Anatomical variation of the carotid bifurcation in a Stellenbosch University cadaver cohort

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Thesis presented in partial fulfilment of the requirements for the degree Master of Science in Anatomy at Stellenbosch University

Pectora roborant cultus recti

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April 2019

DECLARATION

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April 2019

ABSTRACT

The carotid bifurcation is the point where the common carotid artery bifurcates into the internal and external carotid artery. A precise anatomical knowledge of the carotid bifurcation is required for various medical specialities. The anatomy of the carotid bifurcation influences the risks, location and prognosis of related pathology. Furthermore, the anatomy of the carotid bifurcation affects treatment as it determines which surgical techniques can be used in an area of high risk. The aim of the study was to determine the anatomical variations of the carotid bifurcation in a Stellenbosch cadaver cohort. One hundred and twenty-eight specimens were examined. This research focuses on the height, angle, general structure, and diameters of the carotid bifurcation, as well as the length and diameter of the carotid sinus. The internal anatomical variation of the carotid bifurcation was added as the study progressed. This study used the gonion as the landmark when measuring height. The Stellenbosch cadaver cohort had a high frequency of high bifurcation with the mean distance of 2.12 cm on the right and 2.06 cm on the left. The angle of bifurcation was 18.53° on the right and 20.24° on the left and was smaller than previous reports in the literature, which ranged between 51-67°. Females had a higher bifurcation and larger angle of bifurcation than males. Sex affected the correlation between angle and height of the bifurcation. The general structure correlated with the standard description and was not influenced by other factors pertaining to the carotid bifurcation, sex or age. Kinks were found in the internal and external carotid artery. The diameters of the carotid bifurcation were larger on the left than on the right. The height of the bifurcation did not influence the probability of kinks in this study, contrary to the literature. The diameters of the internal, external and common carotid arteries in addition to the carotid sinus diameter were larger on the left side and in males. The external carotid had the weakest correlation with the other diameters, which was due to the external carotid artery's embryological origin. The length of the carotid sinus was 1.74 cm on the right and 1.83 cm on the left. The diameters and the length of the carotid sinus was larger in the males. All external variation slightly increased with age over time as the elasticity of arteries decreased. A variation of the flow diverter was observed in 59% of the cadaver cohort. Supplementary flow diverters were a rare abnormality observed in the internal, external and common carotid arteries. The reason for the carotid bifurcation to present with supplementary flow diverters is still up for debate as this has not been observed in living patients; however, a pathological origin was suggested. Folds in the common carotid were observed. Internal anatomical variation was not affected by external variation or age; however, men had a higher probability of presenting with variation. The Stellenbosch cadaver cohort illustrated variations in the carotid bifurcation which was population-specific. Sex influenced various aspects and correlations of the carotid bifurcation, which means discrepancies can occur and should be considered. Further studies on the carotid bifurcation are needed.

OPSOMMING

Die karotis bifurkasie is die punt waar die gemene karotis arterie verdeel in die interne en eksterne karotis arteries. Presiese anatomiese kennis van die karotis bifurkasie is nodig vir verskeie mediese spesialiteite. Die anatomie van die karotis bifurkasie beïnvloed die risiko's, van ligging en prognose van patologie. Verder, anatomie van die karotis bifurkasie afeckteer behandeling as dit bepaal watter chirurgiese tegnieke gebruik moet word in 'n area van hoë risiko. Die doel van die studie was om die anatomiese variasies van die karotis bifurkasie te bepaal in 'n Stellenbosch kadaver groep. Een honderd agt-en-twintig kadawers was ondersoek. Hierdie navorsing fokus op die hoogte, die hoek, algemene struktuur, en deursnee van die karotis bifurkasie asook die lengte en deursnee van die karotis sinus. Die interne anatomiese variasie van die karotis bifurkasie was by gevoeg later in die studie. Hierdie studie gebruik die gonion as die landmerk baken om die hoogte te meet. Die Stellenbosch kadaver groep het 'n hoë voorkomsvan hoë bifurkasie met n gemiddelde afstand van 2.12 cm aan die regterkant en 2.06 cm aan die linkerkant. Die hoek van bifurckasie was 18.53° aan die regterkant en 20.24° aan die linkerkant en was heelwat kleiner as vorige literatuur. Vroue het hoër bifurkasie en groter hoeke van bifurkasie as mans getoon. Seks bewerkstellig die korrelasie tussen hoek en hoogte van die bifurkasie. Die algemene struktuur gekorreleer met standaard beskrywing en was nie beïnvloed deur ander faktor met betrekking tot die karotis bifurkasie, geslag of ouderdom. Kronkels is gevind in die interne en eksterne karotis arterie. Die deursnee was groter aan die linkerkant as aan die regterkant. Hoogte van die bifurkasie het nie die waarskynlikheid van kronkels in hierdie studie beinvloed nie in teenstelling met wat die literatuur se. Die deursnee van die interne, eksterne en algemene karotis arteries benewens die karotis sinus deursnee was groter aan die linkerkant en by mans. Die eksterne karotis het die swakste korrelasie met die ander diameters, en is die gevolg van sy embriologiese oorsprong. Die lengte van die karotis sinus is 1.74 cm aan die regterkant en 1.83 cm aan die linkerkant. Die deursnee en die lengte van die karotis sinus was groter by die manlike kadawers. Alle eksterne variasie neem effens toe met ouderdom as gevolg van die elastisisteit wat verminder. Variasie van die vloei-herleiers was in 59% van die studie groep waargeneem. Aanvullende vloei herleier was 'n seldsame abnormaliteit waargeneem in die interne, eksterne en algemene karotis areries. Daar is tans geen opvallende rede vir die karotis bifurkasie se aanvullende vloei herleier nie. Verdere navorsing word steeds benodig om te bevestig of hulle waargeneem word in lewende pasiënte. Daar word voorgestel dat die karotis bifurkasie se anvullende vloei herleier van

