD OF STUDY

This study was performed in the field of Clinical Anatomy with application in the disciplines of ophthalmology and radiology.

1.6. SIGNIFICANCE OF THE STUDY

New medical approaches have redefined the importance of these studies, as knowledge of the detailed anatomy of the OA is essential for pathophysiology, diagnostic approach and therapeutic interventions for ocular diseases and intraocular tumours such as retinoblastoma (Troupis *et al.,* 2015:1).

1.7. RESEARCH DESIGN

The study design is a descriptive, observational quantitative study using cadaver material available in the Department of Basic Medical Sciences, University of the Free State and the Department of Human Biology, University of Cape Town.

The study documents the prevalence of the variations that exist in the OA branches within the population that was sampled in order to gain insight through observation into the variations found.

Descriptive statistics, namely means and standard deviation or medians and percentiles were calculated for continuous data frequencies and percentages were calculated for categorical data.

Statistical analysis was performed by a Biostatistician from the Department of Biostatistics at the Faculty of Health Sciences, University of the Free State. A detailed discussion on the methodology will be provided in Chapter 3.

1.8. ARRANGEMENT OF DISSERTATION

To provide more insight into the topic, the methods used and the final outcome of the study will be reported as follows:

Chapter 1, ***Orientation to the study,*** Introduction and brief overview of study presents background to the research problem, problem statement and research questions, goal, aims and objectives of the study. This chapter demarcates the field and scope of the study, the methods of investigation and refers to the practical application of the findings.

Chapter 2, ***Theoretical background to the study*** discusses the ophthalmic artery and the order of origin of its branches. Theoretical literature on the anatomy and embryology of the OA and its branches will be provided in this chapter.

Chapter 3, ***Research design and Methodology,*** describes the materials and methods with data and statistical analysis***.*** The technique used to study the intraorbital part of the OA will be described in detail in this chapter.

Chapter 4, ***Results,*** consists of the results of the study. Descriptive statistics will be used to report the findings and to discuss the dissection results of the OA.

Chapter 5, ***Discussion***. Overview of the results of the study. The overall results of the study will be discussed in comparison to findings in published literature.

Chapter 6, ***Conclusion, limitations of the study and recommendations.*** This chapter will provide an overview of the study, identify the significance and limitations of the findings and make recommendations for further studies and research that will advance the findings of the current study.

1.9. CONCLUSION

In this first chapter, the background and context of the research were laid out. The problem statement, overall goal, aim and objectives were stated. A brief introduction was given on the research design and methods and the arrangement of the study. The next chapter will provide the theoretical foundation of the research project.

CHAPTER 2

THEORETICAL BACKGROUND OF THE STUDY: THE OPHTHALMIC ARTERY AND THE ORDER OF ORIGIN OF ITS BRANCHES

2.1. INTRODUCTION

The orbital vascular pattern can be very complex, with considerable individual variations (Hayreh, 2006:1130). Research by previous authors may refer to these variations as anomalies or abnormalities, which terminology will be retained in this section.

Vascular anomalies may be congenital (present at birth), may appear within weeks to years after birth, or could be acquired (Greene, 2011:2). Vascular anomalies have been reported to have an estimated prevalence of 4.5% in the whole body with anomalies in the head and neck area occuring in 60% of the population (Bisdas, Breuninger, Ernemann, Hoffmann, Kramer, Miller, Rebmann and Zwick, 2010:2; Greene, 2011:1)

2.2. GENERAL OVERVIEW

The source of blood supply to the orbit is mainly the ophthalmic artery (OA) and to a much lesser extent the external carotid artery (ECA) via its infraorbital branch and the anastomoses (Hayreh, 2006:1130; Lemp & Snell, 1998:278; Whitnall, 1932:300). Occasionally the blood supply of the orbit may come as a contribution from different sources, depending on how the primitive embryological arterial system developed and involuted (Anderson, Anderson & Mawn, 2012:164; Hayreh, 1963:938). About 96% of individuals have a blood supply to the orbit coming from the OA, approximately 3% from the middle meningeal artery (MMA), a branch of the ECA, and 3% from the recurrent meningeal artery. In 1% of individuals, the MMA is the only source of supply to the orbit through the recurrent meningeal artery. In this situation, the recurrent meningeal artery is larger than normal, enters the orbit through the superior orbital fissure and begins branching within the orbit (Anderson *et al.*, 2012:163). Figure 2.1 shows the circulation of the head and neck as supplied by the common carotid artery, which divides into the external carotid artery (ECA) and the internal carotid artery (ICA).

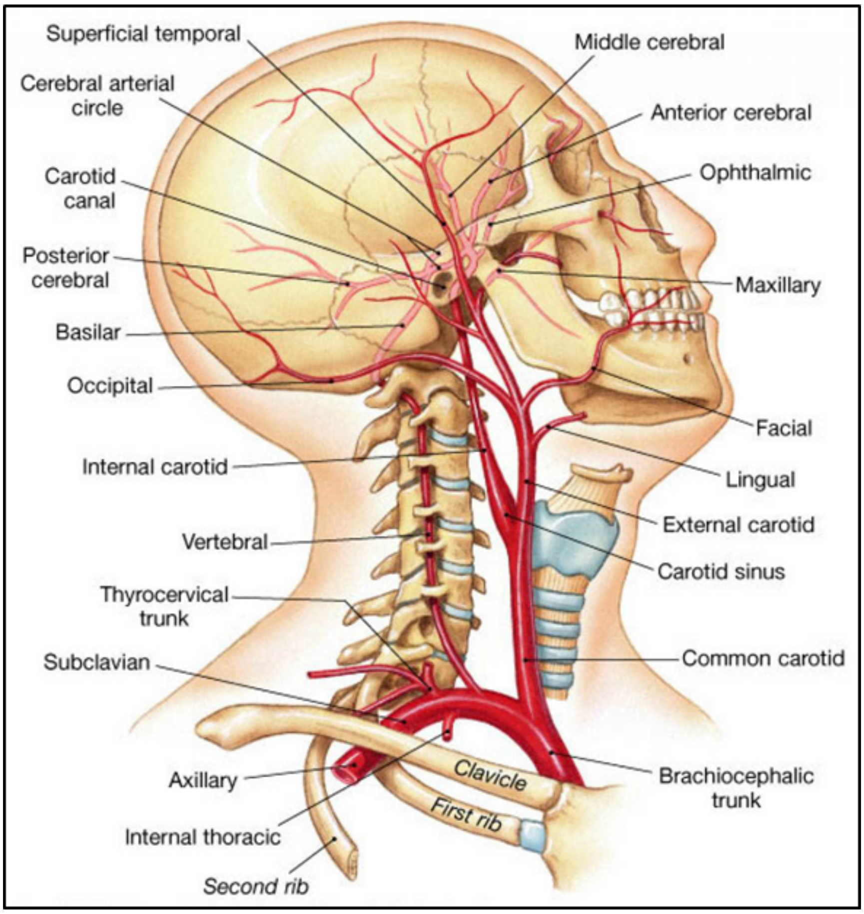

Figure 2.1: **Arterial blood supply to the head and neck (Source:online).**

Krause's Law states: that the varieties originate through abnormal development of normal anastomoses, as quoted by Hayreh (2006:1131). This is illustrated in Figure 2.2. The ICA supplies the structures within the cranium, including the eye and related structures, while the superficial areas of the head and neck and a small portion of the circulation to ocular adnexa are supplied by the ECA (Remington, 2012:202).

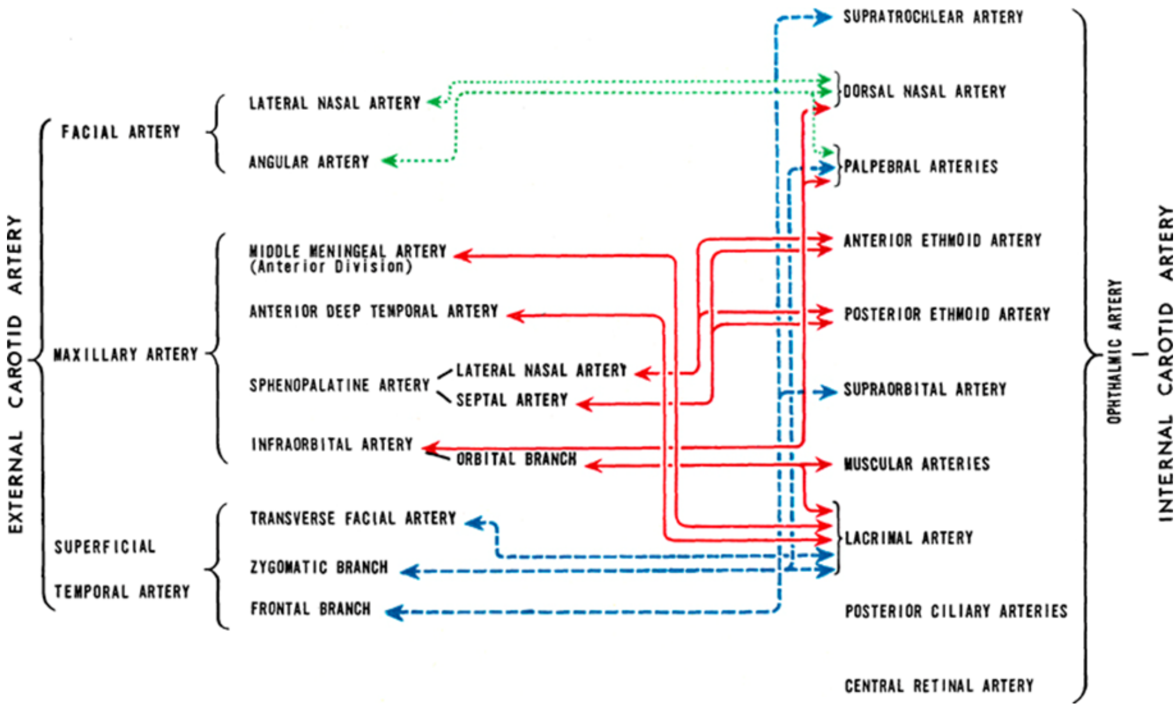

Figure 2.2: **A diagrammatic representation of the anastomoses between ECA and ICA in the head and neck (Hayreh, 2006:1134).**

2.3. THE BONY ORBIT

Knowledge of the precise anatomy of the orbit is required as well as familiarity with endoscopic equipment in order to increase the technical safety, predictability of the results and overall success, as surgical procedures involving the orbit are commonly performed by surgeons from different specialities (Cheng, Lam, Lucas, Yuen & So, 2008:139).

The human orbital cavities flank the sagittal plane of the skull between its cranial (neurocranium) and facial (viscerocranium) parts encroaching about equally on both sides following the bilateral symmetry of other vertebrates. The orbital cavities serve as sockets for the eyes. The roof of the orbit is in the anterior cranial fossa; medially, the nasal cavity and ethmoidal air sinuses are found and the floor is formed by the roof of the maxillary sinus (antrum) and laterally from behind anteriorly are the middle cranial and temporal fossae (Bron, Tripathi & Tripathi,1997:1). Figure 2.3 illustrates that the orbital bone and the structures within the orbit (connective tissue, fat, nerves and blood vessels) act to support, protect and maximise the function of the eye (Anderson *et al.,* 2012:73). The orbital rim is rounded and thickened and serves to protect the eye from facial impacts (Dutton, 1994:2).

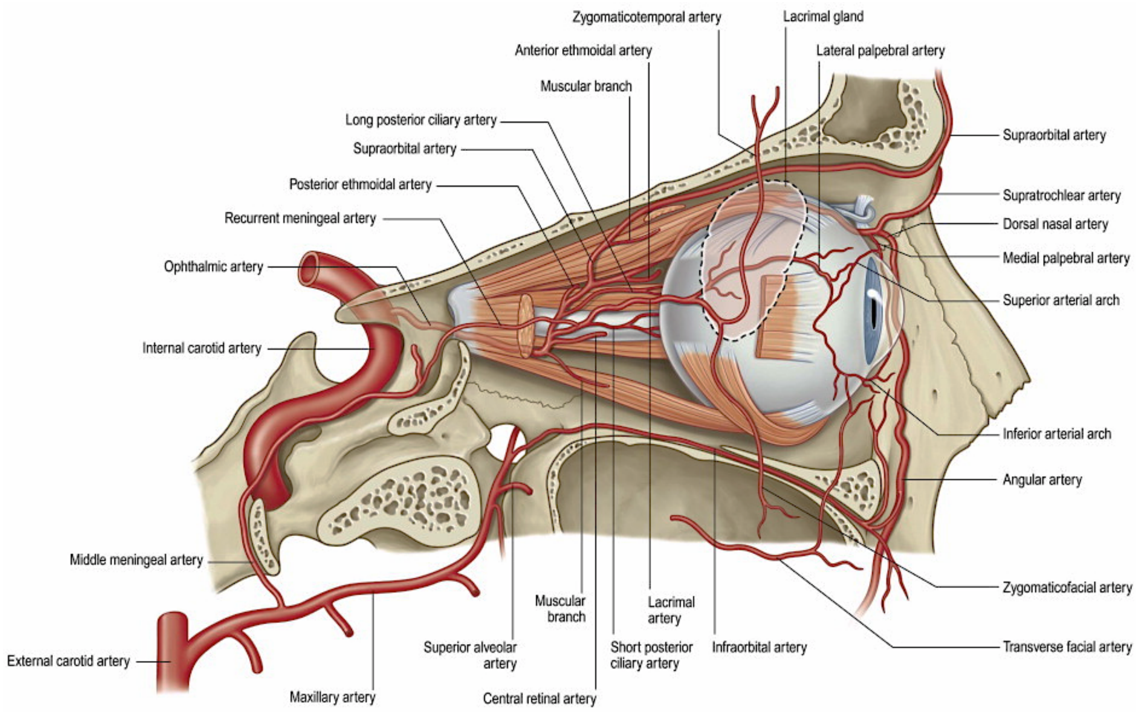

Figure 2.3: **Lateral view of the orbit with the ophthalmic artery and its branches (Galetta, Liu & Volpe, 2010**: **online).**

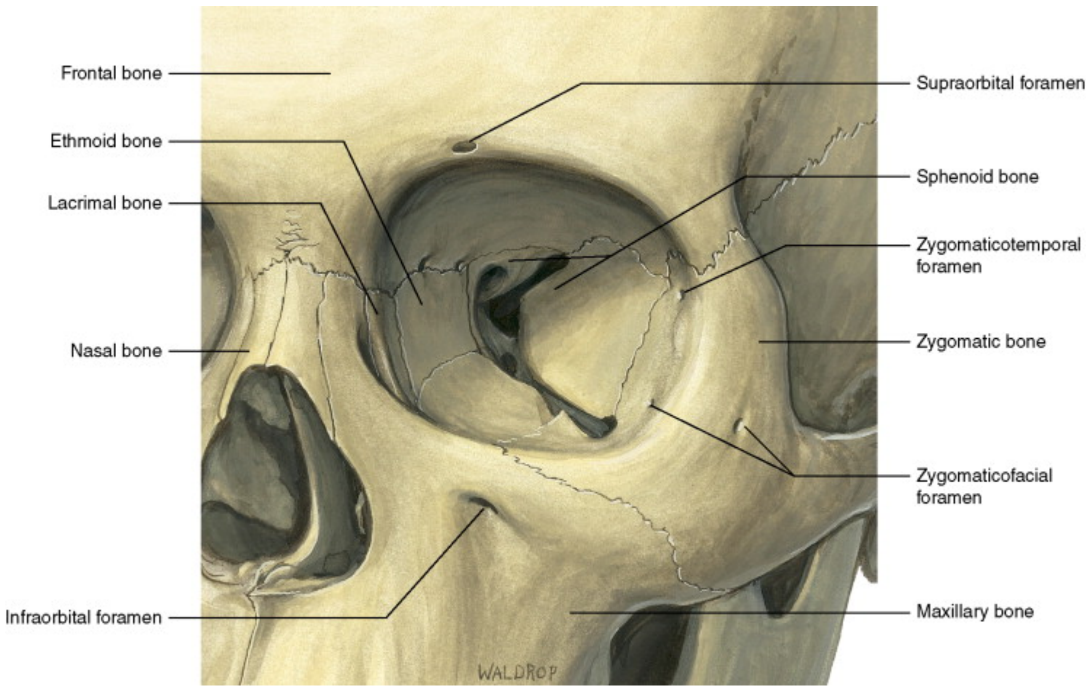

Figure 2.4: **Anterior view of the bony orbit (Dutton, 1994**:**8).**

In the adult, the bony orbit is roughly a quadrilateral pyramid in shape with rounded angles and resembles a pear. It has an open anterior margin (or base), a posterior apex, a roof, a floor, and medial and lateral walls (Figure 2.4). The medial walls are parallel, approximately

2.5 cm apart separated by paired ethmoidal sinuses whereas the lateral walls diverge from one another at 90° (Darrell, John, Kenneth & Pedro, 2005:58; Dutton, 1994:2; Hayreh 2006:1119; Anderson *et al.,* 2012:73).

2.4. THE ORIGIN OF THE OPHTHALMIC ARTERY

The OA is the first major branch of the ICA, and leaves the ICA as it exits the cavernous sinus medial to the anterior clinoid process just after it has pierced the dura mater (Figure 2.7) (Hayreh, 2006:1130; Standring, 2006:676). At its origin from the ICA, the OA lies within the subarachnoid space as it runs anteriorly on its way to the optic canal. A network of sympathetic nerves surrounds the OA. Dutton (2011:online) states that in 10% of individuals, the ophthalmic artery may arise from the clinoid or even the cavernous segments, or more rarely from the inferolateral trunk of the cavernous segment of the ICA. In such cases, the OA may enter the orbit through the superior orbital fissure instead of the optic canal.

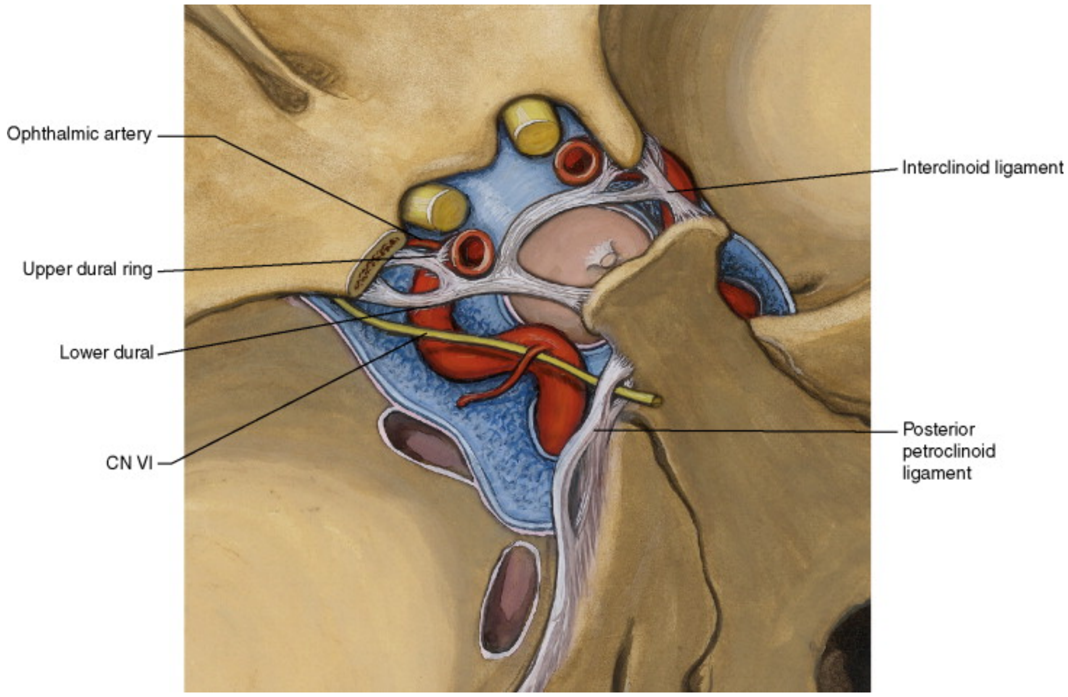

Figure 2.5: **The relationships of the ophthalmic artery within the cavernous sinus (Dutton, 2011**:**online)**.