patologiese oorsprong is. Voue in die algemene karotis was waargeneem. Interne anatomiese variasie is nie beïnvloed deur eksterne variasie of ouderdom, maar seks het geïllustreer dat mans het 'n hoër waarskynlikheid van voorkoms van die variasie Die Stellenbosch kadaver groep geïllustreer variasie in die karotis bifurkasie wat bevolking spesifieke is. Geslag beinvloed die verskillende aspekte van die karotis bifurkasie wat beteken teenstrydighede kan voorkom indien dit nie in ag geneem word nie, nie oorweeg. Verdere studies is nodig op die karotis bifurkasie.

ACKNOWLEDGEMENTS

Firstly, I would like to thank God for His presence in my life. I would also like to thank my supervisor, Prof BJ Page. Thank you to the University of Stellenbosch and the Division of Anatomy and Histology. Thank you K. Cilliers support and editing.

I am grateful to T. Estherhuizen for statistical analysis

I am grateful for the continuous support of the fellow students and for the support of family and friends.

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LIST OF ABBREVIATIONS

APA	Ascending Pharyngeal Artery
CB	Carotid Bifurcation
CCA	Common Carotid Artery
CN	Cranial Nerve
ECA	External Carotid Artery
FA	Facial Artery
HB	Hyoid Bone
HCB	Height of the Carotid Bifurcation
ICA	Internal Carotid Artery
LA	Lingual Artery
MRA	Magnetic Resonance Angiography
NTS	Nucleus Tractus Solitarii
STA	Superior Thyroid Artery
Std	Standard
TC	Thyroid Cartilages
TIA's	Transient ischemic attacks

1 CHAPTER 1: INTRODUCTION

Anatomy is a continuous study due to individual and population group variations. Previous research has focused more on the Northern Hemisphere. However, this is starting to change with research being conducted more frequently in the Southern Hemisphere. Studies on the South African population regarding the anatomical variation of the carotid bifurcation have yet to be done.

The reasoning behind the study lies in the carotid bifurcation anatomy, which is essential to various medical specialities [1,2]. The carotid bifurcation is home to the carotid sinus which regulates blood pressure. This can be used as a diagnostic tool for underlying cardiovascular disorders when pressure is applied to trigger the carotid sinus reflex [3]. The carotid bifurcation has been observed to be highly variable and asymmetrical when comparing the left and right side [1].

Its proximity to the mandible can hinder certain surgical procedures as well as increase the risk of damage to nerves [1]. Thus, the anatomy of the carotid bifurcation determines the surgical technique to be selected. Furthermore, the anatomy of the carotid bifurcation affects the risk of underlying pathology, which can lead to disabling and possible fatal strokes [1,2]. The anatomy of the carotid bifurcation plays a vital role in the diagnosis, prognosis and treatment of pathology associated with the carotid bifurcation.

However, current research has yet to provide answers to many aspects of the carotid bifurcation. Various studies focus on certain factors without discussing the interaction of variables or the influence of sex and age on the carotid bifurcation. The height of the carotid bifurcation, or more specifically the location of the carotid bifurcation in relation to the angle of the mandible, has yet to be adequately described in research. Furthermore, a genetic factor associated with the carotid bifurcation has been suggested in African population groups [4]. Thus, research on an African population such as the Stellenbosch cadaver cohort is needed.