2.4.1 The internal carotid artery

The internal carotid artery runs in a cranial direction through the neck and enters the skull through the carotid canal, located in the petrous portion of the temporal bone just superior to the jugular fossa. It leaves the canal and immediately enters the cavernous sinus, where it runs anteriorly along the medial wall beside the sphenoid bone (Remington, 2012:202).

Figure 2.6 describes the ICA as divided into seven segments: C1 (cervical segment), C2 (petrous segment), C3 (lacerum segment), C4 (cavernous segment), C5 (clinoid segment), C6 (ophthalmic artery), C7 (communicating segment) (Bouthillier, Harry, Keller & Van Loveren, 1996:426).

The ophthalmic artery emerges from the sixth segment of the ICA at the distal dural ring and ends just proximal to the origin of the posterior communicating artery. The proximal segment is the intradural portion of the anterior loop of the ICA (Bouthillier *et al.,* 1996:429).

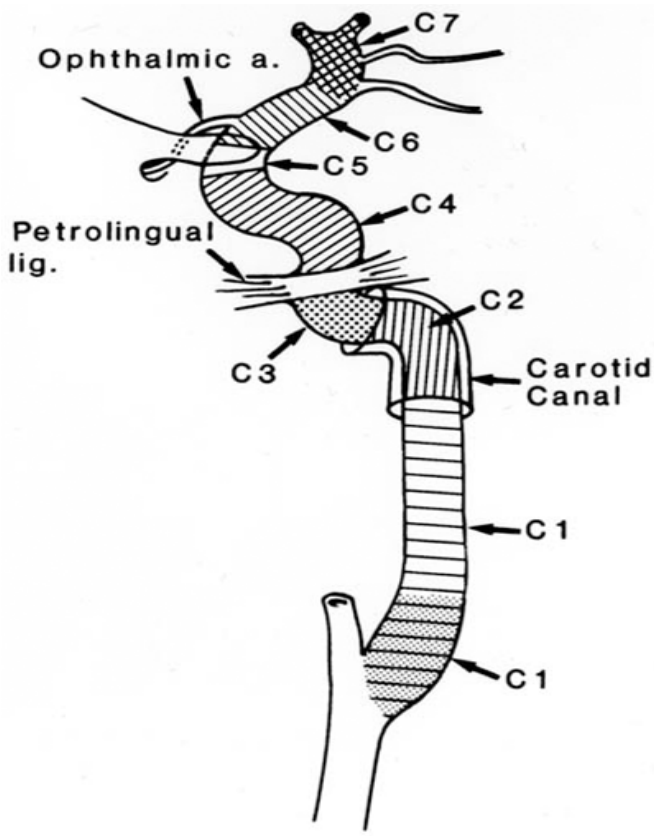

Figure 2.6: **The internal carotid artery showing its seven segments (Amini, Couldwell, Gottfried, Liu & Oren, 2004:2). Labels associated with the segments reflected on the digram above: C1 (cervical segment), C2 (Petrous segment), C3 (Lacerum segment), C4 (Cavernous segment), C5 (Clinoid segment), C6 (Ophthalmic artery), C7 (Communicating segment).**

2.5. THE COURSE OF THE OPHTHALMIC ARTERY

The OA emerges through the optic canal into the orbit, as illustrated in Figures 2.7. and 2.8. Anderson *et al.* (2012:160) state that in rare cases, the OA enters the orbit from the cranial cavity in a separate bony canal (duplicate optic canal) enclosed in dural covering and also through the medial part of the supraorbital fissure (SOF).

The OA progresses further anteriorly within the dural arachnoid sheath of the optic nerve. It eventually pierces the meningeal sheath and comes to lie on the outside of the optic nerve. It courses inferolateral to the optic nerve for a short distance and then crosses either above or below the optic nerve. It runs together with the nasociliary nerve towards the medial wall of the orbit (Remington, 2012:202; Lemp & Snell 1998:278).

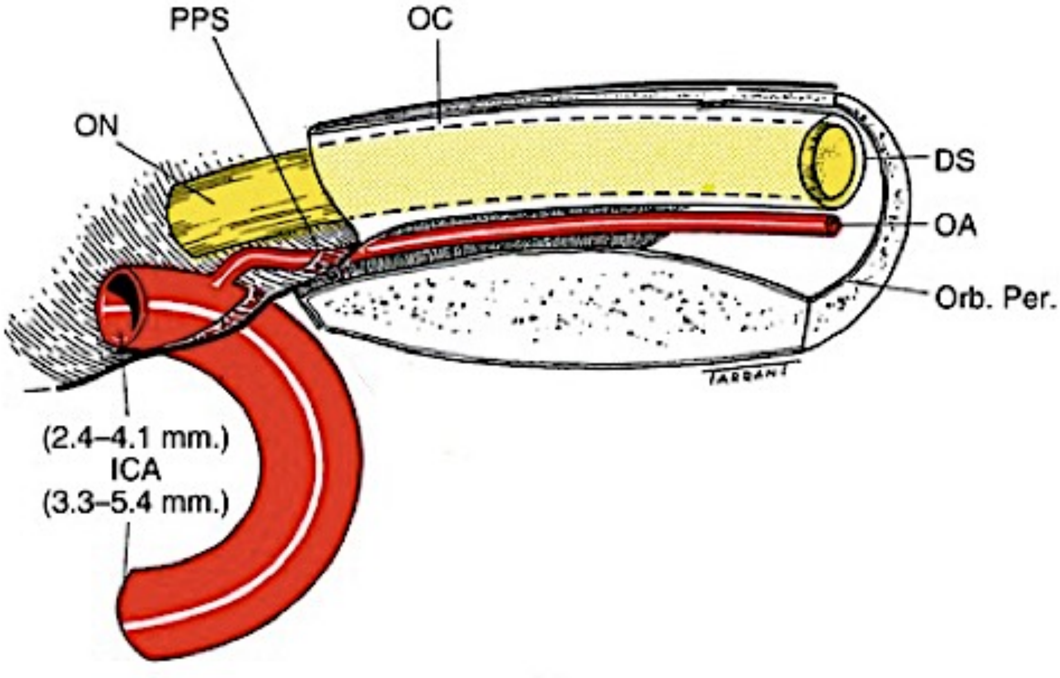

Figure 2.7: **A lateral view of the optic canal, cavernous and intracranial parts of the internal carotid artery, showing details of the origin and the intracranial and intracanalicular course of the OA (ophthalmic artery) (Hayreh, 1963:938). DS= Dural Sheath,ICA= Internal Carotid Artery, OC= Optic Canal,ON= Optic Nerve, Orb. Per. = Orbital Periosteum, PPS = Point of Penetration of the dural Sheath.**

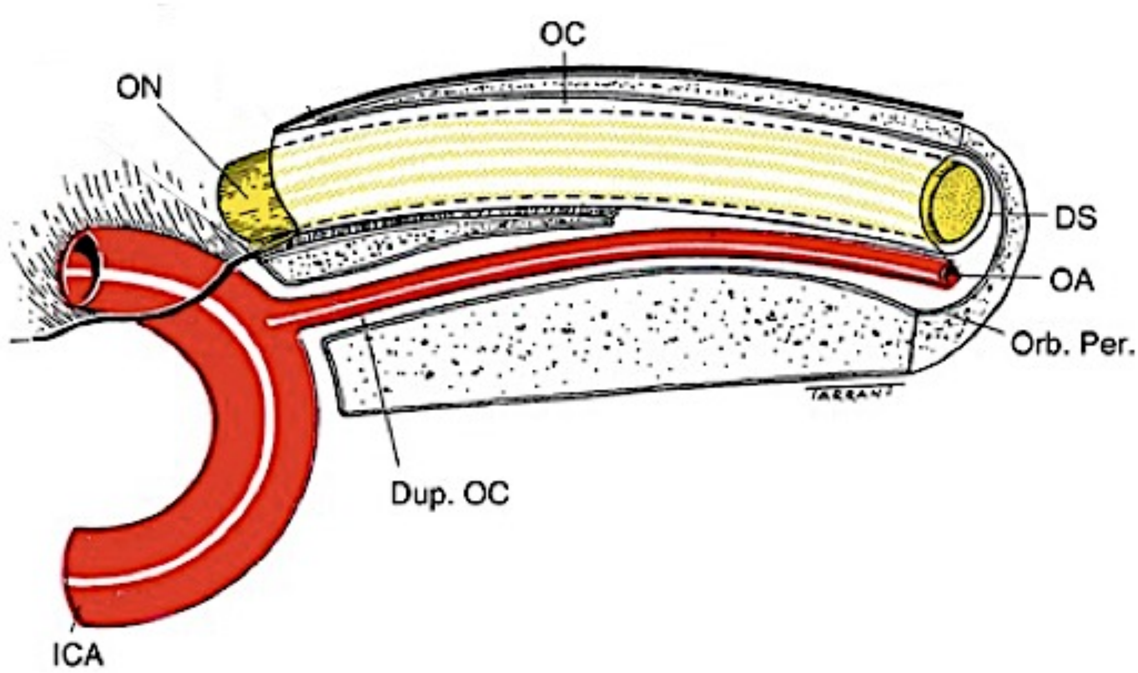

Figure 2.8: **Ophthalmic artery (OA) originating extradurally with its course through the duplicate optic canal (Hayreh, 1963:939). DS= Dural Sheath,ICA= Internal Carotid Artery, OC= Optic Canal,ON= Optic Nerve, Orb. Per.= Orbital Periosteum, PPS= Point of Penetration of the dural Sheath.**

The OA usually has three parts, namely: the intracranial part, intracanalicular part and the intraorbital part, with each part having varying branching patterns (Hayreh, 2006:1135). It continues anteriorly between the medial rectus and superior oblique muscles posterior to the superior medial margin of the orbit giving off branches to various structures along its path. It then ends in its two terminal branches, the supratrochlear and dorsal nasal arteries (Remington, 2012:202; Saude, 1993:128).

One branch, the central artery of the retina, transcends all others in importance. This is an end artery and if occluded (e.g. from embolism) results in complete and irreversible blindness. Beyond the orbit, the ophthalmic artery supplies the forehead to the vertex and the lateral wall of the nose. Here, especially in the scalp, exists a field of anastomosis between branches of the external and internal carotid arteries (Lemp & Snell, 1998: 279).

2.5.1. The intraorbital part of the OA

The intraorbital course of the OA and its branching patterns are quite variable (Anderson *et al.,* 2012:161). This is not only in its course and relations, but also in its sites of origin and number of collateral branches (Jimenez-Castellanos *et al.,* 1995:139). The focus of this study is on the intraorbital part of the OA.

The intraorbital arteries run within the adipose compartments of the orbit, piercing the septae when passing from one compartment to the other. This part of the OA is usually curved and this curvature is more prominent near the dural sheath. The course of the arteries is predominantly radial from the centre of the orbital apex.

Three parts of the intraorbital part of the OA can be distinguished. The first part runs anteriorly, closely related to the infero-lateral surface of the optic nerve and is attached to its surface by connective tissue, and forms an angle at the nerve's lateral margin (obtuse angle of 120º to 135º in 56% of people, right angle in 40%, and acute angle in 4% of people) (Hayreh, 1963:940).

The second part ascends lateral to the optic nerve, then courses medially over the optic nerve (in 82.6% of subjects) and deep to the superior rectus muscle. In 17.4% of cases, the artery spirals medially under the nerve to reach its supero-medial aspect. This marked tortuosity of the OA permits unrestricted ocular movements without impairing blood supply. The difference in the origin of the branches of OA depends on whether the OA crosses over or under the optic nerve in the second part of OA (Hayreh, 1963:940-943). In 15% of people, the artery crosses below the optic nerve (Lemp & Snell, 1998:278). Bron *et al.* (1997:371) added that this marked variation in origin and order of the branches of OA depends on their composite fetal derivation.

The third part of the artery begins at a well-defined bend as it crosses the tendon of the superior oblique muscle to reach the medial orbital wall close to the anterior ethmoidal foramen (Bron *et al.,* 1997:372; Kocabiyik, Ozan & Yazar, 2009:37; Lemp & Snell, 1998: 279).

2.5.2. The order of origin of the branches of the OA

No single branching pattern can be considered as *normal* because of significant variations between individuals, but rather an *unusual branching pattern* (Anderson *et al.,* 2012:161; Toma, 2016:2) is often reported. The order of the branches, as well as the site of origin of the branches given off to various structures, varies a great deal even between the two sides of the same individual. A marked degree of variation exists and this will lead to references to a *usual* branching pattern, rather than a *normal* branching pattern (Hayreh, 1962c:216; Anderson *et al.,* 2012:164).

Remington (2012:202) furthermore stated that a marked variability in the order of origin of the branches of the OA shows the sequence of the branches appearing in correlation with whether the artery crossed below or above the optic nerve (Figure 1.1). Table 2.1 also shows the usual branching pattern of the OA according to Hayreh (2006:1137).

The central retinal artery (CRA) is usually the first branch of the OA when the artery crosses over the ON; the lateral posterior ciliary artery (LPCA) comes as the first branch when OA crosses below the ON and the CRA will then be the second branch (Anderson *et al.,* 2012:164).

Table 2.1 below shows the branching patterns of the OA according to the order of origin of OA as was described by authors such as Meyer as early as 1887 through to Schaeffer in 1953. The most recent study was done by Hayreh (2006) (cf. Table 3.1) and this table was used to identify the branches during data collection in the current study. The findings of this study will be discussed in reference to Tables 2.1 and 3.1.

Table 2.1: **The order of origin of branches of the OA by various authors (Hayreh, 1962c**:**213)**.

Author		Meyer	Whitnall	Quain	Brash	Wolff	Bedrossian	Duke-Elder	Johnston and Others	Wood Jones	Hollinshead	Schaeffer
Date		1887	1932	1892	1951	1954	1958	1932	1958	1949	1954	1953
Order of Branches	1	CAR + MPCA		CAR + MPCA	CAR			CAR		MPCA	MPCA	CAR
	2	LPCA		LPCA	Posterior ciliary			Lacrimal		CAR	MPCA + CAR	Lacrimal
	3	Lacrimal		Lacrimal	Lacrimal			Muscular		LPCA	Lacrimal	Posterior ciliary
	4	Supero-lateral muscular		Recurrent branches	Recurrent branches			Posterior ciliary		Lacrimal	LPCA	Muscular
	5	Supra-orbital + posterior ethmoid		Muscular	Muscular			Supra-orbital		Muscular	Supra-orbital	Supra-orbital
	6	Infero-medial muscular		Supra-orbital	Supra-orbital			Posterior ethmoid		Supra-orbital	Posterior ethmoid	Posterior ethmoid
	7	Anterior ethmoid		Posterior ethmoid	Posterior ethmoid			Anterior ethmoid		Posterior ethmoid	Anterior ethmoid	Anterior ethmoid
	8	—		Anterior ethmoid	Anterior ethmoid			Anterior meningeal		Anterior ethmoid	Medial palpebral	Medial palpebral
	9	—		Superior and inferior medial palpebral	Superior and inferior medial palpebral			Medial palpebral		—	—	—
	Terminal	Medial palpebral Frontal Dorsal nasal		Frontal Nasal	Frontal Nasal			Frontal Dorsal nasal		Two medial palpebrals Supra-trochlear Dorsal nasal	Frontal Dorsal nasal	Frontal Dorsal nasal

CAR = Central retinal
LPCA = Lateral posterior ciliary
MPCA = Medial posterior ciliary

2.6. BRANCHES OF THE OPHTHALMIC ARTERY

In general, the arterial system of the orbital region appears to be more variable than the venous sytem (Erturk, Govsa, Kayalioglu, Ozer, Ozgur & Pinar, 1999:329).

The branches of the OA can be classified in three ways: according to order of origin of the branches, topographically (cf Table 2.1) and according to the relationship of the site of origin from the OA with the ON (Whitnall, 1932:302).

Although Gray (2000:568) stated that the branches of OA can be classified into two groups: orbital and ocular, Whitnall (1932:302) considerd three groups: the ocular group, supplying the eyeball, the orbital, supplying the orbital structures, and extra-orbital groups supplying the extra-orbital structures.

Both Figure 2.9 and Table 2.2 below show a representation of the ophthalmic artery and its branches.

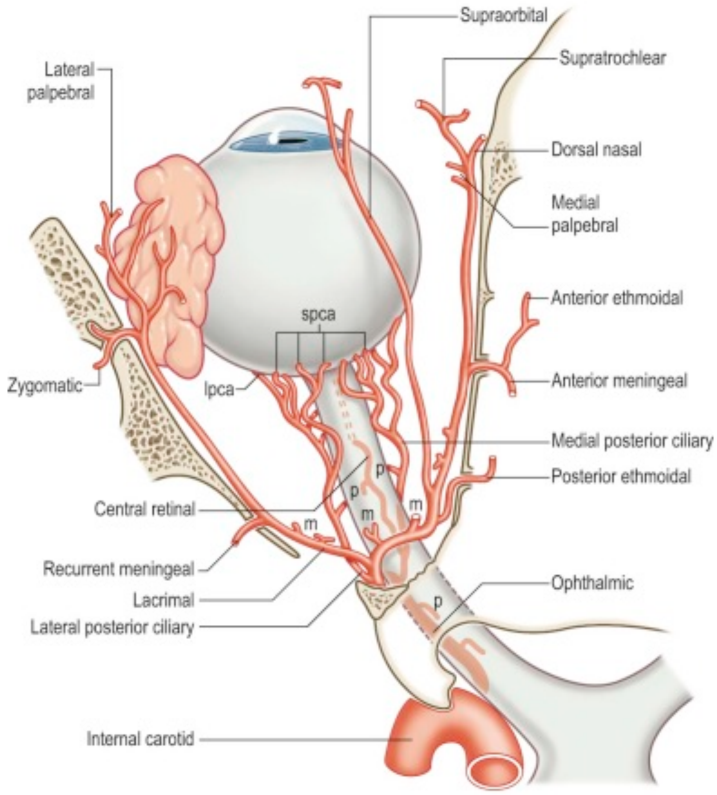

Figure 2.9: **Ophthalmic artery and its branches (Standing, 2015:676).**

Table 2.2: **Topographical classification of the OA branches (Hayreh III, 1962:216)**.

Orbital Group	**Ocular Group**	**Extra-orbital Group**
Lacrimal artery	Central retinal artery	Posterior ethmoidal artery
Small branches to the periosteum	Long posterior ciliary artery	Anterior ethmoidal artery
Small branches to the Areolar tissue	Short posterior ciliary artery	Supraorbital artery
Muscular arteries	Anterior ciliary artery	Medial palpebral artery
		Dorsal nasal artery
		Supratrochlear
		Branches of the lacrimal artery: Zygomatic and lateral palpebrals

2.6.1. Central retinal artery (CRA)

One of the first branches of the OA is the CRA, which is also among the smallest branches. It leaves the OA as it lies below the ON and runs forward a short distance before entering the meningeal sheath of the nerve. While within the optic nerve, the CRA supplies collateral branches to the nerve and pia mater. It passes through the lamina cribrosa and enters the optic canal just nasal to the centre, branching superiorly and inferiorly (Remington, 2012:202).

2.6.2. Lacrimal artery (LA)

The LA is a large branch that arises from the OA close to its exit from the optic canal outside the ON, and close to the origin of the CRA. It arises from the OA before entering the orbit through the superior orbital fissure inside the tendinous ring, and then runs anteriorly on the superior border of the lateral rectus muscle. The lacrimal gland gets its supply from the lacrimal artery when the artery passes through the gland before sending its terminal branches to pierce the orbital septum and to enter the lateral side of the upper and lower eyelids (Figure 2.12). Other terminal branches enter the conjunctiva and form a capillary network (Fournier, Hayek & Mercier, 2006:44; Anderson *et al.,* 2012:65; Remington, 2012:204; Lemp & Snell, 1998:279).

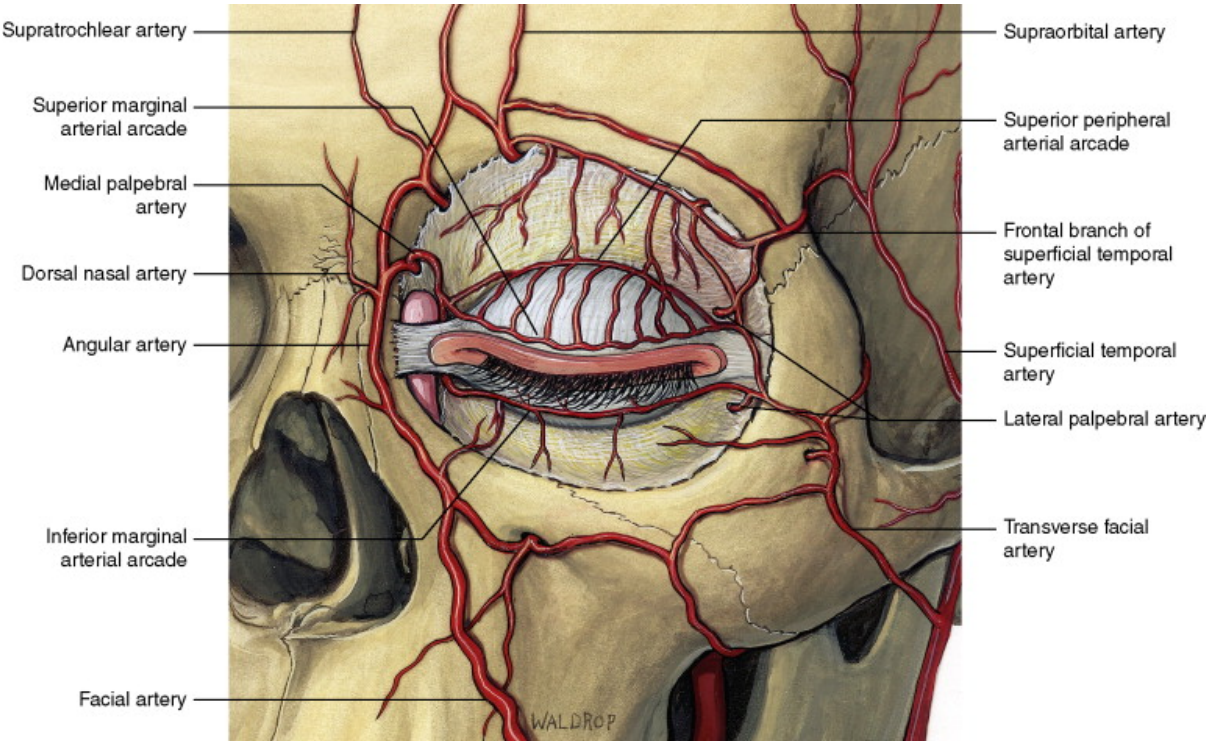

Figure 2.10: **Anastomoses between the terminal branches of the lacrimal artery and branches of the external carotid artery (Dutton, 2011**:**online).**

The lacrimal artery gives rise to the following branches:

- Zygomatic branches that pass through the zygomaticofacial and zygomatico-temporal foramina to anastomose with arteries on the face and in the temporal fossa, and a muscular branch to the lateral rectus muscle.
- Lateral palpebral arteries which pass medially into the upper and lower eyelids and anastomose with the medial palpebral arteries.
- The glandular branches (to the lacrimal gland), some of which continue through the gland or around it and divide to form the superior and inferior palpebral arteries and forms anastomoses with the corresponding medial palpebral arteries to form the arterial arcades of the upper and lower eyelid (Anderson *et al.,* 2012:165).
- Extra-ocular muscular branches to the lateral rectus muscle.
- Recurrent meningeal branches.

2.6.3. Muscular branches

Numerous muscular branches arise from the OA as it runs anteriorly within the orbital cavity and there are considerable variations in the vessels supplying the muscles. In an individual, any combination of the vessels named below may be present (Remington, 2012:207). These arterial branches accompany branches of the oculomotor nerve.

i) The lateral branch supplies the lateral rectus and the superior branch supplies the superior rectus, superior oblique and levator muscles.
ii) The medial branch supplies the medial rectus and the inferior branch supplies the inferior rectus and inferior oblique muscles.

2.6.4. Anterior ciliary arteries (ACA), long posterior ciliary arteries (LPCA) and short posterior ciliary arteries (SPCA)

Three groups of ciliary arteries are described:

i) Long posterior ciliary arteries

There are usually two arteries. The long posterior ciliary arteries arise from the OA at the point at which it crosses above the ON. They pierce and enter the sclera of the eyeball not far from the ON and run anteriorly between the sclera and the choroid to the ciliary body. At the iris they divide into upper and lower branches which encircle the iris and anastomose with corresponding branches of the artery on the anterior surface of the iris.

ii) Short posterior ciliary arteries

There are seven arteries and they pass anteriorly around the optic nerve to enter the eye by piercing the sclera.

iii) The anterior ciliary arteries

Arteries supplying the rectus muscles also give origin to the anterior ciliary arteries. These arteries exit the muscles near their insertions, run anteriorly along the tendons for a short distance, and then loop inward to pierce the sclera just outside of the limbus. The anterior ciliary arteries enter the ciliary body and anastomose with the branches of the LPCA (Hayek *et al.,* 2006:45; Remington, 2012:207; Lemp & Snell, 1998:280-282).

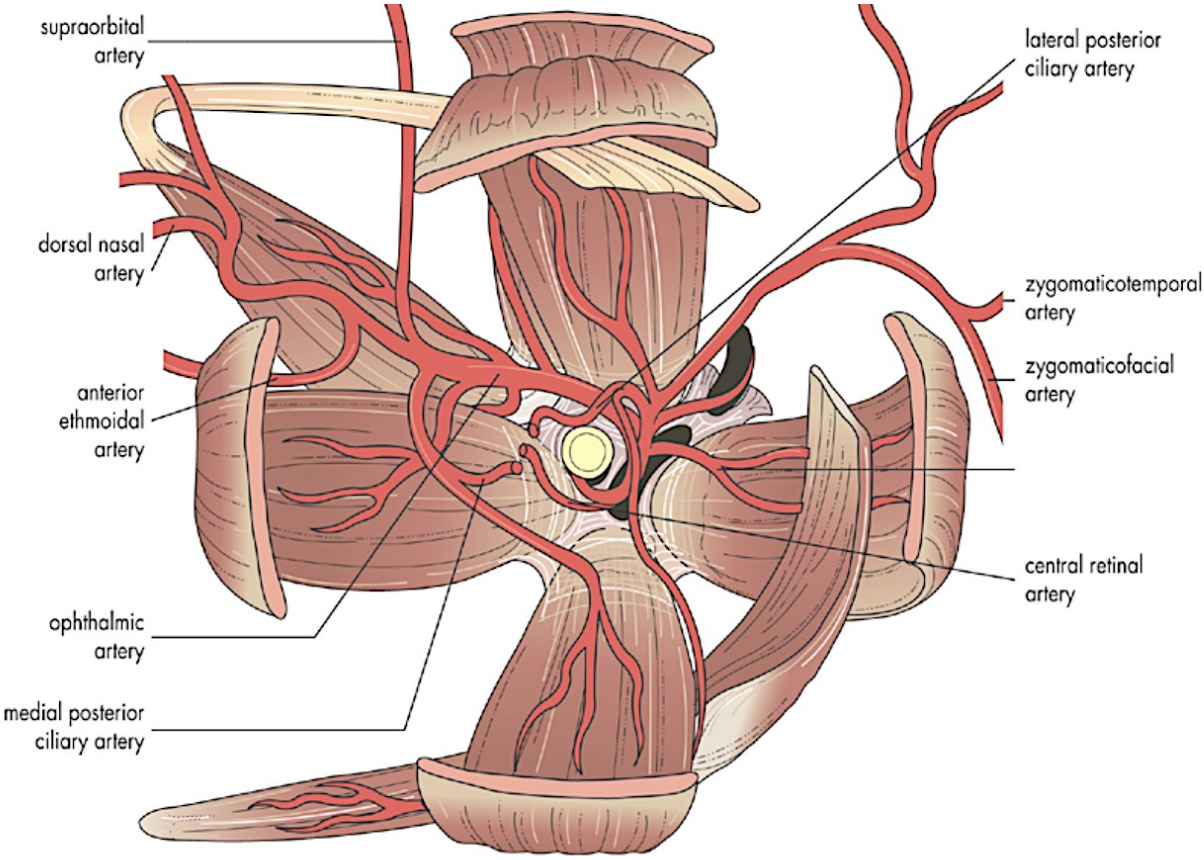

Figure 2.11: **The intraorbital course of the ophthalmic artery (Friedman,Kaiser and Trattler, 2005**:**162).**

2.6.5. Supraorbital artery (SOA)

The SOA arises from the OA as it crosses the ON, often on its medio-optic part and passes superiorly and anteriorly around the medial borders of the superior rectus muscle and the levator palpebrae superioris muscle (Figure 2.12). It is absent in 10% to 20% of individuals (Anderson *et al.,* 2012:167; Lemp and Snell, 1998:282).

The SOA then exists between the levator palpebrae superioris muscle and the superior oblique muscle running with the supraorbital nerve between the levator palpebral superioris muscle and the roof of the orbit giving rise to muscular branches and the supratrochlear artery.

The SOA then leaves the orbit passing through the supraorbital notch or foramen and ascends to the scalp, deep to the frontal belly of the fronto-occipitalis muscle giving the terminal branches that anastomose with branches of the supratrochlear and superficial temporal arteries (Hayek *et al*., 2006:46; Lemp & Snell, 1998:282).

The levator palpebrae superioris muscle, the diploe of the frontal bone, frontal sinus, upper eyelid and the skin of the forehead and the scalp are supplied by the SOA (Lemp & Snell 1998:282; Remington 2012:207).

Hayek *et al.,* (2006:46) found the supraorbital artery to be absent in 12% of the subjects in their study.

2.6.6. Posterior ethmoidal artery (PEA)

The OA gives rise to the PEA after reaching the medial wall of the orbit (Figure 2.11) and passes between the upper border of the medial rectus and the superior oblique muscles medially to enter the posterior ethmoidal canal (Hayek *et al*., 2006:46; Lemp & Snell, 1998). The PEA is absent in 15% to 20% of the population (Anderson *et al.,* 2012:167).

The posterior ethmoidal air sinuses, the dura of the anterior cranial fossa and the upper part of the nasal mucosa are supplied by the PEA (Hayek *et al*., 2006:46; Lemp & Snell, 1998:282).

2.6.7. Anterior ethmoidal artery (AEA)

The AEA arises from the OA near the anterior ethmoid canal and enters the ethmoidal canal accompanied by the anterior ethmoidal nerve (Figure 2.11) and enters the anterior cranial fossa by passing into the nasal cavity through the plate of the ethmoid. The AEA then descends in a groove on the deep surface of the nasal bone to enter the face between the nasal bone and the upper nasal cartilage (Fournier *et al*., 2006:45; Lemp & Snell, 1998:282).

The AEA is larger than the PEA and is more consistently present and is absent in less than 2% of cases (Anderson *et al.,* 2012:168).

The anterior and middle ethmoidal air sinuses, the meninges, the mucous membrane of the anterior part of the nasal cavity and the skin of the nose are supplied by the AEA (Fournier *et al*., 2006:45; Lemp & Snell 1998:282).

Anderson *et al.* (2012:168) stated that the anterior and posterior ethmoidal arteries and their foramina are important landmarks during orbital surgery.

2.6.8 Meningeal artery (MA)

The MA is a small branch that runs posteriorly through the superior orbital fissure, into the middle cerebral fossa and forms an anastomosis with the middle and accessory meningeal artery (Hayek *et al*., 2006:47; Lemp & Snell 1998:283).

2.6.9. Medial palpebral arteries (MPA)

The superior and inferior medial palpebral arteries arise from the anterior part of the OA below the pulley (trochlea) of the superior oblique muscle and they descend behind the lacrimal sac and pierce the orbital septum above and below the medial palpebral ligament. Each artery passes laterally to enter the upper and lower eyelid and divides into two branches which form the peripheral and marginal arterial arches. The arches run laterally between the orbicularis oculi muscle and the tarsal plates. Branches from the arches supply the eyelids and conjunctiva (Hayek *et al*., 2006:47; Lemp & Snell, 1998:283).

2.6.10. Supratrochlear arteries (STA)

The STA is a terminal branch of the OA and it leaves the orbit by piercing the orbital septum above the pulley of the superior oblique muscle in the superomedial part of the orbit and accompanies the supratrochlear nerve. The STA supplies the skin of the forehead, the scalp and the muscles of the forehead, forming anastomoses with SOA, the opposite STA and the anterior temporal artery from the external carotid artery (Hayek *et al*., 2006:47; Remington, 2012:209; Lemp & Snell, 1998:283).

2.6.11. Dorsal nasal artery (DNA)

The DNA is also a terminal branch of the OA that pierces the orbital septum and emerge from the orbit between the trochlea and the medial palpebral ligament and descend to the side of the nose giving off branches to the lacrimal sac and anastomoses with the angular artery from the external carotid artery (Hayek *et al*., 2006:47; Remington, 2012:209; Lemp & Snell, 1998:283).

2.7. EMBRYOLOGICAL DEVELOPMENT

The arterial supply to the orbit combines, in its normal adult configuration, vascular elements taken from several primitive arterial systems. A few basic embryonic concepts are introduced to clarify the type of variations and collateral pathways existing in the orbital region (Gailloud, Gregg & Ruiz, 2009:169).

Several aspects of the normality and abnormalities of the eye structure and its surroundings are best understood through the knowledge of embryological development (Saude, 1993:150). During human development, several arterial systems such as the OA exist for a time, only to regress later (Hasso, Lasjaunias, Manelfe, Moret, Seegeer & Theron, 1977:267). The appearance and disappearance of vessels as part of the normal developmental process can sometimes be disturbed and this will then lead to variations and anomalies of an arterial system (Figure 2.12) (Alvarez, Rodesch, Garcia-Monaco and Lasjaunias 1990:296).

The embryological development of vascular structures of the eyeball and the orbit is gradual and complicated. Two primitive OA's supply the orbit at first, the primitive ventral ophthalmic artery (PVOA) and primitive dorsal ophthalmic artery (PDOA). The primitive OA is originally formed by the PVOA which develops from the primordial of the anterior cerebral artery (ACA) and passes through the optic canal and the primitive dorsal ophthalmic artery (PDOA) which develops from the ICA (C4 segment) at the carotid siphon and passes through the superior orbital fissure (SOF) (Kocabiyik *et al.,* 2009:37; Louw, 2015:577).

Two anastomotic vascular networks are formed: one near the optic nerve in the orbit between the PVOA and PDOA and an additional anastomoses near the intradural optic canal between the PVOA and the supra cavernous portion of the ICA. The proximal parts of the PVOA and PDOA partially regress, and give rise to the future inferolateral trunk (ILT) and primitive OA. The primitive OA annexes with the supraorbital branch of the stapedial artery (SA) and transforms into the adult OA. This occurs during embryonic development (4-18 mm stages) (Figure 2.12) (Komiyama, 2009:363; Louw, 2015:577).

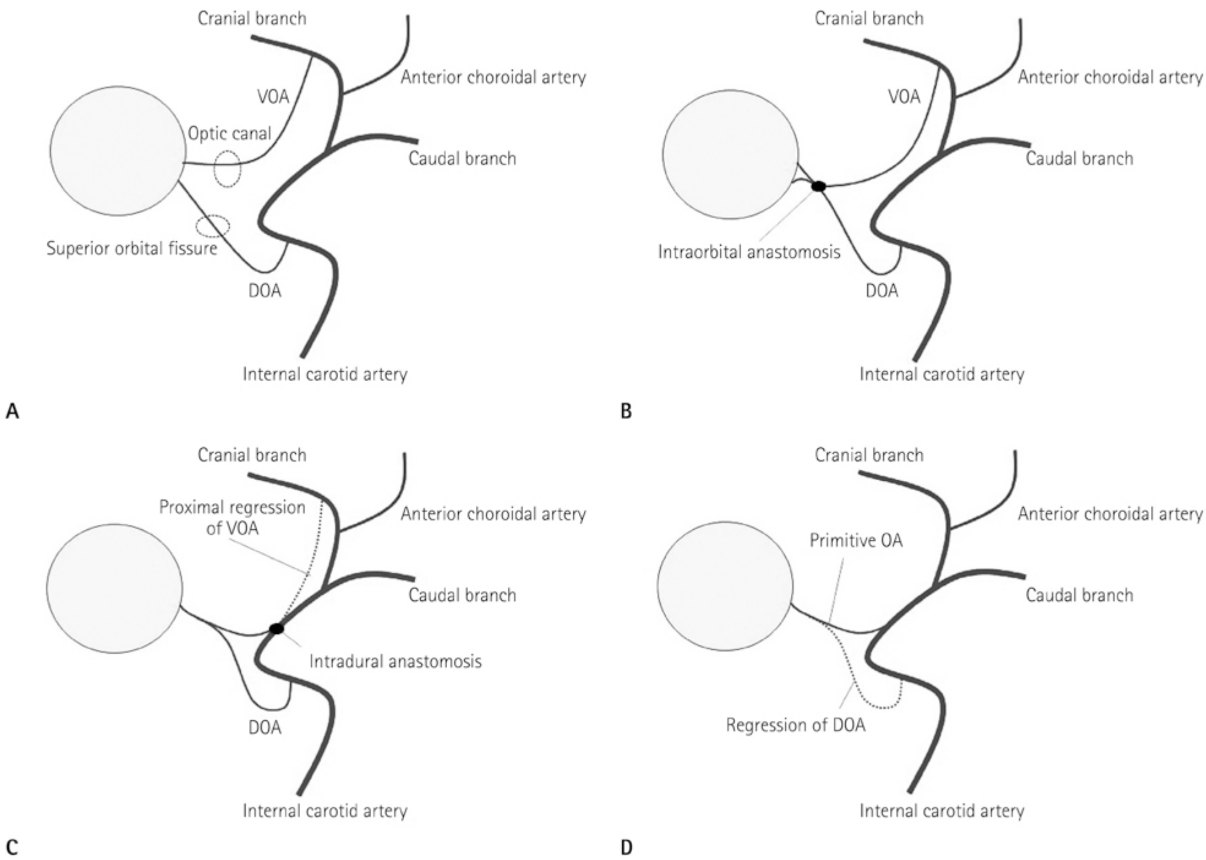

Figure 2.12: **Embryological development of the ophthalmic artery. (A) The VOA originates from the ACA and the DOA originates from the ICA. (B, C) Two anastomoses formed. (D) The proximal parts of the VOA and DOA regress (Lasjaunias *et al.,* 1977:online). ACA= Anterior Choroidal Artery, DOA= Dorsal Ophthalmic Artery, ICA= Internal Caortid Artery,VOA= Ventral Ophthalmic Artery.**

The stapedial artery (SA) arises from the primitive hyoid branch of the petrous ICA in embryonic development stages 18-40 mm and gives rise to the maxillofacial and supraorbital branches; the supra orbital branch anastomoses with the primitive OA, the primitive OA assimilates the supraorbital branch of the OA and becomes the adult OA (Louw, 2015:577).