2 CHAPTER 2: LITERATURE REVIEW

2.1 CAROTID BIFURCATION

A precise anatomical definition of the carotid bifurcation is required as it is essential for various medical specialities [1,2]. The carotid bifurcation is located where the common carotid artery divides into the internal carotid and external carotid arteries [5,6,7]. The carotid bifurcation is defined to divide at the level of the superior border of the thyroid cartilage (TC) or the vertebral level C4 [7]. The carotid arteries are the two principal arteries that supply blood to the head and neck [5].

The right and the left common carotid arteries have different origins [8]. The right common carotid is a branch off the bifurcating brachiocephalic trunk [5]. The other branch of the brachiocephalic bifurcation being the right subclavian artery [5]. The left common carotid artery originates from the arch of the aorta [9].

The common carotid artery bifurcates into the internal carotid and external carotid arteries. The internal carotid artery is a direct continuation of the common carotid artery [5,8,9]. The internal carotid artery does not branch in the neck and is the main blood supply to the brain [9]. The external carotid artery supplies the majority of external cranial features [8]. There are six branches off the external carotid artery before terminating into the maxillary and superficial temporal arteries [5]. These branches are the ascending pharyngeal, occipital, posterior auricular, superior thyroid, lingual and facial arteries [5,8,9].

The carotid bifurcation is home to the carotid sinus and carotid body [7]. The carotid sinus is a localised dilatation of the bilateral internal carotid artery [5]. This dilation originates at the bifurcation of the common carotid artery [3]. In some variations the dilation originates in the common carotid artery. The carotid sinus contains baroreceptors in the adventitia of the arterial wall [10]. The arterial wall consists of tunica intima which is the smooth innermost layer, tunica media which is the muscular middle layer and lastly the adventitia which is the outer layer that contains the baroreceptors [11]. These baroreceptors sense changes in systemic blood pressure [10]. The carotid sinus is a distinct organ from the carotid body. The carotid sinus acts as a regulator for maintaining blood pressure [12]. The homeostatic mechanisms are relayed to nucleus tractus solitarii (NTS) located in the medulla oblongata of the brainstem via the glossopharyngeal nerve [10]. The NTS then relays the signal to parasympathetic and sympathetic vagal neurons [10]. This is done through the hypothalamus as the vagal neurons are located in the pons and the medulla. The function of the vagal neurons is to regulate the autonomic control of the blood vessels and the heart [11,12]. There is a second set of baroreceptors in the aortic arch which combines with the CN IX to maintain homeostasis [10]. The carotid sinus' functional ability can be affected by carotid body resectioning or carotid sinus syndrome [10]. The location of the carotid body has an intimate relationship with the carotid sinus [10]. This intimate relationship is due to the carotid body and sinus sharing the same innervation by the Hering's nerve which branches off the CN IX, the glossopharyngeal nerve [10]. The carotid body is located in the adventitia of the carotid bifurcation [5,8,9]. The carotid body is a chemoreceptor, which regulates respiratory and cardiovascular functions. This is done by the chemoreceptor's monitoring of the pH, pO_2 and pCO_2 in the blood [10]. Changes in pH, pO_2 and pCO_2 can lead to a response such as a change of blood pressure, respiratory rate and heart rate [10]. The carotid body is made up of chief cells and sustentacular cells. Complementary chemoreceptors are located in the aortic arch [12].

Access to the carotid arteries, internal jugular vein, hypoglossal and vagus nerves are gained via the carotid triangle [5]. The borders of the carotid triangle are defined as the posterior belly of the digastric muscle superiorly, the medial border of the sternocleidomastoid muscle laterally and the superior belly of the omohyoid muscle inferiorly [5,8,9].

2.1.1 Embryological origin

The external carotid artery develops from the second aortic arch while the internal carotid artery and carotid bifurcation develop from the third aortic arch [13]. As the internal carotid artery and carotid bifurcation develop from the second aortic arch, it is a continuation of the common carotid artery while the external carotid artery is a branch thereof [5,8,9,13]. Vascularization of the corresponding area interacts with the development of the origin of branches of the external carotid artery [13]. In cases of embryologic arrest, a non-bifurcating artery with origins of internal carotid artery is found at C2 or C1 level [13]. Branches of the external carotid artery then originate from the non-bifurcating artery, which indicates the persistence of primitive hyoid-stapedial system which acts as a substitute for normal development [5,8,9,13]. In other cases, when the mechanism was unknown, the proposal of regression or duplication of primitive vessels were used to explain the variations in the area. Variations in this area are often asymptomatic and go unnoticed [13]. Any connection between these variations and pathologies, such as strokes and atherosclerosis, remains unclear [13].