The supraorbital artery, a branch of the stapedial artery that formed from the second aortic arch, also passes through the SOF and contributes to give off branches to the orbit, including the ethmoidnasal and lacrimal arteries (Komiyama, 2009:363).

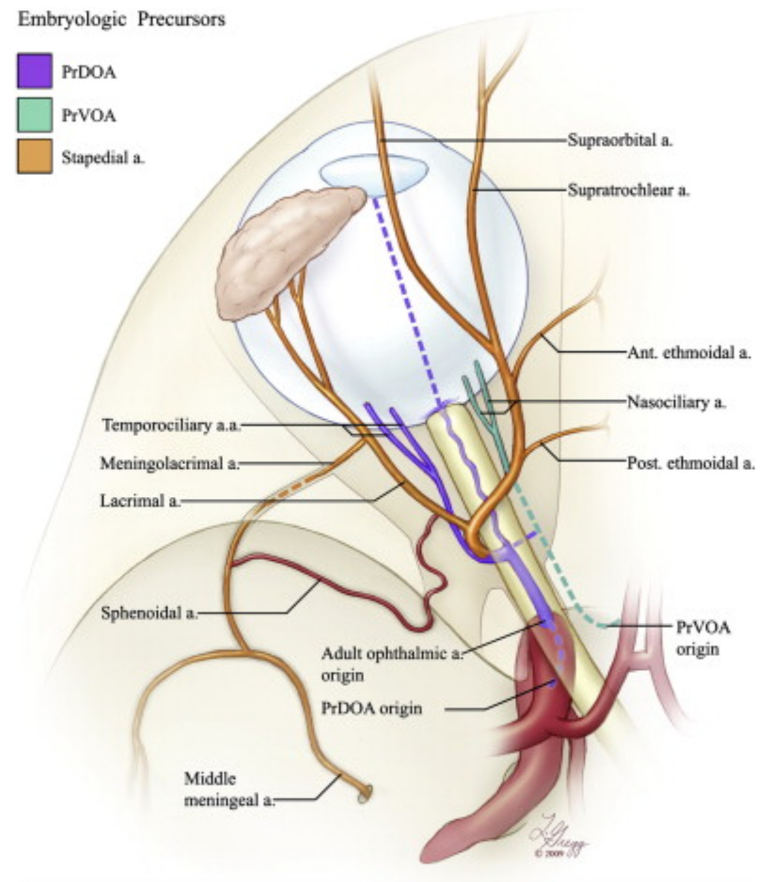

Figure 2.13: **Ophthalmic artery developmental anatomy and its adult derivatives (Gailloud *et al*., 2009**:**170)**. **Pr VOA= Primitive Ventral Artery, Pr DOA= Primitive Dorsal Artery.**

Louw (2015:2) stated that in principle OA variants originate through the abnormal development of anastomotic networks (i.e. between the PVOA and the PDOA or primitive OA and SA). Although excellent embryological explanations for variants exist, differences still occur and some explanations remain speculative at best. The main focus of this study is on the intraorbital part of the OA and its branches (Figure 2.13).

2.8. IMPORTANCE OF KNOWLEDGE OF OA ANATOMY AND ITS VARIATIONS

Variations in the branches of the OA are common (Whitnall, 1932:308). Documentation on various OA origins and on variations in branching patterns, as well as the proximal course of OA for orbital supply is knowledge that is indispensible to the endovascular and microsurgical surgeon for the evaluation, diagnosis and for the treatment of certain orbital disorders and aneurysms (Huyn-Le, Natori & Sasaki, 2005:236; Kageyama & Lang, 1990:83; Basic, Basic, Jo-Ostovic, Jukic, Nikolic & Stimac, 1999:371; Loggenberg, Louw & Steyl, 2014:3).

The intracranial portions of the ON and OA are susceptible to various diseases and injuries. A working knowledge of the orbital vasculature and related structures is important during, orbital, extraocular or ocular surgery. This knowledge will help prevent injury to the blood vessels during operative procedures within the orbit or the eyelid, since injury to any part of the optic pathway results in visual defects (Bleier, 2016:58; Govsa *et al.,* 1999:329; Anderson *et al.,* 2012:159). Moreover, unintentional injury to the vasculature not only causes a deformation of the anatomy and disrupts a landmark but also prolongs the surgery and might compromise blood flow to an important orbital or ocular structure (Anderson *et al.,* 2012:159).

Jimenez-Catellanos *et al.*(1995:142) state that in the last few years more surgical treatments for certain orbital pathologies were seen, especially for those from tumorous or vascular origin, due mainly to technical advances in microsurgery, chemosurgery, imaging and interventional radiology. This necessitated more precise and profound anatomic knowledge of the orbital cavity and its contents for surgeons.

Among the treatments, one for intraocular retinoblastoma has improved substantially over the past century as it aims for preservation of life. Current therapies have made it possible to aim for globe retention and the maintenance of visual potential by one of the most captivating new treatment modalities, intra-arterial chemotherapy, also known as ophthalmic artery chemotherapy (OAC), a noble method of treatment choice for retinoblastomas. An eye survival rate of 81.7% was achieved for those who received the treatment as primary method (Abramson, Francis & Klufas, 2013:39).

Several clinical complications may occur due to the anomalous origins of the CRA. This requires knowledge of their usual occurrence when planning an intraorbital surgery such as optic nerve fenestrations. Not knowing the unusual anatomical positions of the CRA in such cases may increase the probability of severing the CRA during the procedure causing long term visual impairment or even blindness (Harris, Loukas, Primus, Siesky, Shoja, Shoshani & Tubbs, 2012:189).

Thus, general knowledge of the variations in the possible patterns of origin and course of the OA and its branches is imperative.

2.9. CONCLUSION

In Chapter 2, a general overview of the anatomy of the OA was given from embryology to adult life. The variations and clinical implications were also outlined. Chapter 3, ***Research design and methodology***, describes the techniques used to carry out the study.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY: THE TECHNIQUES USED TO STUDY THE INTRAORBITAL PART OF THE OA

3.1. INTRODUCTION

As stated in the preceding chapters, the OA has three parts. The main focus of this study is the intraorbital part of the OA. The dissection and recording of the course and variations of the OA and its branches with the abnormalities or variations will be described in detail in this chapter.

The dissection techniques used to study the course of the OA and the variations encountered in all specimens, were recorded by means of digital photographs and schematic drawing and described in detail.

3.2. THEORETICAL PERSPECTIVES ON THE RESEARCH DESIGN

In this study, the researcher investigated the course and variations in the branches of the OA. The study was a descriptive, observational quantitative study, describing the individual findings that were observed in the sampled population. Quantitative research methods and designs see the researcher as independent from the investigation, which means the researcher does not try to influence the outcomes of the research (Burns & Grove, 2005:23). Qualitative research was not done for this study.

3.3. DESCRIPTION OF THE POPULATION FORMING THE SAMPLE

The Department of Basic Medical Sciences, University of the Free State and Department of Human Biology, University of Cape Town receive cadavers each year in the form of donations, unclaimed bodies and indigent people to be used for educational purposes by undergraduate and postgraduate Anatomy students. The sample population consisted of these human embalmed bodies which included 23 cadavers from the Department of Basic Medical Sciences, University of the Free State and 36 Cadavers from the Department of Human Biology, University of Cape Town. Both eyes of each cadaver were dissected and blood vessels were exposed thoroughly. Digital photographs were taken and schematic representations were drawn by the researcher.

The demographic data (age, sex and population group) was also documented in accordance with the records that are kept at both departments. The study population consisted of Black, White and Coloured cadavers.

South Africa is home to more than 49 million people of diverse origins, cultures, languages and beliefs. These people are socially classified into four main population groups, namely Black (African ancestry), White (European or Caucasian ancestry), Coloureds (mixed ancestry) and Asian/Indian (Becker, L'Abbe, Nawrocki & Van Rooyen, 2011:195). Upper case Black South Africans originally descended from the Bantu speaking groups from Western and Central Africa, who migrated throughout sub-saharan Africa. This descent can be divided into two main groups: the Nguni (comprising the Zulu, Xhosa, Ndebele and Swazi) and the Sotho-Tswana (including Southern, Northern and Western Sotho), and the Tsonga and Venda.

White South Africans descended largely from colonial immigrants of the late 17th, 18th and 19th centuries and included European groups such as the British, Dutch, German and French Huguenots. Coloured and Brown people are social terms used to define persons who descended from slaves brought in from the East and Central Africa, Malaysia, the indigenous Khoisan who live in the Cape as well as modern Black and White people. Despite their various origins, South African Coloureds are considered a distinct population group (L'Abbe *et al.,* 2011:195; L'Abbe, Liebenberg & Stull, 2015:522, 523). The three largest groups in South Africa are Blacks, Whites and Coloureds (estimated South African statistics survey, 2016:2).

3.3.1. Target population

The sample size of the study was determined by the cadavers available within the Department of Basic Medical Sciences, University of the Free State and within the Department of Human Biology, University of Cape Town, during the year 2016.

3.3.2. Sample size

At the Department of Basic Medical Sciences, University of the Free State, there were 23 cadavers available and a total number of 46 eyes were dissected. At the Department of Human Biology, University of Cape Town, 36 cadavers were used, resulting in a total number of 72 eyes that were dissected.

3.3.3. Sample selection

The dissections were done at a non-random consecutive selection sampling. The cadavers at the two institutions were used in the study period between May and July, 2016.

3.3.4. Exclusion criteria

Four cadavers in the UCT sample had their eyes removed from the orbits and were therefore not included because the blood vessels were destroyed.

Cadavers with pathology of the orbit and /or signs of previous surgical operation around the orbital area would also have been excluded from the study but no such cadavers were found.

3.3.5. Pilot study

A specific pilot study was not conducted prior to the main study. The first four eyes that were dissected from the UFS sample were considered to be the equivalent of a pilot study and they were included in the overall sample.

3.3.6. Data gathering

The dissected specimens were given sequential reference numbers in the following manner: OA1R1 (for the right ophthalmic artery of the first cadaver) and OA1L1 (for the left ophthalmic artery of the first cadaver) for the UFS population and OA1R2 and OA1L2 for the UCT population. The numbering sequence was followed for all specimens and recorded on the report sheets to identify the orbits and eyes extracted from the cadavers (see Appendix D). Digital photographs taken with an LG G4 smartphone camera were of satisfactory quality. The dissected eyes were placed on a table under a light source to show the dissected arteries clearly. Markings were made on the background surface with a permanent marker pen for easy orientation and identification of the sides of the eyes after capturing photographs, N (for the nasal side) and T (for the temporal side). The photographs were taken at a distance of 15 cm away from the table with the camera at an angle directly above the eyes of the cadavers. A 15 cm long ruler was used for accuracy as an alternative for using a tripod stand to ensure that all photographs were taken at a fairly equal distance. The room was darkened during the photographic sessions. Plain white sheets of paper were used for the drawing of the schematic representations. The same labelling was used on the data recording sheets, photographs and schematic drawings.

3.3.7 Data analysis

Detailed observations of the usual patterns of branching and of the variations were recorded on the data sheets during dissection and the same data was also recorded on a computer using Microsoft Excel 2010 (for later use in the statistical analysis), Microsoft Word (used to compile a database and for storing all observations for report compilation) and Microsoft PowerPoint (used to compile a slide show of all the photographed eyes).

Schematic representations of all specimens were also redrawn from the specimens by the researcher on the data sheets (see Appendix D).

Table 3.1 shows the usual anatomical branching patterns following the order of origin of the ophthalmic artery as it was observed and recorded by Hayreh (2006:1137). This table was used as a guideline to the researcher to identify the branches according to the order of origin of the OA.

Table 3.1: **The usual branching pattern according to the order of OA origins (Hayreh, 2006**:**1137).**

Order of origin	Ophthalmic artery crossed over optic nerve	Ophthalmic artery crossed under optic nerve
1	Central retinal + medial posterior ciliary	Lateral posterior ciliary
2	Lateral posterior ciliary	Central retinal
3	Lacrimal	Medial muscular
4	Muscular to superior rectus and/or levator palpebrae superioris	Medial posterior ciliary
5	Posterior ethmoid and supraorbital, jointly or separately	Lacrimal
6	Medial posterior ciliary	Muscular to superior rectus and levator
7	Medial muscular	Posterior ethmoid and supraorbital jointly or separately
8	Muscular to superior oblique and medial rectus, jointly or separately or to either	Muscular to superior oblique and medial rectus, jointly or separately or to either
9	To areolar tissue	Anterior ethmoid
10	Anterior ethmoid	To areolar tissue
11	Medial palpebral or inferior medial palpebral	Medial palpebral or inferior medial palpebral
12	Superior medial palpebral i Dorsal nasal ii. Supratrochlear	Superior medial palpebral Terminal i. Dorsal nasal ii. Supratrochlear

3.4 RESEARCH METHODS

3.4.1. Exenteration of the eye

Exenteration of the eye was performed. The orbital floor dissection commenced from a point on the rim just above the infraorbital foramen and then proceeded along the floor (Campbell, DiRuggiero, McQueen & Shockley*,* 1995:787). The orbital rim was identified by palpation and the orbital content was removed by making cuts with a size 4 scalpel and size 23 blade along that orbital rim from below the level of the eyebrows along the attachment of the orbicularis oculi muscle. The incisions were extended deeper towards the bony orbital rim; the periosteum was elevated first to the anterior lacrimal crest and then back to the anterior ethmoidal foramen as described by Campbell *et al.* (1995:7870). The eye and orbital content were then carefully removed with the aid of a curved pair of scissors before the dissection was started.

3.4.2. The dissection technique

The intraorbital portion of the OA was investigated from a point just after its exit from the SOF to its bifurcation and division into its terminal branches. Fine dissections were performed to reveal the ophthalmic arteries and their branches in both eyes with the aid of a magnifying glass. The vessels in both eyes were dissected thoroughly exposing all the possible branches and all necessary details were recorded. The left and right sides were compared for every cadaver and the same technique was performed on all the specimens to study the course of the OA and its branches.

The eye was dissected further under a magnifier with a light source. All the orbital fat was removed to reveal the OA and other anatomical structures of the eye. The orbit was also studied to determine the position of the ophthalmic artery at its origin with respect to the optic nerve since Hayreh (2006:1136) suggested that this determines how the branches of OA will be arranged. Elaborate dissection was performed until all the branches were revealed. Red coloured stamp pad ink was carefully placed on the arteries individually using an art brush size 2 for identification of the branches. The process of painting the arteries was done under the magnifier. Branching patterns of the OA were recorded and the consistency of collateral branches was identified to see if they frequently originated singularly (independently) or were grouped. Photographs were taken (cf. 3.2.7), field notes were made on the data sheets and sketches were drawn as part of the data capturing.

3.5. STATISTICAL ANALYSIS

The data was captured into Excel spreadsheets and sent for statistical analysis by the biostatistician. Information obtained from the cadaver eyes was statistically analysed using the Statistical Analysis Software (SAS) version 9.4. The types of variations observed were given a code which indicated the type of variation. Results of the statistical analysis will be discussed in detail in Chapter 4.

3.6. ENSURING THE QUALITY, RELIABILITY AND VALIDITY OF THE STUDY

3.6.1. Reliability

Reliability is a concept used for testing or evaluating quantitative research. This determines the consistency of results over time and an accurate representation of the total population under study (Afzal, Azeem & Bashir, 2008:36; Golafshani, 2003: 598). If the results of the study can be reproduced under a similar methodology, then the research instrument is considered to be reliable; ensuring replicability or repeatability of results or observations Afzal *et al.* (2008:37).

The three types of reliability in quantitative research are the following:

- The degree to which a measurement, given repeatedly, remains the same
- The stability of a measurement over time
- The similarity of measurements within a given period

In this study, consistency in methodology was sustained throughout the study to ensure accuracy on the representation of the results of the total study population. The same methodology was used for all dissections and all the findings on all the specimens (eyes) were documented and used accordingly on each and every eye to ensure that the results on each of them were reliable.

Guidelines from the literature as described in Table 3.1 were used and results were recorded in the same way. This table was used as reference for all results obtained.

The researcher was solely responsible for all the dissections and analyses of the OA and its branching patterns. Supervisors conducted additional reviews on dissected specimens to ensure the results were reliable.

<u>Intra-observer error</u>

For both eyes in each cadaver, all the branches were carefully isolated and identified, and were counted to establish whether any were missing. Before moving on to the next cadaver, the data for both eyes (left and right) were checked again to ensure accuracy.

<u>Inter-observer error</u>

The supervisors reviewed the data to eliminate possible errors.

3.6.2. Validity

Validity determines whether the research truly measures that which it was intended to measure or how truthful the research results are. It is also described as "construct validity".

The construct is the initial concept, notion, question or hypothesis that determines which data is to be gathered and how it is to be gathered. Researchers generally determine validity by asking a series of questions and will often look for the answers in the research of others (Golafshani, 2003:599).

The current research did measure that which it was intended to measure and all data was gathered in a step-by-step guideline following the same methodology. In cases where certain findings were not too clear, published literature was consulted. The researcher's prolonged dissection experience was of great advantage in performing the techniques well.

Literature was reviewed on retrospective studies prior to conducting the research to build on the knowledge of the subject. The methods and techniques used in previously published literature were also noted and followed accordingly.

In cases where certain methods and techniques were not found in literature, the co-supervisor who is a registered clinical ophthalmologist was consulted to provide guidance.
A human anatomy textbook was also consulted to perform the dissections. All structures that did not appear in the textbook were identified and noted for the purpose of this study. Data in the form of photographs, schematic representations,etc were recorded in data sheets provided.

3.7. ETHICAL CONSIDERATIONS

The study on the dissection of the human orbit was conducted at two locations: the Department of Basic Medical Sciences, University of the Free State and the Department of Human Biology, University of Cape Town.

According to The National Health Act, 2003, these two institutions are authorised to receive human cadavers. Ethical approval was obtained from the Ethics Committee of the Faculty of Health Sciences, University of the Free State with the number 33/2016.
No ethical approval was needed at the University of Cape Town because it had already been given by the state when cadavers are donated to the university. However, consent forms were obtained for bodies that were bequeathed to UCT and from the Dept of Health for bodies of indigent people.

Permission to conduct the study in the Department of Basic Medical Sciences was obtained from the Head of the Department of Basic Medical Sciences, Dr Sanet van Zyl, University of the Free State and also the Head of Division of Clinical Anatomy and Biological Anthropology, Professor Graham Louw, at the Department of Human Biology, University of Cape Town.

Cadaver confidentiality was ensured throughout the study. Photographs taken for dissection of the orbit did not reveal the identity of cadavers and they were not manipulated in any way.

The study was conducted in strict adherence of the protocol.

3.8. CONCLUSION

In this chapter, the methodology, research design and methods used to address the research questions in the current study were unpacked in detail.

The next chapter reports on the results of the dissections performed in order to collect data during the course of this study.

CHAPTER 4

RESULTS AND FINDINGS OF THE DISSECTION OF THE OPHTHALMIC ARTERY (OA)

4.1. INTRODUCTION

In Chapter 3, the methodology used in this research project and its theoretical aspects were discussed. In this chapter, the results of the dissections performed and data collection methods in the study will be reported. A detailed discussion of the findings is provided in chapter 5.