2.1.2 Branches of the carotid bifurcation

There are six branches on the external carotid artery. These branches are the ascending pharyngeal, occipital, posterior auricular, superior thyroid, lingual and facial arteries [5,8,9]. The first of these branches off the external carotid artery is the superior thyroid artery which is represented in textbooks as descending in an oblique course before entering at the superior lobe of the thyroid gland [5]. The second branch of the external carotid artery is the ascending pharyngeal artery. The ascending pharyngeal artery originates from the posterior wall of the external carotid artery and provides vascularization to the pharynx [5]. The remaining branches originate distally on the external carotid artery [9].

The origin of the superior thyroid artery has been debated in various previous studies. This is due to the variation in the origin of the superior thyroid artery, as it has also been observed branching off the common carotid artery. Additionally, due to embryological variation in the development between the common and external carotid arteries, the origin of these branches is questioned. It was argued by Natsis et al. [14] that the external carotid artery is a branch off the carotid bifurcation due to differences in embryological development. Thus, the superior thyroid artery, which has been observed to originate from the common carotid artery, should not be considered as a branch of the external carotid artery but rather a branch of the common carotid artery. This is due to the high prevalence of superior thyroid arteries originating from the common carotid (61%). Similar results were found in the literature [15-22] where numerous superior thyroid arteries originated from the common carotid in 50-75% of cases. Based on these results it could be argued that the normal origin of the superior thyroid artery is off the common carotid.

Toni et al. [23] observed that the superior thyroid artery had an increased probability on the right side to originate from the common carotid. Additional, Caucasians had an increased probability for the superior thyroid artery to originate from the common carotid artery. Table 2.1 provides a summary of studies that had the superior thyroid artery originating from the common carotid artery.

Table 2.1: Superior thyroid artery originating from the common carotid.

Author	Type of study	Percentage of STA on CCA
Espalieu et al. [20], 1986	Cadaveric (36) Angiographic (50)	55
Lučev et al. [21], 2000	Cadaveric (20)	70
Lo et al. [16], 2006	Cadaveric (65)	53.8
Klosek and Rungruang [15], 2008	Cadaveric (43)	33.3
Ozgur et al. [17], 2008	Cadaveric (20)	75
Vázquez et al. [24], 2009	Cadaveric (207)	76
Al-Rafiah et al. [20], 2011	Cadaveric (30)	94

STA: superior thyroid artery, CCA: common carotid artery.

Small et al. [25] observed in a radiographic study, that the ascending pharyngeal artery originates from the common carotid artery or from the carotid bifurcation in 6.5% of cases. This would indicate that the origin of the ascending pharyngeal artery other than from the external carotid is a rare variation.

Numerous studies [3,14,18,19,] observed high rates (50–70%) of asymmetry between branching patterns. High bifurcations had an increased probability of common trunk formation in addition to an increased proximity to the carotid bifurcation [20,26]. Furthermore, an increased branch origin from the common carotid was observed to be associated with high bifurcations [21,28]. Examples of common trunks are lingual-facial trunk [3,27], thyrolingual trunk [2], thyrolingual-facial trunk [14] and occipitoauricular trunk [28].

Gluncic et al. [29] observed a rare case that had a very high bifurcation with origins of the superior thyroid artery, lingual artery, ascending pharyngeal artery and occipital arteries directly from the common carotid artery while the external carotid artery was hypoplastic. Low bifurcation branches on the external carotid artery were more distal to the bifurcation and rarely had common trunks [30].

The superior thyroid and ascending pharyngeal arteries influences chemoembolization, surgical management, and large defect restoration during management of head and neck tumours. The precise anatomical value of these branches is further illustrated by the selective and super selective chemoembolization of head and neck tumours [31].The origin of the superior thyroid artery is of clinical importance due to it being primarily a feeding vessel for head and neck tumours [32].Anatomical variations such as trunks can affect the diffusion of chemotherapeutic agents [32], thus specific anatomical knowledge is needed regarding these branches.

The repair of large defects with functional and aesthetical disability after the removal of tumours in the neck area relies on anatomical knowledge for tissue transplantation. For example, pedicled nasogenial flaps, islet flaps with subcutaneous pedicles, rotation flaps of Mustardé type, and Estlander's flap have been invented for coverage [22,33]. A proper selection for flap transplantation is based on vessels' sufficiency in terms of diameter and length.

Lastly, a ligation of front branches of the external carotid artery is used practically for tinnitus related to A-V malformation and requires precise anatomical knowledge to prevent ischemia of the larynx or tongue [19].