In some cases, tables, figures and graphs will be used to explain and illustrate the data, followed by a short discussion to elucidate the results obtained. This chapter will conclude with a short summary.

4.2. THE CADAVER SAMPLE

Twenty-three cadavers from the University of the Free State and 36 cadavers from the University of Cape Town were included in the study. Of the 59 dissected cadavers, 25 (42%) were female and 34 (52%) were male.

Tables 4.1 to 4.3, and Figure 4.1 show the ratios in terms of sex and population group according to the departmental registries of both institutions.

Table 4.1: **Number of cadaver eyes included in the study**

	UFS	**UCT**	**Total**
Number of eyes	46	72	**118**

Table 4.2: **Demographic data of the cadavers at the University of the Free State**

	Female	**Male**	**TOTAL**
Black	4	8	**12**
White	5	6	**11**
TOTAL	**9**	**14**	**23**

Table 4.3: **Demographic data of the cadavers at the University of Cape Town**

	Female	Male	TOTAL
Black	4	3	**7**
White	10	8	**18**
Coloured	2	9	**11**
TOTAL	**16**	**20**	**36**

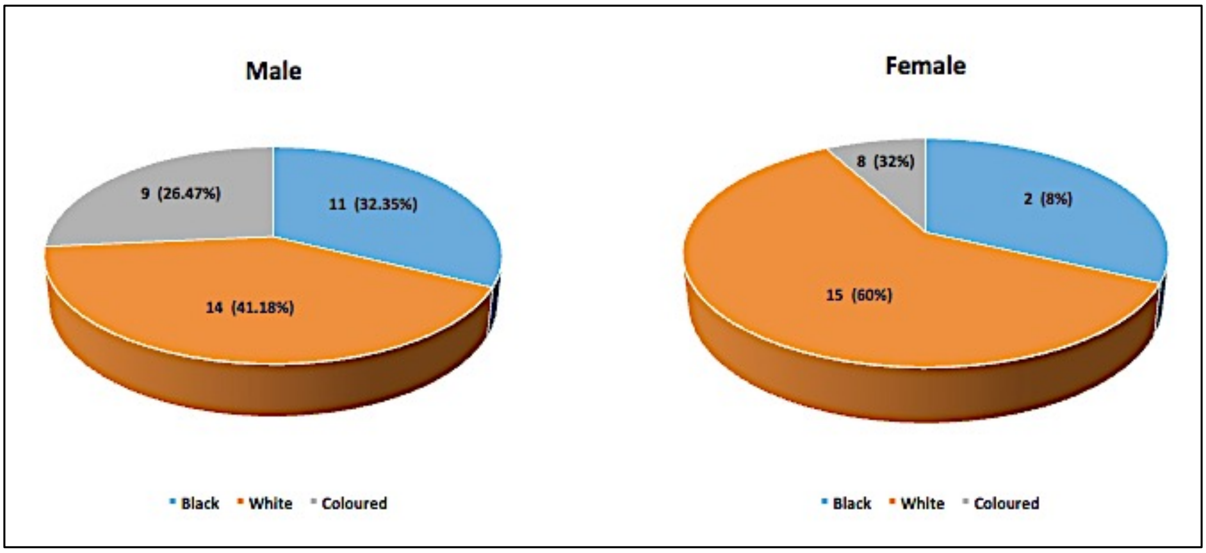

Figure 4.1: **Demographic distribution of sample population.**

4.3. THE USUAL BRANCHING PATTERN WITH NO VARIATIONS

The OA was followed from its point of origin just after it emerged from the superior orbital fissure (SOF) and all branches emerging from it were dissected and exposed thoroughly. Mostly, the OA was observed as crossing above the ON and very rarely below the ON. The dissections were done with reference to the following textbooks: Surgical Anatomy of the Ocular Adnexa: A Clinical Approach (Jordan *et al.,* 2012) and the Atlas of Human Anatomy (Netter, 2014). Table 3.1 was used as a guide to follow the branching patterns as indicated by Hayreh (2006:1137).

The figures below show the dissections that were performed and the colouring done with red stamp pad ink to show the branches. The photographs were taken and given captions and the labels on the figures used for orientation of the specimens, i.e. S = superior, I = inferior, N = nasal (medial side), T = temporal (lateral side).

Figure 4.2 shows the usual branching pattern for the OA with no variations. The OA was exposed to show its branches going to the different parts they respectively supply. The OA originated above the ON in this case.

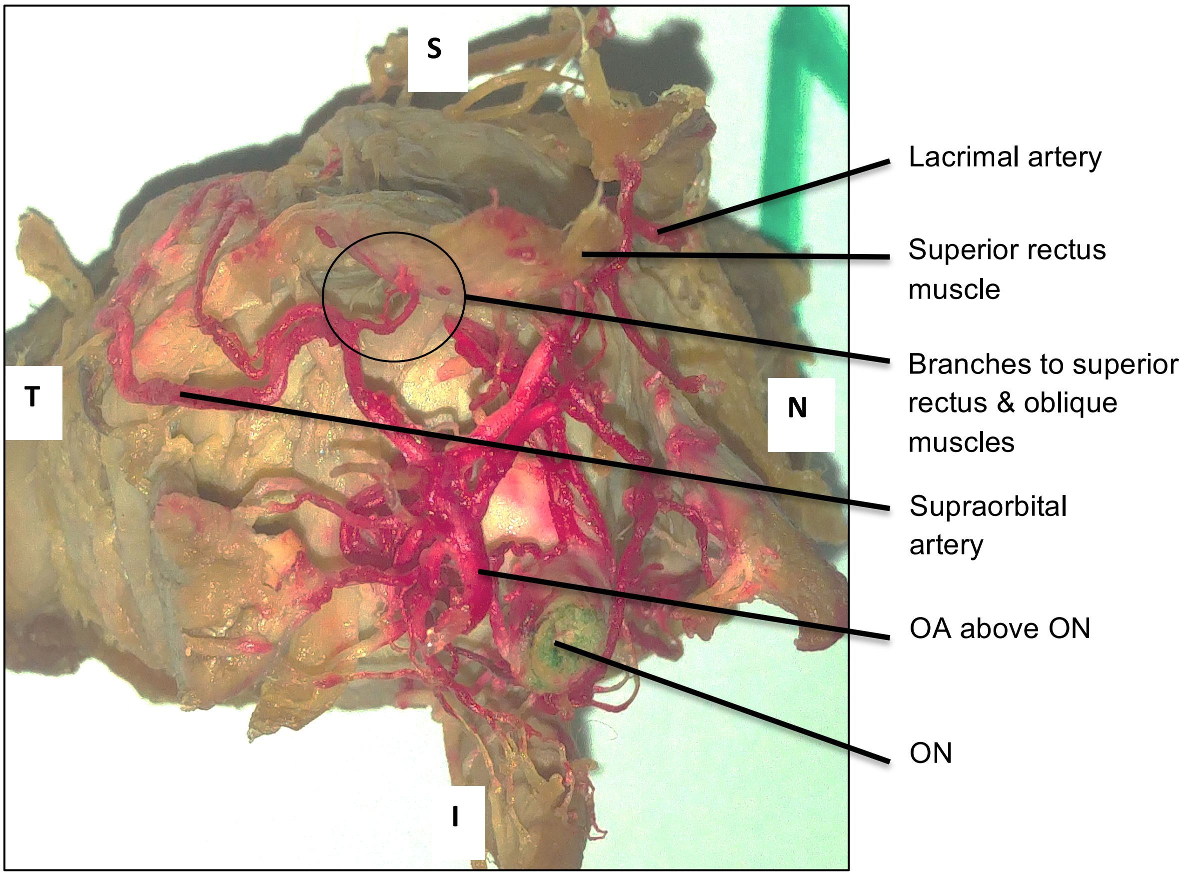

Figure 4.2: **The usual branching pattern when the ophthalmic artery (OA) crosses above the optic nerve (ON).**

Another usual branching pattern is shown in Figure 4.3 when the OA crosses below the ON.

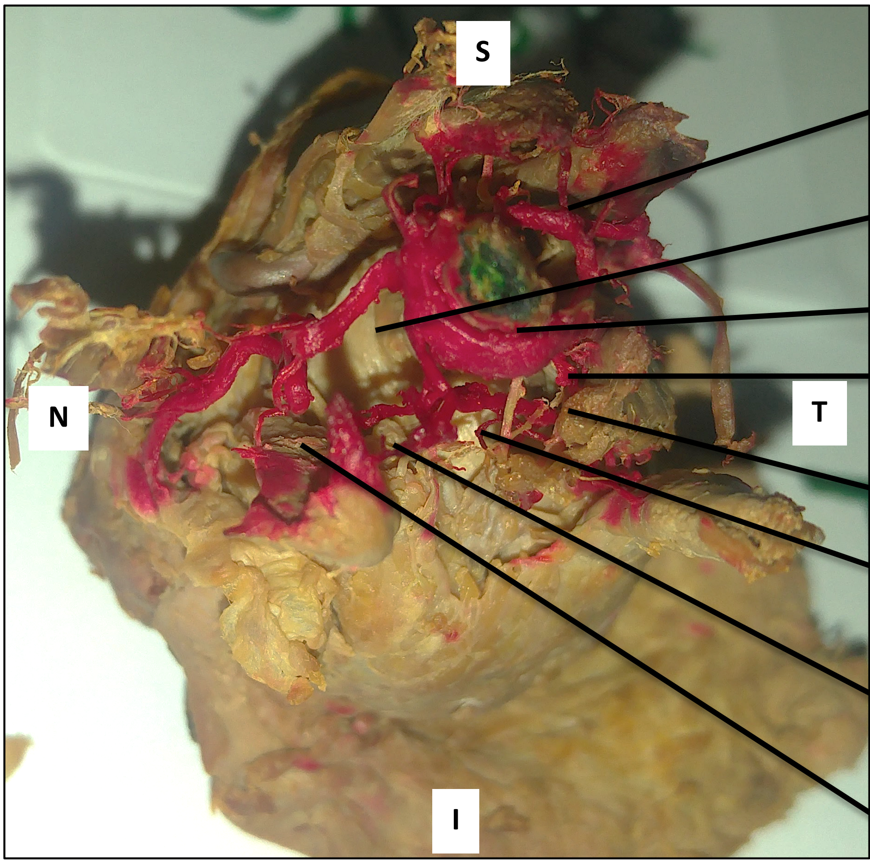

Figure 4.3: **The usual branching pattern when ophthalmic artery (OA) crosses below the optic nerve (ON).**

4.4. UNUSUAL BRANCHING PATTERNS OF THE OA WITHIN THE CADAVER SAMPLE

In the following section different patterns of variations that were observed during the dissections will be presented by using both photographs and descriptions. The figures are presented in a sequence according to the anatomical branching pattern from posterior to anterior when the OA crosses above the ON. Further variations can additionally be seen in Appendix D with schematic representations.

4.4.1. Variations of the CRA

The CRA is the first branch that appears as the OA crosses above ON (cf. Table 3.1). The CRA gave off a branch to the superior rectus muscle as indicated by the black arrow in Figure 4.4. An additional branch going to the superior rectus muscle emerged from the OA at its usual branching position indicated by the blue arrow. Collateral branches to the ON were not considered.

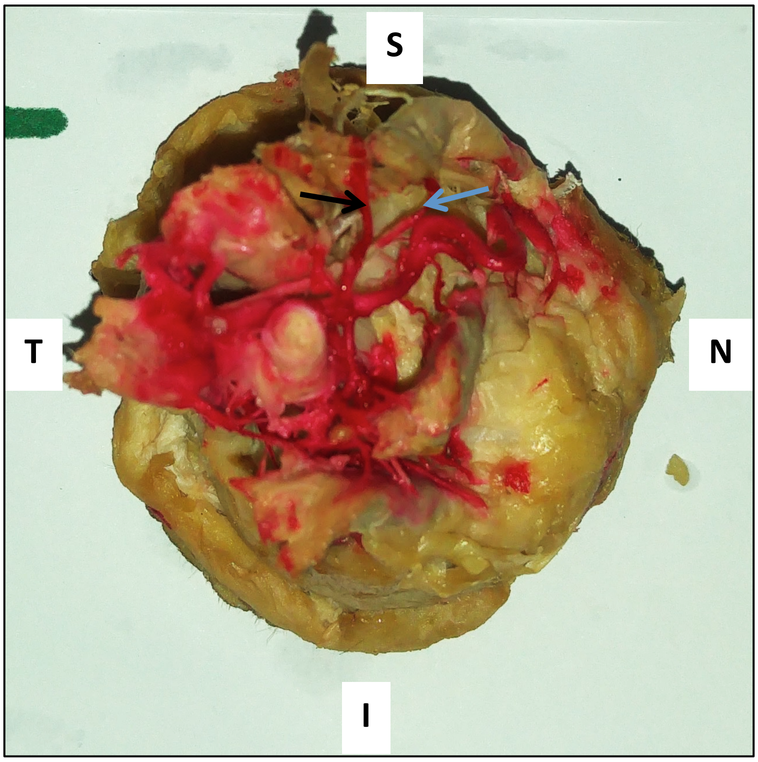

Figure 4.4: **The central retinal artery (CRA) gives off a branch to the superior rectus muscle at an unusual position (black arrow); another branch to the superior rectus appears at the usual branching position (blue arrow).**

4.4.2. Variations of the lateral posterior ciliary artery (LPCA)

Figure 4.5 on the following page shows an unusual branching pattern of the OA. The black arrows indicate two points where the lacrimal artery (LA) and the lateral posterior ciliary artery (LPCA) bifurcated from the OA opposite one another.

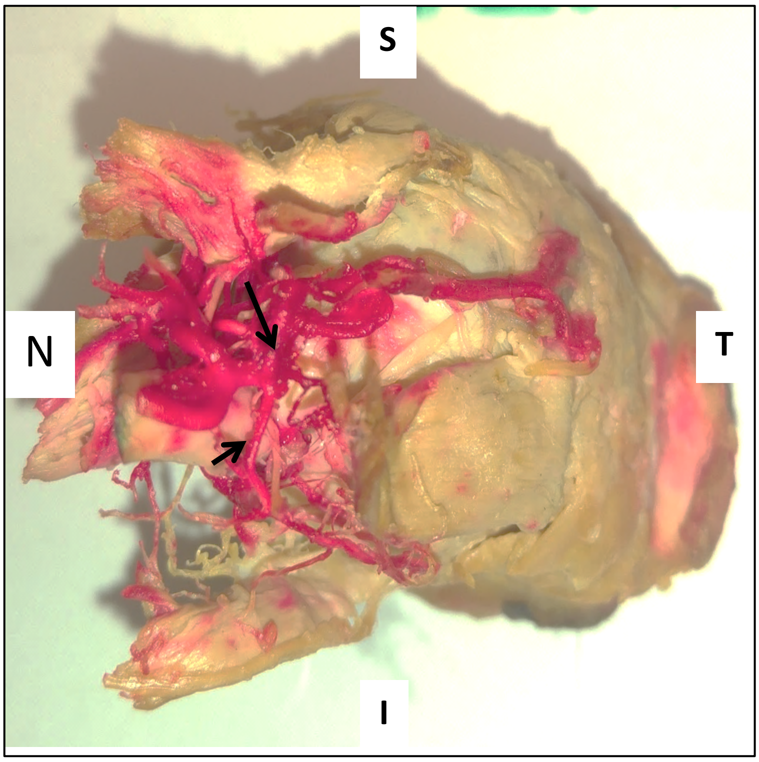

Figure 4.5: **The lacrimal artery (LA) and the lateral posterior ciliary artery (LPCA) bifurcate opposite each other from the OA. The black arrow on the superior side of the OA indicates the branch to the lacrimal artery and the other black arrow on the inferior side of OA indicates the LPCA.**

4.4.3. Variations of the lacrimal artery (LA)

The lacrimal artery (LA) supplies the lacrimal gland and pierces it, giving off its terminal branches of which there may be several (cf. paragraph 2.6.2).

Figure 4.6 and Figure 4.7 show some of the lacrimal artery branching patterns that were observed.

The black arrow in Figure 4.6 indicates the branch of the lacrimal artery going towards the lateral side of the frontal nerve after the lacrimal artery divides into two branches.

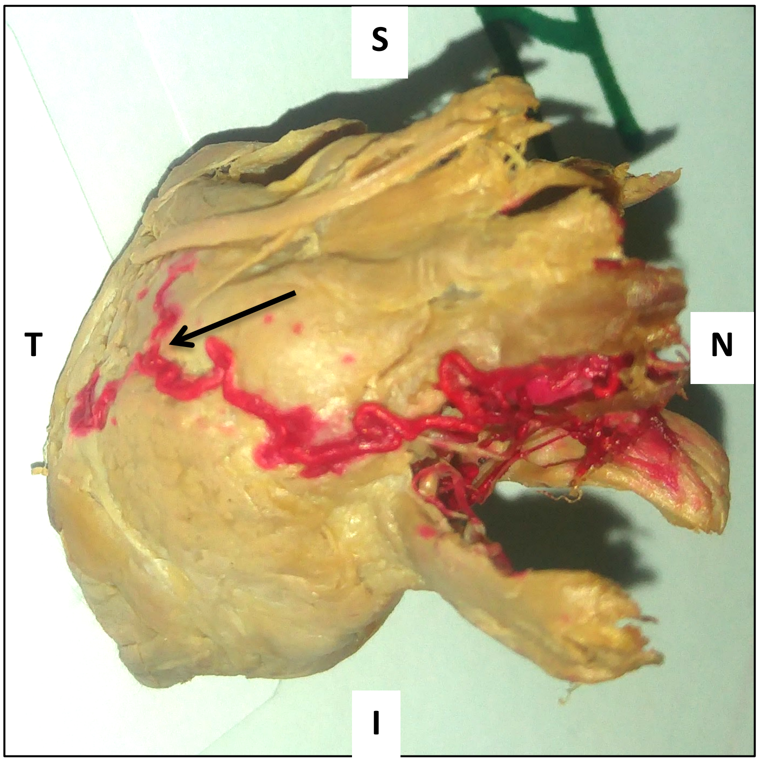

Figure 4.6: **The lacrimal artery bifurcates (black arrow).**

In Figure 4.7 the black arrow points to the lacrimal artery as it divides into 3 branches: one to the lacrimal gland, and two branches forming the zygomatic branches.

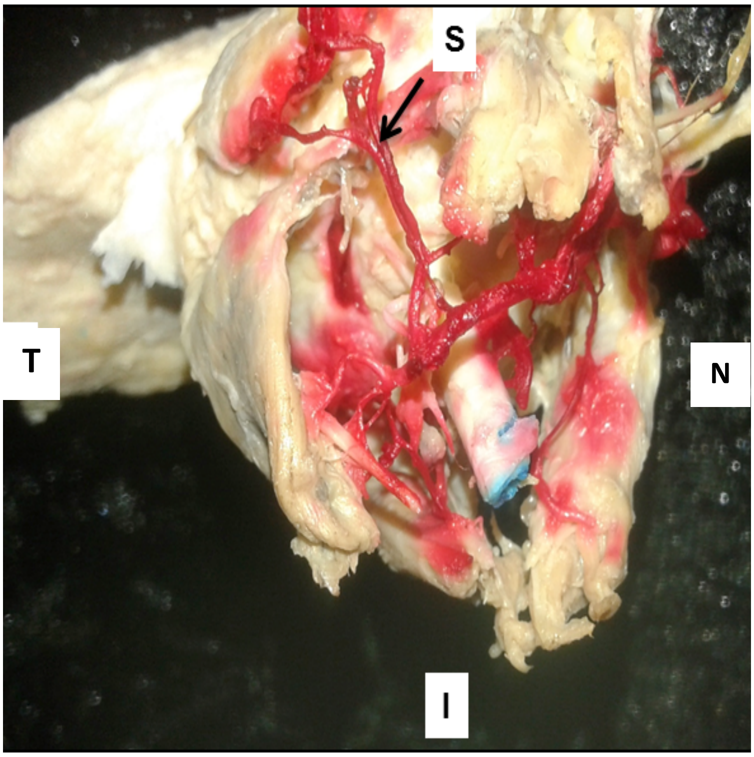

Figure 4.7: **The lacrimal artery dividing into 3 branches (black arrow).**

4.4.4. Variations of the supraorbital artery

Figure 4.8 shows the supraorbital artery branching off the OA and coursing along the medial side of the frontal nerve. In Figure 4.9 the supraorbital artery was absent.

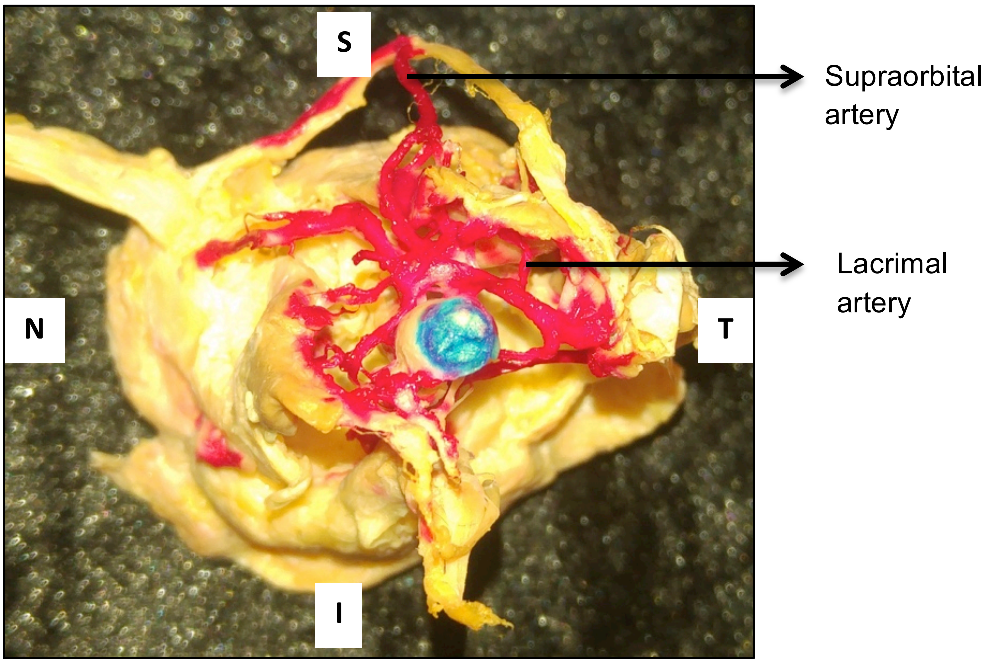

Figure 4.8: **The supraorbital artery branches off the OA and lies on the medial side of the frontal nerve.**

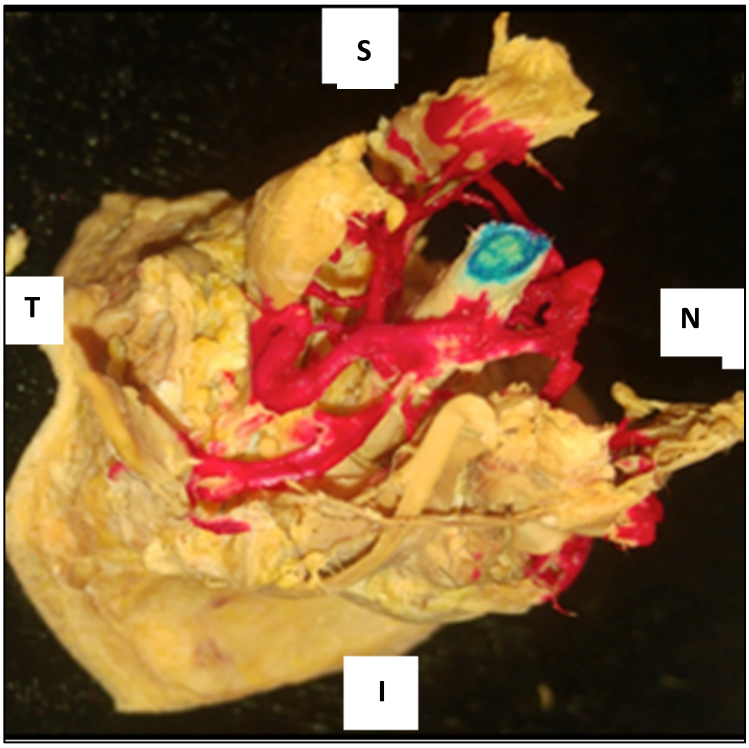

Figure 4.9: **Absence of the supraorbital artery.**

Figure 4.10 shows the common origin of the PEA and supraorbital artery as indicated by the black arrow.

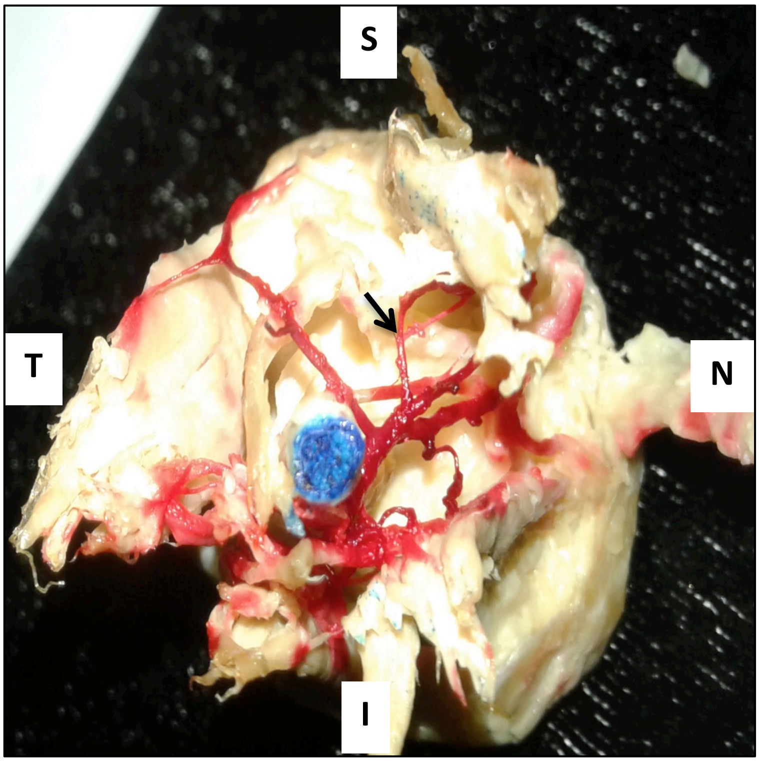

Figure 4.10: **The common origin of the supraorbital artery with the PEA (at the point indicated by the black arrow).**

4.4.5. Variations of the medial palpebral ciliary artery

The black arrow in Figure 4.11 shows the point of an unusual branching pattern where the medial palpebral ciliary artery (MPCA) emerges directly from the medial muscular branch of the OA.

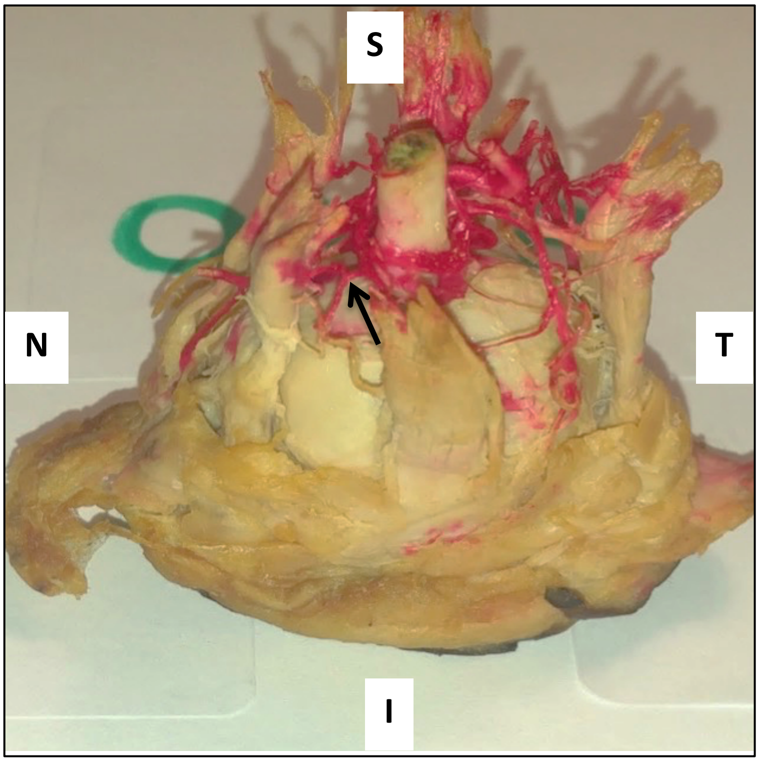

Figure 4.11: **The medial posterior ciliary artery (MPCA) emerges directly from the medial muscular branch of the OA. The black arrow indicates the point of emergence.**

4.4.6. Variations of the medial muscular branch

The medial muscular branch of the OA encircled with yellow marker on Figure 4.12 below appears before the MPCA branches that are encircled with the green markers.

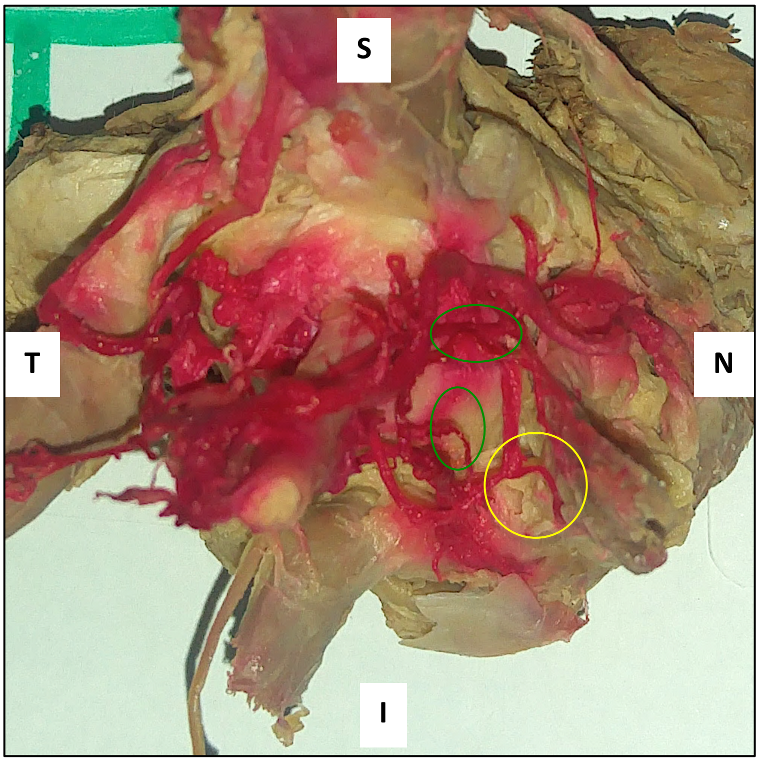

Figure 4.12: **The medial muscular branch of the OA appears before the medial posterior ciliary artery (MPCA) directly from the OA. Yellow circle = medial muscular branch; green circle = MPCA.**

4.4.7. Variations of the branch to the medial rectus muscle

The black arrow in Figure 4.13 shows the muscular branch of the OA giving off a branch that supplies the inferior rectus muscle.

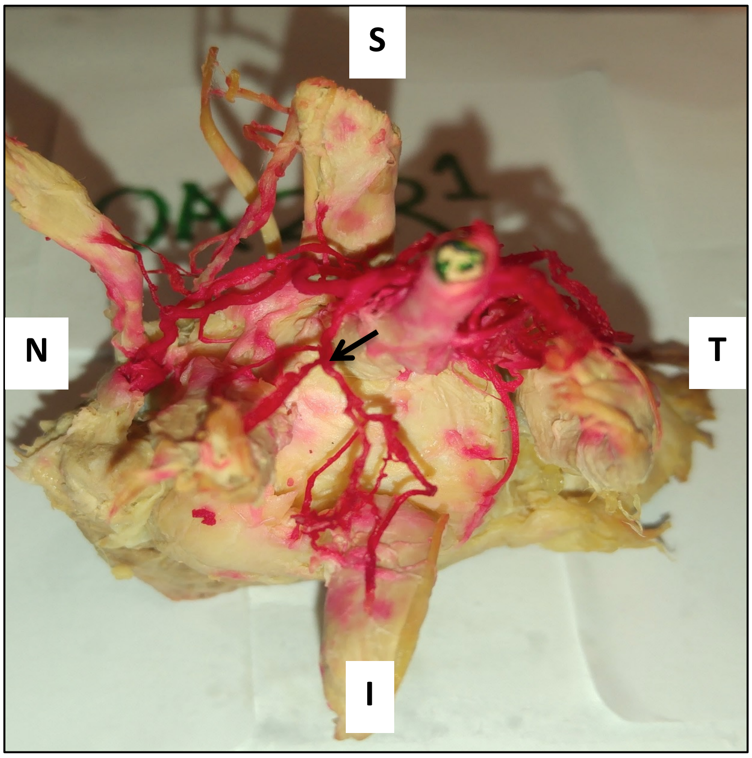

Figure 4.13: Muscular branch of the OA gives off a branch that supplies the inferior rectus muscle. The black arrow indicates the point where they divide.

4.5. A SUMMARY OF ALL VARIATIONS FOUND IN THE CADAVERS

The figures 4.4 to 4.13 show some of the variations that were noted in the cadavers during the data collection. Some variations were not visible on certain photographs; but were still listed in addition to those that were photographed and recorded in Table 4.4.

All the patterns of variation that were observed are described. In some cases, variations were found only on the one side while the other side showed the usual branching pattern or showed a different variation. Descriptive statistics were done for all variations observed.

Table 4.4: **Description of variations identified by the researcher in the current study**

Variation	Description
1	Supraorbital artery emerges from the OA (between superior rectus + levator palpebrae) – goes to the medial side of the frontal nerve
2	Lacrimal artery divides into 3 branches
3	Supraorbital artery emerges from the OA on the medial side of the frontal nerve
4	Lacrimal artery divides into 2 branches
5	Supraorbital artery shares a common origin with PEA and courses to the medial side of the frontal nerve
6	Supraorbital artery is absent
7	One branch divides into two: medial rectus and medial muscular branches
8	An unusual branching pattern (see description in appendix D)
9	Unusual branching pattern: MPCA arises before medial muscular branch
10	LPCA emerged directly opposite the LA
11	An unusual branching pattern (see description in appendix D)
12	Muscular branch to medial gives off branch to inferior rectus
13	Different arrangement pattern of the OA crossing above the ON
14	Branch arising between the LA and the branch to superior rectus muscle
15	No AEA
16	Unusual branching pattern: LA emerges as the first branch from OA (see description in appendix D)

4.5.1. Statistical analysis

Statistical analysis was performed on all the data obtained from the dissected cadaver eyes using SAS version 9.4. The coding values on a spreadsheet in Appendix D were used for interpretation of the data as advised by the biostatistician for accuracy of the statistics. The cadaver sample was divided into two groups, UFS (Group 1) and UCT (Group 2) for statistical analysis. Individual eyes were identified according to the variations that were noted as seen in Table 4.4. The categories showed the different patterns of variations that were noted in this table to answer the research questions (cf. paragraph 1.3). The following aspects were investigated:

- Order of crossing of the OA (whether the OA crossed above or below the ON)
- Unilateral or bilateral variations (branches of the OA within the eyes)

- Variations identified in the branches of the OA
- Overall prevalence of the variations observed
- Influence of population group on the variations found

In Table 4.5, the order of crossing of the OA in the UFS group (Group 1) is shown.

Table 4.5: **Order of crossing of the OA in the UFS group (Group 1) (n=23)**

Order of crossing	Left eye		Right eye	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Above ON	18	**78.26**	19	**82.61**
Below ON	5	**21.74**	4	**17.39**
TOTAL	**23**	**100.00**	**23**	**100.00**

In the left eye, the OA crossed above the ON in 78.26% and below the ON in 21.74% in Group 1. On the right side however, the OA crossed above the ON in 82.61% cases and below the ON 17.39% of cases.

In Table 4.6, the order of crossing of the OA is summarised for the UCT cadavers (Group 2). In this population, the OA crossed above ON in the right eye in all cases and only 11.11% cases in the left eye, had the OA crossing below the ON.

Table 4.6: **Order of crossing of the OA in the UCT group (Group 2) (n=36)**

Order of crossing	Left eye		Right eye	
	Frequency	Percentage (%)	Frequency	Percentage (%)
Above ON	32	**88.89**	36	**100.00**
Below ON	4	**11.11**	0	**0**
TOTAL	**36**	**100.00**	**36**	**100.00**

4.5.2. Frequency of variations in the branches of the OA.

Certain variations were noted either unilaterally or bilaterally and were coded as indicated in appendix D. Table 4.7 and Table 4.8 show the frequencies and percentages of the variations found in the two groups.

Table 4.7: **Variations: the left orbit vs the right orbit in the UFS group (Group 1)**

Variations	Frequency (left orbit)	Percentage	Frequency (right orbit)	Percentage
1	-	-	-	-
2	-	-	-	-
3	-	-	1	4.35
4	2	8.69	1	4.35
5	-	-	-	-
6	14	60.87	9	39.13
7	-	-	-	-
8	-	-	-	-
9	2	8.70	2	8.70
10	-	-	1	4.35
11	-	-	1	4.35
12	-	-	1	4.35
13	-	-	1	4.35
14	2	8.70	4	17.39
15	2	8.70	1	4.35
16	1	8.70	1	4.35
TOTAL	**23**	**100.00**	**23**	**100.00**

- **No variation was noted in the category**

Table 4.8: **Variations: the left orbit vs the right orbit in the UCT group (Group 2)**

Variations	Frequency (left orbit)	Percentage	Frequency (right orbit)	Percentage
1	1	2.78	-	-
2	1	2.78	1	2.78
3	7	19.44	3	8.33
4	1	2.78	4	11.11
5	1	2.78	-	-
6	24	66.67	27	75.00
7	-	-	1	2.78
8	1	2.78	-	-
9	-	-	-	-
10	-	-	-	-
11	-	-	-	-
12	-	-	-	-
13	-	-	-	-
14	-	-	-	-
15	-	-	-	-
16	-	-	-	-
TOTAL	**36**	**100.00**	**36**	**100.00**

- No variation was noted in the category

Variation 1 showed the lowest frequency, appearing unilateral in the left orbit, at 2, 78%. **Variation 6** (supraorbital artery absent) showed the highest frequencies in both orbits, appearing bilaterally at an average of 70.84%.

Photographic and schematic representations of all the variations are included in Appendix C.

4.5.3. Frequency of laterality in variations

In Figure 4.14, the results are demonstrated in the form of a flow diagram that shows the overall sample size.