2.1.3 Anatomical position

The anatomical position of the bifurcation is most commonly defined to occur at the C4 vertebra level posteriorly and at the superior border of the thyroid cartilages (TC) anteriorly [5]. These two landmarks are thought to limit surgical intervention as they are defined when the subject is in the erect anatomical position [31]. Most head and neck operations are done while the patient has their head in an extended position. Extending the head changes the height of the carotid bifurcation (HCB) in relation to these landmarks. The vertebral landmarks are not visible in surgery or easily seen during consultation as there is also the variability in the location of these landmarks [31]. The hyoid bone (HB) and the angle of the mandible are also used as a bony landmark when defining the height of the carotid bifurcation. The lack of correspondence between anterior and posterior landmarks was observed in a study by Mirjalili et al. [31] which compared the anterior landmark of the HB and the TC to the posterior vertebral level. The results showed that the HB and the TC level can be located anywhere between C3 and C5/6 intervertebral discs.

The height of the carotid bifurcation is highly variable. Furthermore, race has been seen to play a part in the variability [4]. The variability of height of the carotid bifurcation (HCB) can be seen in a study by Querry et al. [34], where the distance between the gonion of the mandible and the bifurcation varied between 0–7.5 cm [34]. The carotid sinus is found bilaterally but varies from one side to the other. Querry et al. [34] further illustrate asymmetry in the carotid bifurcation with the left side averaging a distance of 32 mm while the right averages 36 mm. This study, however, only had 19 male subjects from unknown origins.

The angle of the mandible is an important landmark because it is a barrier when operating in the vicinity of the CB and is clearly visible during surgery and consultation. McNamara et al. [1] used the angle of the mandible as a landmark with the carotid bifurcation an averaged distance of 25 mm away [1]. Ozgur et al. [17] compared all the anterior landmarks. In this study the distance between the angle of the mandible (AM) and the CB averaged 36.2 ± 9.9 mm. The distance between TC and the CB was 9.8 ± 6.7 mm and the distance between HB and the CB was 8.7 ± 6 mm. Table 2.2 provides a summary of larger studies investigating height of the carotid bifurcation (HCB) in relation to the hyoid bone (HB); thyroid cartilages (TC); angle of the mandible AM and the vertebral level [17].

The CB is further classified as either having a high or a low bifurcation. These terms are often used in literature, but they lack a precise anatomical definition in relation to most landmarks. High bifurcation is generally defined as posteriorly higher than C3/4 intervertebral discs and anteriorly as higher than the great horn of the HB [32]. McNamara et al. [1] statically defined a high bifurcation as CB lying in the first quartile of the HCB distribution [1]. De Syo et al. [35] defined a low bifurcation at the level of 5th and 6th cervical vertebra or lower, whereas a high bifurcation was defined at the level of superior 2/3 of C3 or higher [35]. A normal bifurcation was defined as being between C3 and C5 [35]. High bifurcations in De Syo *et al*. [35] were linked with increased occurrence of elongation or kinking and an increased bifurcation angle. High bifurcation implies that it is difficult to operate on due to its proximity to bony elements, mainly the AM [32,35,]. Lui et al. [36] stated that the angle of the mandible is a superior external landmark as it consistently corresponds to the cervical spine. Furthermore, the study stated that the angle of the mandible corresponded to the C2/3 intervertebral disc [36]. The average length of the cervical spine according to Henry et al. [37] was 125 mm, thus the length of a cervical vertebra can be roughly estimated as 17.9 mm. High bifurcation was defined as C3/4 intervertebral discs or superior 2/3 of C3 or higher while the angle of the mandible corresponds to C2/3 intervertebral disc. Thus, it can be argued that roughly 17.9 mm lower than the angle of the mandible is the border for high bifurcation.

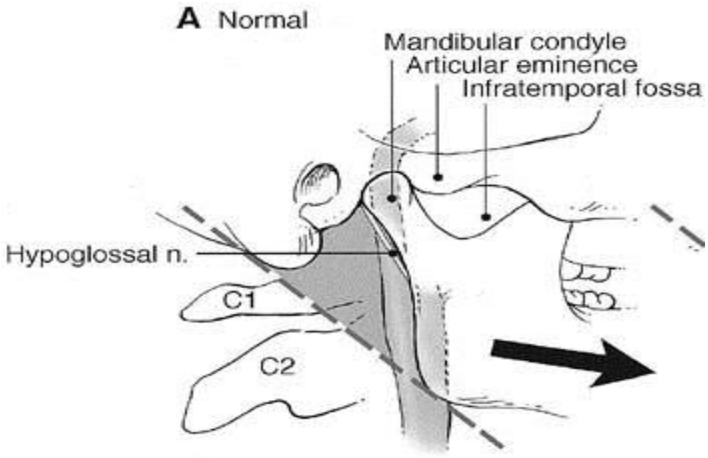


Figure 2.1: Angle of the mandible compared to cervical vertebrae [36]