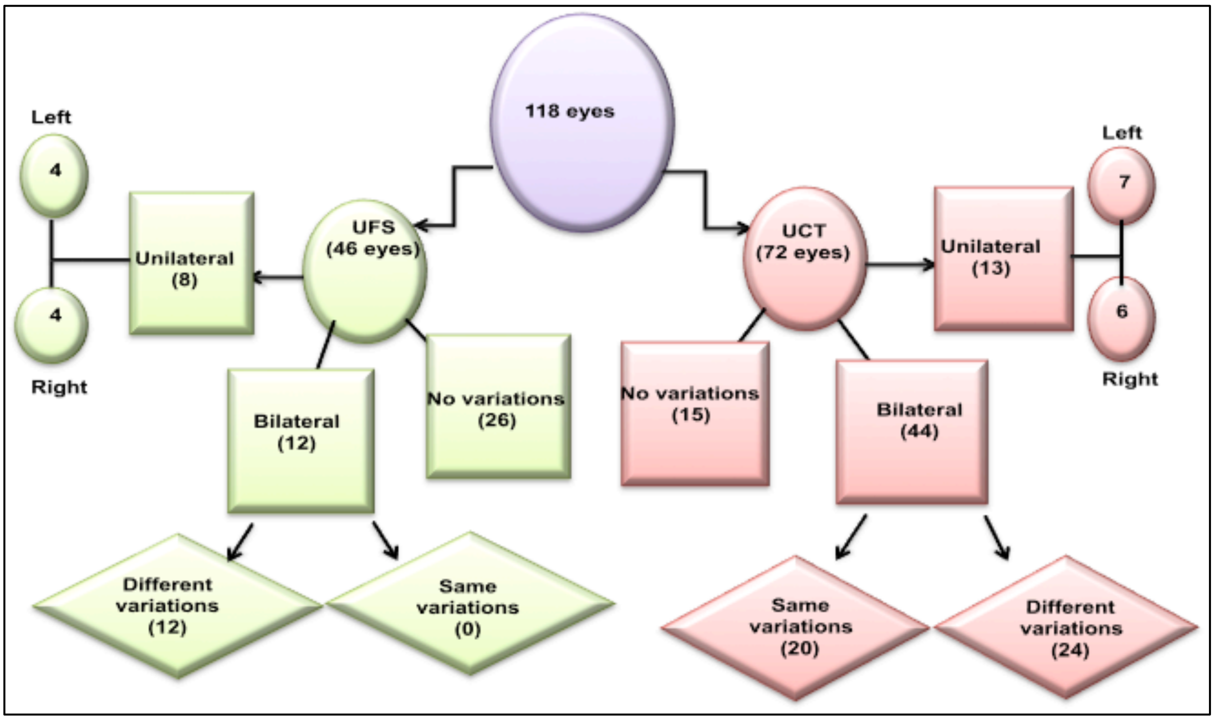

Figure 4.14: **The frequency of the unilaterality and the bilaterality in the UFS group (Group 1) and the UCT group (Group 2)**

More variations were seen to be occurring bilaterally than unilaterally. Twelve eyes in the UFS cadaver group and 24 eyes in the UCT cadaver group showed different variations that occurred bilaterally in both eyes of the same individual. Thirteen eyes in the UCT group and 8 eyes in the UFS group showed the frequency of unilateral variations.

A total of 41 eyes (26 eyes UFS and 15 eyes UCT) in the sample did not have any type of the variations recorded.

4.5.4. Sex and population group distribution variations of the OA

Tables 4.9 and 4.10 were used to further elaborate on the variations found according to the population description. The aim was to determine if there was any relation between the sexes and population groups of the cadavers and the variations found in the OA branches in this research project.

Table 4.9: **The variation frequencies for the 16 patterns found in Group 1 cadavers according to population group and sex (cf. Table 4.4)**

Variations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Sex																
Male	-	-	1	2	-	15	-	-	-	-	-	-	1	4	-	1
Female	-	-	-	1	-	8	-	-	4	1	1	1	-	2	2	-
Population group																
White	-	-	-	1	-	11	-	-	4	1	1	1	1	1	-	1
Black	-	-	1	2	-	12	-	-	-	-	-	-	-	-	1	1

- No variation was noted in the category

Certain variations were absent from the Group 1 cadavers but present in Group 2 as indicated in Table 4.10.

Table 4.10: **The variation frequencies for 16 patterns found in Group 2 cadavers according to population group and sex (cf. Table 4.4)**

Variations	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Sex																
Male	-	1	6	3	-	19	1	1	-	-	-	-	-	-	-	-
Female	1	-	4	1	1	16	-	-	-	-	-	-	-	-	-	-
Population group																
White	1	-	7	2	1	19	1	-	-	-	-	-	-	-	-	-
Coloured	-	1	1	1	-	10	-	1	-	-	-	-	-	-	-	-
Black	-	-	2	1	-	7	-	-	-	-	-	-	-	-	-	-

- **No variation was noted in the category**

Most variations were absent from Group 2 (Table 4.9) but present in Group 1 (Table 4.10). The absence of the supraorbital artery had the highest incidence in both groups.

4.5.5. Distinctive results

The following variations appeared only once and the coding in Appendices B and C was used for identification:

Variation 1: unilaterally in OA15L2
Variation 2: bilaterally in OA21R2 and OA21L2
Variation 5: unilaterally in OA31L2
Variation 7: unilaterally in OA31R2
Variation 8: unilaterally in OA8L2

4.6. CONCLUSION

In this chapter,descriptive statistics was used to analyse the data obtained from the dissection of the OA and its branches.

CHAPTER 5

DISCUSSION: OVERVIEW OF THE RESULTS OF THE STUDY

5.1. INTRODUCTION

In Chapter 4, the results were presented in labelled photographs, tables and graphs.

In this chapter the overall results of the study will be discussed and compared with the findings of other authors in the published literature.

In 1962, Hayreh (1962c:212) (cf. paragraph 1.1), reported that published findings reveal limited information about the anomalies, as he termed it, and branching patterns of the OA. In some of the cases the findings were referred to as the "unusual branching patterns" rather than the "abnormal". The "usual branching pattern" was the acceptable term used by a number of authors (Whitnall, 1932:302; Hayreh, 1962c:216).

In the present study the findings that showed a difference from the usual norm were referred to as variations. This term seems to be appropriate according to the definition extracted from the Concise Medical Dictionary (Stedman, 2006:2090).

5.2. VARIATIONS IN THE CROSSING OF ON

Variation between the eyes was recorded in terms of whether the OA crossed above or below the ON. This observation had also been recorded by Hayreh (1962c:245) in seven specimens.

In the current study, both eyes of 59 cadavers were compared to record the findings according to the objectives set out in paragraph 1.4.2. Hayreh (1962c:214) noted that Meyer who was a pioneer researcher of the OA and its branches worked on 20 specimens, while he had a total of 61 eyes in his study. He recorded the findings of 23 cadavers bilaterally and the remaining 15 were only recorded unilaterally. In this study, the overall unilateral and bilateral frequencies of variations were captured, as depicted in Figure 4.13.

The branches of the OA were more or less uniformly distributed between the first part and the initial part of the third part of the OA when it crossed above the ON. The majority of the branches originated on the medial side and less frequently from the lateral side of the ON. When the OA crossed below the ON, most branches were evenly distributed on the part of the artery lying underneath and medial to the nerve and also at the bend. Very rarely they came from the first part or the angle of the OA. This observation is confirmed by Hayreh (1962c:222) in his study.

Hayreh (1962c:214) found a marked degree of variation in the branching pattern of the OA with regard to whether the OA crossed above or below the ON. In the current study 83.05% of the cadavers showed the OA crossing above the ON, and 16.9% showed the OA crossing below the ON. In three cadavers from Group 1, the OA crossed unilaterally below the ON in the left eye, and bilaterally in three of the cadavers. No two specimens, (even from the same cadaver), showed identical patterns.

5.3. VARIATIONS NOTED IN THE BRANCHES OF THE OA

According to Kupersmith (1993:1), variations of the normal circulation between individuals and in a single subject are numerous. All the observed variations are described in table 2.1.
Hayreh (1962c:216) observed that the CRA arises independently or in common with the medial posterior ciliary as the most frequent first branch, which he also observed. However, in this study only the CRA was taken into consideration and the small collateral branches to the ON were not taken into consideration. A record of the different authors and their findings over the years from as early as 1887 to 1953 is shown in Table 2.1.These findings are supplemented in Table 3.1 by Hayreh (2006:1137). These observations were used as the foundation for the present study. Like Hayreh, the collateral branches were not taken into consideration while recording the findings. Table 5.1 shows a comparison of the variations reported in literature according to Hayreh (1962c). Additionally, the results of the UFS and UCT groups are also included and the variations will be discussed and compared with the literature.

Table 5.1: **Variations of the OA found in the literature, compared with the UFS and UCT groups. (Table continues over three pages).**

Variation	Description	Literature	UFS (Group 1)	UCT(Group 2)
1	Supraorbital artery emerges from the OA (between superior rectus + levator palpebrae) – goes to the medial side of the frontal nerve	None	None	Present in 2.78% of the eyes where the OA crossed above the ON
2	Lacrimal artery divides into 3 branches	Hayreh (1962:229) 5 branches present in most cases	None	Present in 2.78% of the eyes where the OA crossed above the ON
3	Supraorbital artery emerges from the OA on the medial side of the frontal nerve	In 81.8% of the specimens in which the OA crossed above the ON and in 92.9% of those in which it crossed below the ON	Present in 2.17% of the eyes where the OA crossed below the ON	Present in 13.89% of the eyes of the eyes where OA crossed above the ON
4	Lacrimal artery divides into 2 branches	Hayreh (1962:229) 5 branches present in most cases	Present in 6.52% of the eyes where OA crossed above the ON	Present in 6.94% of the eyes where the OA crossed above the ON
5	Supraorbital artery shares a common origin with PEA and courses to the medial side of the frontal nerve	Meyer 1887: PEA absent in 4, and the usual type in 11 of his 20 specimens (Hayreh, 1962c:237). Hayreh (1962c:237) found the PEA to be	None	Present in 1.32% of the eyes where the OA crossed above the ON

Variation	Description	Literature	UFS (Group 1)	UCT(Group 2)
		present in 81.8% of the specimens of which the OA crossed over the ON and in 85.7% of those that crossed under the ON		
6	Supraorbital artery is absent	Meyer 1887: missing in one of 20 specimens. Hayreh (1962: 240): absent in 18.2% of the specimens in which the OA crossed over the ON and in 7.1% of those in which it crossed under the ON	In 50% of the eyes the supraorbital artery was absent. (refer to text)	In 70.83% of the eyes the supraorbital artery was absent. (refer to text)
7	One branch divides into medial rectus and medial muscular branches	The medial muscular was present in 98.3% (Hayreh, 1962c:232)	None	Present in 1.38% of the eyes where the OA crossed below the ON
8	An unusual branching pattern (see description in appendix E)	None	None	Present in 1.38% of the eyes where the OA crossed above the ON
9	Unusual branching pattern: MPCA arises before medial muscular branch	Meyer (1887): 6 of his 7 eyes the MPCA did not arise from the first part but more distally (Hayreh, 1962c:236)	Present in 2.17% of the eyes where the OA crossed below the ON	None

Variation	Description	Literature	UFS (Group 1)	UCT(Group 2)
10	LPCA emerged directly opposite the LA	None	Present in 2.17% where the OA crossed above the ON	None
11	An unusual branching pattern (see description in appendix D)	None	Present in 2.17% where the OA crossed above the ON	None
12	Muscular branch to medial rectus gives off branch to inferior rectus	None	Present in 2.17% of the eyes of which the OA crossed above the ON	None
13	Different arrangement pattern of the OA crossing above the ON	None	Present in 6.52% of the eyes where the OA crossed above the ON, and in 2.17% of the eyes where the OA crossed below the ON	None
14	Branch arising between the LA and the branch to superior rectus muscle	None	Present in 13.04% of the eyes of which OA crossed over the ON	None
15	No AEA	AEA present in 90.9% of the specimens in which OA crossed over the optic nerve and in 80% of those which crossed under ON	AEA absent in 4.35% of the eyes where the OA crossed below the ON and 4.35% of the eyes where the OA crossed above the ON; and present in 91.3% of the eyes	AEA present in all the eyes, in 11.11% of the eyes the OA crossed below the ON and in 88.88% of the eyes the OA crossed above the ON
16	Unusual branching pattern (see description in appendix C)	None	Present in 4.35% of the eyes where the OA crossed above the ON	None

The **PEA** was described by Whitnall (1932:308) as a small and inconstant branch. Whitnall further stated that the PEA may emerge from the supraorbital artery instead of coming directly off the ophthalmic artery. Variation 5 confirms this statement, as was seen in one specimen in the UCT group where the OA crossed below the ON. Hayreh (1962c:237) stated that in 1887 Meyer found the PEA to be absent in 4 (20%), weakly developed in 3 (15%), strong developed in 2 (10%) and the usual type in 11 (55%) of his 20 specimens. In his study (Hayreh, 1962c:237) found the PEA to be present in 81.8% of the specimens where the OA crossed above the ON and in 85.7% of those where the OA crossed under the ON. Anderson *et al.,*(2012:167) further reported that PEA is absent in 15% 20% of population (c.f. paragraph 2.6.6). In this study, the PEA was present in all the eyes.

The **supraorbital artery** had the highest frequency of absence in both the UCT and UFS groups. Whitnall (1932:308) described the artery as inconstant although it was usually present. Meyer in 1887 observed that it was missing in 5% of his 20 specimens. Hayreh (1962:240) observed the artery to be absent in 18.2% of the specimens where the OA crossed above the ON and in 7.1% of those where it crossed below the ON.

When looking at Variation 6, only one male cadaver from Group 1 had the supraorbital artery unilaterally in the right eye. The remaining 22 cadavers did not have the supraorbital artery. Ten cadavers in Group 2 (most frequently in males) showed the supraorbital artery as present; in 7 males it was unilateral in the left orbit and twenty-six cadavers did not have the supraorbital artery.

These findings can best be explained in comparison with the published literature that shows the supraorbital artery to be absent in approximately 10% to 20% in a population of normal individuals (cf. paragraph 2.5) as was noted by some of the authors (Anderson *et al.,* 2012:167; Lemp & Snell,1998:282). The present study shows the supraorbital artery to be absent in 90,68% of the sampled cadavers. This could most probably be attributed to the exenteration technique used for the dissection in this study. When removing the eyes, the periosteum was stripped away from the orbital wall and in the process most of the supraorbital branches were damaged. Technically it was a challenge to distinguish between natural absence or the iatrogenic damage to the supraorbital branches.

Cadaver 57 showed bilateral appearance of the **lacrimal artery** splitting into two branches. All cadavers that showed these variations were seen unilaterally and frequently in males.

The medial posterior ciliary artery was observed as coming before the medial muscular branch in the left eye unilaterally in two cadavers and in the right eye unilaterally in two cadavers.

The **AEA** is absent in less than 2% of cases (Anderson et al., 2012:168) (c.f. paragraph 2.6.7). The AEA was absent in 3.39% eyes in the current study. This could also be attributed to the exenteration technique; however the researcher made a point to identify the anterior and posterior ethmoid arteries during the exenteration process. During the exenteration it was easy to identify the anterior and posterior ethmoid arteries. This was in contrast with Hayreh's findings (Hayreh, 1962:241) in his study of 20 cadavers. The AEA was present in 90.9% of the specimens where the OA crossed over the optic nerve and in 80% of those which crossed under ON.

The Coloured population was under-represented, the White population well represented and the Black population was at a midpoint. Departmental registers at both institutions show high numbers of the dominating group to be regular body donors while the lower numbers were mainly through indigent people and unclaimed bodies.

The study was carried out on 118 eyes from 59 cadavers. The order of origin of the OA and the branches of the OA were investigated. Many variability was observed between the eyes. The branches were distributed along the course of the OA, but most of the branches were usually crowded together at two points: where the OA bent from first to the second part and from the second to the third part. This confirms the observation made by Hayreh, (1962c:246).

5.4. CONCLUSION

In this chapter, the results of the study were discussed and compared with other published data. Many discrepancies were found on certain variations.

The current study also confirmed the variations to be occurring in both orbits, and at specific locations when comparing the eyes. Not all the variations were duplicated in both eyes of the same individual.

Chapter 6 presents **Conclusion, recommendations and limitations of the study**. This chapter will provide an overview of the study, identify the significance and limitations of the findings, and make suggestions for further studies and research.

CHAPTER 6

CONCLUSION, RECOMMENDATIONS AND LIMITATIONS OF THE STUDY

6.1 INTRODUCTION

This study consisted of research with the title: **The prevalence of anatomical variations in the intraorbital part of the ophththalmic artery and its branches in cadavers**.

The previous chapter documented and interpreted the results of the dissections in relation to the objectives of the study.

The aim of Chapter 6 is to provide a conclusive overview of the study. The chapter begins with a general overview of the study. This is followed by providing answers to the research questions and addressing the objectives of the study. The chapter concludes with recommendations, limitations and concluding remarks.

6.2 OVERVIEW OF THE STUDY

The study was performed and completed on the basis of four research questions. The research findings served as the basis for noting and reporting back the prevalence of the variations in the intraorbital part of the OA that were found within the population under study. The study focused on the intraorbital part of the OA in South African cadavers in the Free State and Western Cape provinces. No South African data on the intraorbital OA and its branches was previously available, creating the need for original research in this area. New medical interventions have redefined the importance of these studies: knowledge of the detailed anatomy of the OA is essential for the pathophysiology, diagnostic approach and therapeutic interventions for various ocular diseases and intraocular tumours such as retinoblastoma.

The research questions were presented in Chapter 1 (cf.1.3) and directed the study and its outcome. The four research questions and main findings are reviewed below.

6.2.1 Research question 1

The first research question was formulated as: *Which variations are present in the OA and its branches in the orbit of a human cadavers in the Department of Basic Medical Sciences,* *University of the Free State and the Department of Human Biology, University of Cape Town?*

The following objective was pursued: *To gain a better understanding regarding the OA and its branches in cadavers from two institutions in South Africa.*

This objective addressed research question 1:

To dissect cadaver eyes and document the variations by means of a data sheet, photography and annotated schematic presentations.

Chapter 2 provided a detailed conceptualisation and contextualisation of the subject. The literature review provided a clear understanding of the anatomy of the OA, from its embryological point until the adult stage; the clinical significance of the OA and an overview of abnormalities and variations of the OA (cf. paragraph 2.6 and 2.7), as well as the necessary information for the dissections, data collection and reporting of the findings.

Data collection was done by means of fine dissections, data capturing with digital photographs and diagrammatic illustrations with notes (cf. Appendix D). The data of the dissection findings were reported in Chapter 4. Several variations were identified. Some had already been known and previously reported in literature and while others had never been reported in the published literature before. The reliability, validity and quality assurance of the study were described in Chapter 3 (cf. 3.5).

The researcher reported several anomalies and variations of the branches of the OA in the cadavers dissected at the University of the Free State and at the University of Cape Town (cf. paragraph 4.4 and Table 4.5).

6.2.2 Research question 2

The second research question was: *Do these variations occur unilaterally or bilaterally?*

The following objective was pursued: *To determine if the variations which occur on one side only or on both sides.*

This objective addressed research question 2:

An assessment of the two sides was done to see if the variations existed unilaterally or bilaterally. This was documented by means of data sheets, photography and annotated schematic presentations. A possible relationship between the variations in one or both sides was reported (cf. paragraph 4.5.3).

The findings started by determining the order of origin of OA; whether it was crossing above or below the ON (cf. Table 4.6 and 4.7).The left eye was affected more commonly with the variation of the OA crossing below the ON in 21.74% of the UFS cadaver group. The UCT cadaver group had no OA crossing below the ON.

The majority of variations were found to occur bilaterally, and in most cases, variations in the left differed from the variations in the right eye.

6.2.3 Research question 3

- The third research question was: *What is the frequency of the unilaterality or bilaterality?*

The following objective was pursued: *To determine the frequency of the variations on a specific side.*

This objective addressed research question 3.