High bifurcations were difficult to operate on due to the close proximity of the hypoglossal nerve and vagus nerve in the extremely limited space between the mandibular angle and the mastoid process [38]. The classification of high or low bifurcation aids in determining the appropriate surgical technique. Having a high or a low CB is a factor used to select between carotid endarterectomy and carotid stenting [32,39]. The HCB is determined radiologically as there are no other reliable anatomical features that exist [16]. Hayashi et al. [28] observed that a Japanese population had a higher prevalence of high CB. Ito et al. [30] showed that females were more likely to have a higher CB. Klosek et al. [15] further demonstrated that there was asymmetry in the body as the left CB showed to have a greater risk of high CB. A high incidence of high CB was reported by Woldeyes et al. [4] in an Ethiopian population which also suggested that high CB occurs due to a genetic factor.

The CB is a common site for variations as mentioned above. The variations of the carotid bifurcation can affect the typology and morphology of the branches of external carotid artery (ECA). This means that variations of CB affect where and how the arteries branch off the external carotid artery.

Table 2.2: Studies on HCB in relation to different anatomical landmarks.

Author	Study type/sample	HCB (anterior)	HCB (posterior)
Espalieu et al. [20], 1986	Cadaveric (36) Angiographic (50)		C2/3: 6% C3/4: 25% C4: 65% C4-C5: 4%
Lućev et al. [22], 2000	Cadaveric (20)	Superior level of HB: 12.5% Inferior level of HB: 10% Superior level of TC: 50% Inferior level of TC: 5%	
Zümre et al. [19], 2005	Cadaveric (40)		C3 (L): 60% (R): 55% C4 (L): 45% (R): 35% C5 (L): 0% (R):10%
Ito et al. [30], 2006	Cadaveric (40)		C2, C2/3, C3, C3/4: 31% C4: 58% C4/5: 11%
Lo et al. [16], 2006	Cadaveric (36)	Greater horn of HB: 15% Body of HB: 40% Superior border of TC: 39% Body of TC: 6%	
Pai et al. [33], 2007	Cadaveric (95)		C2 (L): 10% (R): 9% C3 (L): 50% (R): 55% C4 (L): 40% (R): 35% C5 (L): 0% (R): 1%
Klosek and Rungruang [15], 2008	Cadaveric (43)		C2/3: 2.3% C3: 10.4% C3/4: 20.,9% C4: 30.2% C4/5: 16.3% C5: 8.1%
Al-Rafiah et al. [18], 2011	Cadaveric (30)	Higher than HB: 3.3% HB: 25% Between HB and TC: 15,3% Superior level of TC: 48,3% Lower than TC: 5%	
McNamara et al. [1], 2015	Angiographic (76)	Above AM:0,7% Same level with AM Below AM: 95.7% Above HB: 62.9% Same level with HB: 26.4% Below HB: 10,7% Above TC: 79.3% Same level with TC: 16.4% Below TC: 4.3%	

2.1.4 Diameters

The local flow parameters of the carotid bifurcation influence the prognosis of carotid atheromatous disease. The anatomical structure of the carotid bifurcation affects flow parameters [40]. Firstly, the flow diverter of the carotid bifurcation naturally divides blood flow [41]. The risk of plaque development increases with tortuous and angled vessels due to turbulent flow [42,43]. A detailed anatomical study was done by Ozgur et al., where the common carotid artery (CCA), external carotid artery (ECA), internal carotid artery (ICA), and CB diameter was calculated at 8.1 ± 2.24 mm, 6.6 ± 1.3 mm, 6.1 ± 1.3 mm and 12.79 ± 0.87 mm, respectively [17]. Goubergrits et al. [41], however, illustrated that these measurements, although useful for intravascular catheter design and stent development, could only have limited use for carotid atheromatous disease investigations. As Goubergrits et al. [41] considered the vessels to be oval, which contradicted previous studies, the major axes were used for measurements. The diameters were calculated as ECA at 5.98 mm, ICA at 7.38 mm and CCA is 6.61 mm.

Several other authors selected to calculate flow ratios from the diameters, ICA/CCA, ICA/ECA and ECA/CCA which predicts the distribution of blood flow in carotid bifurcation as illustrated in Table 2.3 [17,41,43,44,45]. The results illustrated that there was no difference between atheromatous and non-atheromatous CCAs [44,45]. A method of 3-dimensional volumetric assessment was suggested by Miralles et al. due to the inconclusive results of previous studies [54]. This method correlated the differences in endovascular volumetry with progression of atheromatous plaque. Thomas et al. [46] went further by stating that early markers of carotid atheromatous disease were an increase in ICA/CCA, ECA/CCA as well as an increase in vessel tortuosity and ECA/ICA angle. Lo et al.'s [16] research of the tortuosity of the CCA showed that only 63% of the CCAs follow a straight course while 26% are curved and 6% were coiled or kinked. Cvetko et al. [47] reported a rare case of bilateral coiling with extreme tortuosity of the ECA and kinking of the ICA. The histology of the carotid bifurcation of this rare case differed from the normal due to the reduction of muscular cells and elastic fibres, metaplasia of tunica media, and consequently arterial wall thinness. These histological changes are defining characteristics often seen in atheromatous carotid arteries. The tortuosity of the ICA and CCA can lead to the use of carotid artery stenting instead of carotid endarterectomy [49]. The anatomical structure of the carotid bifurcation was described as the ECA being anteromedial to ICA, but in 1.7–7.5% of cases this position can be reversed [17,30,18].

Table 2.3: Diameter ratios of the carotid arterial system.

Author	Study Type	ICA/CCA	ECA/CCA	ICA/ECA	Inflow/Outflow area
Goubergrits et al. [41], 2002	Cadaveric (86)	1.1 (0.63-1.47)			1.78 (0,67 - 3.21)
Schulz and Rothwell [44], 2001	Angiographic (5395)	0.63 (0.44-0.86)	0.55 (0.34 - 0.80)	0.88 (0.55 - 1.33)	0.73 (0.38 - 1.28)
Sehirli et al. [45], 2005	Cadaveric (20)	0.71 ± 0.12	0.78 ± 0.12	0.93 ± 0.16	1.14 ± 0.28
Thomas et al. [43], 2005	MRA (50)	0.81 ± 0.06	0.81 ± 0.06		
Ozgur et al. [17], 2008	Cadaveric (20)	0.98	0.85	0.86	

MRA: magnetic resonance angiography; ICA: internal carotid artery; CCA: common carotid artery; ECA: external carotid artery.

2.1.5 Angle

De Syo et al. [35] observed that larger bifurcation angles were accompanied with increased frequency of elongation and kinking and that carotid bifurcation shape influenced the distribution of atherosclerosis. Furthermore, a correlation between the angle and the height of the carotid bifurcation was observed, where the carotid bifurcation angle increased/decreased by 3.34° for each third of the cervical vertebral body height or intervertebral space height. The carotid bifurcation height was a little higher on the left side. Goubergrits et al. [41] determined that the angle of bifurcation was 67° in males and 51° in females and that the angle of carotid bifurcation was an indicator in atherosclerotic diseases.

2.1.6 Modalities

The geometry and the depiction of HCB was visualised in previous studies using modalities such as ultrasound, magnetic resonance angiography and computerized tomographic angiography [3]. The selection of modules is based on availability, applicability for the speculated disease or the characteristics of the patients, such as allergies. The most commonly used method is 3-dimensional computerized tomography imaging to provide information needed to guide surgical approach [49].

There are parts of the carotid artery that are of clinical importance which are not sufficiently covered in the overview given by these standard methods. These anatomical features include HCB, morphometric values of the carotid arties, and the variations of the ECA and the anatomy of the carotid sinus. The anatomical features mentioned play a role in the pathological mechanisms as well as their management and treatment [49].

2.1.7 Clinical importance

The carotid sinus contains stretch or baroreceptors that communicate with the brainstem which play a key role in regulating cardiovascular function [15]. A distinctive characteristic of the carotid sinus is that it can be stimulated by outside components. This is seen when pressure is applied to this area or when the area is massaged. These external stimuli may affect blood pressure, heart rate and rhythms. The carotid sinus reaction to external stimuli can be used as a diagnostic aid in diagnosing underlying cardiac disturbances [50].

Treatments such as embolization and chemoembolization for head and neck tumours, which are intravascular treatments, have sparked new interest in the anatomical variations of this area [15]. Carotid sinus syndrome is treated by surgical denervation of the CB which also relies on the knowledge of anatomical structures in this area. [51]. Furthermore, carotid atheromatosis, carotid tumour, carotid stenting, carotid endarterectomy and other surgical treatments rely on the anatomical knowledge of the area as it a high-risk area [3].

Complications with these surgeries can occur due to a high CB, which might indicate injury to cranial nerves. The most commonly injured cranial nerves are the marginal mandibular and hypoglossal nerves, with an incidence rate as high as 5.2% [1,52]. The hypoglossal nerve is not affected by the HCB. Thus, the distance between the nerve and the CB is smaller when the person has a high CB. This increases the risk of injury during surgical procedures [30,52]. To compensate for this, many complicated, yet dangerous surgical techniques have been introduced. The main techniques being mandibular subluxation, [54] styloidectomy [55] and mandibulotomy [56]. These surgical techniques have their own complications such as facial palsy, bone infection, difficulty with mastication and non-union of the mandible [54]. Foremen et al. [56] showed that the use of nasotracheal intubation in place of orotracheal intubation further complicates the procedure and is not advisable. Thus, a precise knowledge of the anatomy of the carotid bifurcation is needed to prevent injuries.