In response to research question 3, the literature review as described in Chapter 2 provided the necessary background and the data gathered from the dissections and presented in Chapter 4 were used to answer the question.

A possible relationship of variations between the two eyes was reported (cf. Figure 4.14). The left eye within the UCT cadaver group showed a higher frequency of variations, for instance 7 eyes were recorded whereas 4 eyes were recorded in the UFS group.

6.2.4 Research question 4

The last research question was identified as: *Are the variations observed in this study also influenced by sex?*

The following objective was pursued: *To determine if sex plays a role in the occurrence of some of the variations of the branches of OA.*

This objective addressed research question 4.

In response to research question 4, the literature review as described in Chapter 2 provided the necessary background and the data gathered from the dissections and presented in Chapter 4 were used to answer the question. The sex of the cadavers was noted on the data sheet for the purpose of determining its prevalence.

A possible relationship of variations between the sexes was discussed in Chapter 4. (cf. paragraph 4.7). The males generally showed the highest frequency of variations.The researcher endeavoured to provide a number of examples of the variations in the branches of the OA. The researcher documented the symmetry, if one side wa affected more than the other and noted when the variations were more prevalent in males than in females (cf. Table 4.8 and Table 4.9).

6.3 LIMITATIONS OF THE STUDY

The researcher recognises the following limitations in the study:

Only 118 eyes were dissected in two training institutions, the University of the Free State and the University of Cape Town. The present study consisted of three of the major population groups of South Africa. Common in the two places. A multi-centred study could have yielded more results by increasing the sample size. This would also increase the diversity of the study sample because some of the population groups could have been excluded due to the demographics of the study centre.

The methods used for the dissection required considerable skill. The method that was commonly used in literature for the administering of the latex solution was tried during a dissection skill development pilot before starting with the main study. This method however, proved to be problematic and did not deliver the required results. The method of choice, exenteration, was then introduced and this was time-consuming and required considerable concentration to give detail to the work. This has however proved to be very successful.

A thorough knowledge of the anatomy of the structures is of great value to ensure the correct identification of the OA and its branches. The OA and its branches were then coloured individually. In one instance, the vein was mistaken for the artery and required removal of the ink. The eye had to be timeously soaked in clean water for 3 days for the ink to be diluted enough to repeat the process.

The absence of the supraorbital branch became evident in most eye specimens studied. This is most probably due to the exenteration technique. Technically during the exenteration the branches of the supraorbital artery were probably removed. However, in certain eyes they were possibly missing. Exenteration proved a very useful method of study as it gave the advantage of removing the eye with easy access to the arteries for dissection. Another method that may have been used is accessing the ophthalmic artery through the removal of the skull cap and the brain, but this method was seen to be disadvantageous as it required the researcher to open the orbital roof. This would have damaged the skulls, rendering them useless for the anatomy students and their training.

The verification of findings and accuracy of the dissection technique relied solely on the quality of the dissected eye. Branches of the OA are very thin and mostly fragile; if the dissection technique is not executed with care the artery and branches will easily be damaged or destroyed.

Between 4 to 8 eyes could, depending on the researcher’s dissection skills, be dissected in a day leaving the colouring and data capturing for the next day. If fewer eyes are dissected, this could prolong the data collection period.

Having a small number of female cadavers in the study restricted the significance of comparison between the sexes. The female cadavers at the University of Cape Town are kept aside for obstetricians and gynaecologists and other surgical trainees, while the University of the Free State also usually receives more male bodies than female bodies at their facility.

6.4 CONTRIBUTION OF THE STUDY TO KNOWLEDGE

The research constitutes a valuable contribution by providing information about the variations of the OA and its branches in cadavers in two provinces of South Africa. There is no published information in literature regarding any previous studies of the blood supply to the eye and orbit in South Africa. Valuable data about the bilaterality, unilaterality, population group and sex differences were recorded.

By assessing the results, recommendations could be made to assist with the clinical application of the findings, especially in ophthalmology and specifically with regard to chemosurgery and orbital surgery. The data will also be of value to radiologists reporting on angiograms and for interventional radiology.

6.5 RECOMMENDATIONS

The researcher takes the opportunity to make the following additional recommendations:

- A future study could investigate the distribution of variations across population groups drawing a genetic study as well, because certain variations were seen as more distributed across certain population groups.
- Only two institutions, from the Free State and Western Cape respectively, were used in the current study. The representation can be increased by including other institutions in more provinces.
- It will be helpful during dissections to determine the best way to inject the coloured latex to the OA from the cranial point so that it can penetrate to all its branches as this will distinguish OA and its branches easily from the other blood vessels in the orbit.
- It is recommended to have a larger number of individuals in each population group. Cheng *et al.* (2008:140) noted that the knowledge of population group variations are essential in some surgical procedures, such as ethmoidal artery ligation for control of epistaxis that requires ligation of all the ethmoidal arteries haemostasis during medial orbital wall surgeries.
- A future study can also look at the differences within the different population groups because great variation was noted in the current study.

6.6 CONCLUDING REMARKS

The study investigated the cadaver eyes in a South Africa population to determine the occurrence of variations in the OA and its branches. The bilaterality, unilaterality and the sides more affected were reported on. The sex-specific prevalence of the variations were noted and documented. These findings may contribute to clinical application in ophthalmology and radiology and inform anatomy students studying the blood supply to the eye and surrounding structures.

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APPENDICES

APPENDIX A: ETHICAL CLEARANCE

APPENDIX B: SUMMARY OF CADAVER SAMPLE

APPENDIX C: SUMMARY OF IMAGES AND SCHEMATIC REPRESENTATIONS OF THE CADAVER SAMPLE

APPENDIX D: LIST OF CATEGORICAL VALUES

APPENDIX E: CERTIFICATE OF EDITING

APPENDIX F: TURN IT IN CERTIFICATE

APPENDIX A: ETHICAL CLEARANCE

APPENDIX A: ETHICAL CLEARANCE

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26 February 2016

MS KS MPOLOKENG
DEPT OF BASIC MEDICAL SCIENCES
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Dear Ms Mpolokeng

HSREC 33/2016
PROJECT TITLE: THE PREVALENCE OF ANATOMICAL VARIATIONS IN THE INTRAORBITAL PART OF THE OPHTHALMIC ARTERY AND ITS BRANCHES IN CADAVERS.

1. You are hereby kindly informed that, at the meeting held on 23 February 2016, the Health Sciences Research Ethics Committee (HSREC) approved the above project.

2. The Committee must be informed of any serious adverse event and/or termination of the study.

3. Any amendment, extension or other modifications to the protocol must be submitted to the HSREC for approval.

4. A progress report should be submitted within one year of approval and annually for long term studies.

5. A final report should be submitted at the completion of the study.

6. Kindly use the **HSREC NR** as reference in correspondence to the HSREC Secretariat.

7. The HSREC functions in compliance with, but not limited to, the following documents and guidelines: The SA National Health Act. No. 61 of 2003; Ethics in Health Research: Principles, Structures and Processes (2015); SA GCP(2006); Declaration of Helsinki; The Belmont Report; The US Office of Human Research Protections 45 CFR 461 (for non-exempt research with human participants conducted or supported by the US Department of Health and Human Services- (HHS), 21 CFR 50, 21 CFR 56; CIOMS; ICH-GCP-E6 Sections 1-4; The International Conference on Harmonization and Technical Requirements for Registration of Pharmaceuticals for Human Use (ICH Tripartite), Guidelines of the SA Medicines Control Council as well as Laws and Regulations with regard to the Control of Medicines, Constitution of the HSREC of the Faculty of Health Sciences.

Yours faithfully

....
DR SM LE GRANGE
CHAIR: HEALTH SCIENCES RESEARCH ETHICS COMMITTEE

Health Sciences Research Ethics Committee
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APPENDIX B: SUMMARY OF THE CADAVER SAMPLE

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CADAVER IDENTIFICATION NUMBER	ORDER OF ORIGIN (ABOVE ON/BELOW ON)	AGE	POPULATION GROUP	GENDER	VARIATION
OA1R1	Above ON	31	Black	Male	Yes
OA1L1	Above ON				Yes
OA2R1	Below ON	72	White	Male	Yes
OA2L1	Below ON				Yes
OA3R1	Above ON	77	White	Female	Yes
OA3L1	Above ON				Yes
OA4R1	Above ON	80	White	Female	Yes
OA4L1	Above ON				Yes
OA5R1	Below ON	82	White	Male	Yes
OA5L1	Below ON				Yes
OA6R1	Above ON	49	White	Male	No
OA6L1	Above ON				Yes
OA7R1	Above ON	87	White	Female	Yes
OA7L1	Above ON				Yes
OA8R1	Below ON	74	Black	Male	No
OA8L1	Below ON				No
OA9R1	Above ON	49	Black	Female	Yes
OA9L1	Above ON				Yes
OA10R1	Above ON	74	White	Male	Yes
OA10L1	Above ON				No
OA11R1	Above ON	82	Black	Male	No
OA11L1	Above ON				Yes
OA12R1	Above ON	52	Black	Male	No
OA12L1	Above ON				No
OA13R1	Above ON	31	Black	Female	No
OA13L1	Above ON				Yes
OA14R1	Above ON	77	White	Female	No
OA14L1	Above ON				No
OA15R1	Above ON	51	White	Male	No
OA15L1	Above ON				No
OA16R1	Above ON	55	Black	Male	No
OA16L1	Below ON				Yes
OA17R1	Above ON	69	White	Male	No
OA17L1	Below ON				No
OA18R1	Above ON	50	Black	Male	Yes
OA18L1	Above ON				No
OA19R1	Above ON	28	Black	Male	No
OA19L1	Above ON				No
OA20R1	Above ON	62	White	Female	No
OA20L1	Above ON				No
OA21R1	Above ON	48	Black	Male	No
OA21L1	Below ON				No
OA22R1	Above ON	41	Black	Male	Yes
OA22L1	Above ON				No
OA23R1	Above ON	27	Black	Female	Yes

OA23L1	Above ON				No
OA1R2	Above ON	31	Coloured	Male	Yes
OA1L2	Above ON				Yes
OA2R2	Above ON	78	White	Male	Yes
OA2R2	Above ON				No
OA3R2	Above ON	51	Coloured	Male	Yes
OA3L2	Above ON				No
OA4R2	Above ON	23	Black	Female	Yes
OA4L2	Above ON				Yes
OA5R2	Above ON	29	Coloured	Female	Yes
OA5L2	Above ON				Yes
OA6R2	Above ON	78	White	Female	Yes
OA6L2	Above ON				Yes
OA7R2	Above ON	26	Black	Female	Yes
OA7L2	Above ON				Yes
OA8R2	Above ON	89	White	Male	No
OA8L2	Above ON				No
OA9R2	Above ON	36	Coloured	Male	Yes
OA9R2	Above ON				Yes
OA10R2	Above ON	28	Black	Female	Yes
OA10L2	Above ON				Yes
OA11R2	Above ON	44	Coloured	Male	No
OA11L2	Above ON				Yes
OA12R2	Above ON	77	White	Female	Yes
OA12L2	Above ON				No
OA13R2	Above ON	49	White	Female	No
OA13L2	Below ON				Yes
OA14R2	Above ON	84	White	Female	Yes
OA14L2	Above ON				Yes
OA15R2	Above ON	57	White	Female	No
OA15L2	Below ON				Yes
OA16R2	Above ON	67	White	Male	Yes
OA16L2	Above ON				Yes
OA17R2	Above ON	42	Coloured	Male	Yes
OA17L2	Above ON				No
OA18R2	Above ON	93	White	Female	Yes
OA18L2	Above ON				Yes
OA19R2	Above ON	80	White	Male	Yes
OA19L2	Below ON				Yes
OA20R2	Above ON	71	White	Male	Yes
OA20L2	Above ON				Yes
OA21R2	Above ON	48	Coloured	Male	Yes
OA21L2	Above ON				Yes
OA22R2	Above ON	41	Black	Male	Yes
OA22L2	Above ON				Yes
OA23R2	Above ON	82	White	Female	Yes
OA23L2	Above ON				No
OA24R2	Above ON	81	White	Female	Yes
OA24L2	Above ON				No
OA25R2	Above ON	35	Coloured	Male	Yes
OA25L2	Above ON				Yes
OA26R2	Above ON	30	Black	Male	Yes
OA26L2	Above ON				Yes

OA27R2	Above ON	83	White	Female	No
OA27L2	Above ON				Yes
OA28R2	Above ON	55	Black	Male	Yes
OA28L2	Below ON				Yes
OA29R2	Above ON	67	White	Male	No
OA29L2	Above ON				Yes
OA30R2	Above ON	30	Coloured	Male	Yes
OA30L2	Above ON				No
OA31R2	Above ON	68	White	Male	Yes
OA31L2	Above ON				Yes
OA32R2	Above ON	47	Coloured	Male	Yes
OA32L2	Above ON				Yes
OA33R2	Above ON	82	White	Male	Yes
OA33L2	Above ON				Yes
OA34R2	Above ON	32	Black	Female	No
OA34L2	Above ON				No
OA35R2	Above ON	67	White	Female	Yes
OA35L2	Above ON				Yes
OA36R2	Above ON	35	Coloured	Female	Yes
OA36L2	Above ON				Yes

APPENDIX C: SUMMARY OF IMAGES AND SCHEMATIC REPRESENTATIONS OF THE CADAVER SAMPLE

APPENDIX D: LIST OF CATEGORICAL VALUES

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CODING USED

1- Black
2- White
3- Coloured

1- Female
2- Male

1- Unilateral
2- Bilateral

1- Above ON
2- Below ON

Variations noted:

1. Supraorbital artery emerges from the OA (between superior rectus + levator palpebrae) – goes to the medial side of the frontal nerve
2. Lacrimal artery divides into 3 branches
3. Supraorbital artery emerges from the OA on the medial side of the frontal nerve
4. Lacrimal artery divides into 2 branches
5. Supraorbital artery shares a common origin with PEA and courses to the medial side of the frontal nerve
6. Supraorbital artery is absent
7. One branch divides into two: medial rectus and medial muscular branches

8. An unusual branching pattern
   1- CRA
   2- LPCA
   3- LA
   4- M. Superior rectus
   5- PEA+ Supraorbital artery → 11-MPA
      12- Supratrochlear
      13- DNA
   6- MPCA
   7- Medial Muscular
   8- Muscular to suprior oblique
   9- Branch to Areolar tissue
   10- AEA

9. Unusual branching pattern: MPCA arises before medial muscular branch
10. LPCA emerged directly opposite the LA
11. An unusual branching pattern
    1- CRA
    2- Muscular to lateral rectus
    3- LA
    4- PEA = Supraorbital
    5- Medial rectus = Inferior rectus
    6- Muscular to superor oblique = Superior rectus
    7- AEA
    8- MPA
    9- SMPA
    10- DNA
    11- Supratrochlear

12. Muscular branch to the medial rectus muscle gives off branch to inferior rectus

13. Different arrangement pattern of the OA crossing above the ON
14. Branch arising between the LA and the branch to superior rectus muscle
15. No AEA

16. Unusual branching pattern: LA emerges as the first branch from OA
    1- LA
    2- Muscular to superior rectus
    3- CRA
    4- LPCA
    5- PEA + Supraorbital
    6- MPCA
    7- Branches to inferior rectus
    8- Medial muscular branch
    9- M. to superior obliqe + superior rectus
    10- AEA
    11- INMPA
    12- SMPA
    13- DNA
    14- Supratrochlear

APPENDIX E: CERTIFICATE OF EDITING

CERTIFICATE OF EDITING

Dr Annemie Grobler

PhD (English), APEd (SATI) SATI accredited member 1003103

Language practitioner - translation, text editing and proofreading

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20 January 2017

The following document has been professionally language edited and proofread:

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Author: Kentse Mpolokeng

Nature of document: Dissertation, M.Med.Sc (Anatomy and Cell Morphology), Department of Basic Health Sciences, Faculty of Health Sciences, University of the Free State

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APPENDIX F: TURN IT IN CERTIFICATE

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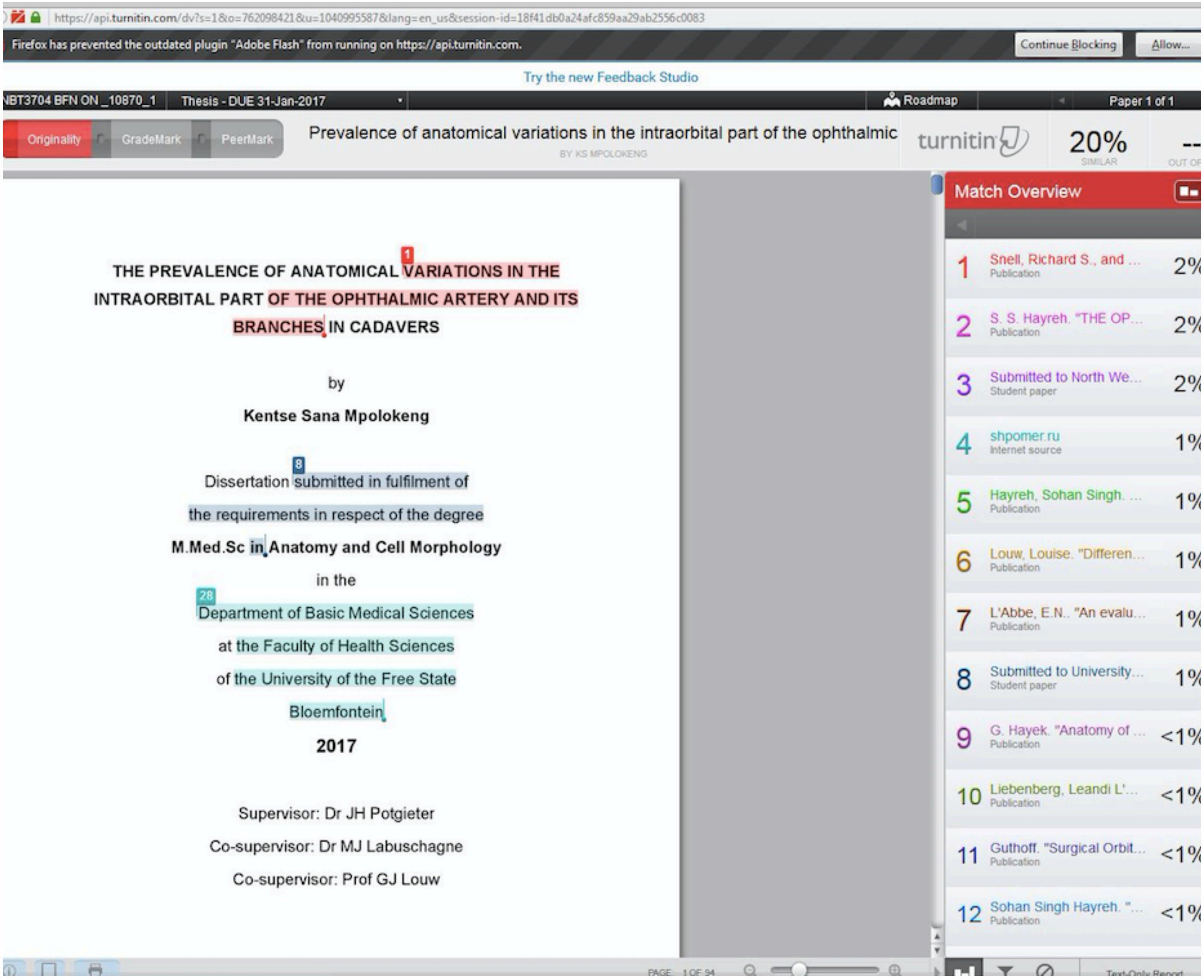

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Kentse Sana Mpolokeng
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2017
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