2.1.8 Non-atherosclerotic disease of the carotid artery

2.1.8.1 Carotid coil and kink

The excessive elongation of the internal carotid artery increases tortuosity of the vessel, forming kinks or coils in the artery [57]. Carotid coils are a congenital condition in children. Kinks and elongation are thought to occur due to the loss of elasticity and abrupt angulation of the vessel in adults. The aetiology of kinks and coils are still a topic of debate. In other studies, the aetiology has been argued as atherosclerosis, post–carotid endarterectomy changes, fibromuscular dysplasia, age-related degeneration, or simply normal variation or developmental differences [58]. Women have been shown to have a higher prevalence to kinks [58]. Kinks can cause cerebral ischemic symptoms that are similar to those from atherosclerotic carotid lesions. These symptoms are often due to cerebral hypoperfusion rather than embolic episodes. Movement in the head and neck that are abrupt can provoke ischemic symptoms by accentuating the kink. Doppler ultrasound is used to determine the effect of movement on the kinks and their clinical significance [58].

The kinks can be further graded using a method developed by Metz et al. as well as Weibel and Fields with the use of visual aid as indicated in Figure 2.2. Togay-Isikay [58] modified and combined these grading systems into a single set of criteria (Table 2.4).

Table 2.4: Modified criteria for the classification of kinks [58]

Malformation	Description
Tortuosity	S- or C-shaped elongation or undulation of ICA course
Mild kinking	Acute angulation of ICA between segments forming kink ≥ 60 degrees
Moderate kinking	Acute angulation of ICA between segments forming kink 30–60 degrees
Severe kinking	Acute angulation of ICA between segments forming kink < 30 degrees
Coiling	Exaggerated S shape or circular configuration of ICA course

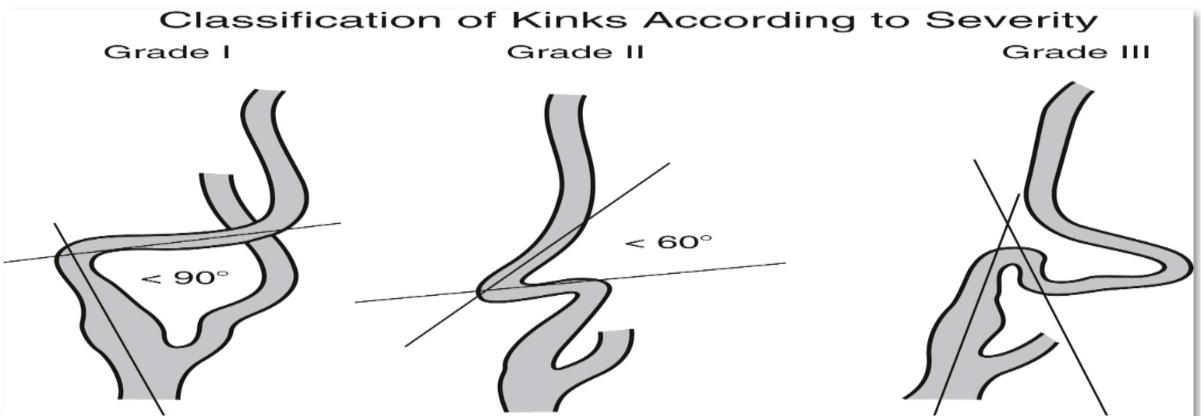


Figure 2.2: Classification of kinks according to severity [58]

2.1.9 Fibromuscular Dysplasia

Fibromuscular Dysplasia (FMD) affects arteries which have few branches and a medium size (Fig:2.3) [57]. The risk of developing FMD is higher in women 40–50 years of age than men. This increased risk of development is due to hormonal effects on the pathogenesis of FMD. Fibromuscular Dysplasia affects carotid bifurcation bilaterally and in 20% of cases it will also affect the vertebral arteries. In 50% of the cases FMD of the carotid bifurcation is accompanied by the development of intracranial saccular aneurysm of the carotid siphon or middle cerebral artery [57]. There are four types of FMD according to histological classification. The first and most prevalent FMD is medial fibroplasia that can present as multiple lesions or a focal stenosis which is accompanied by intervening aneurysmal outpouchings. This occurs due to the FMD replacing the media's smooth muscle with fibrous connective tissue. In most cases this type of FMD is accompanied by mural dilations and microaneurysms [57]. The second type are rare cases of FMD that demonstrate excessive amounts of smooth muscle in the media and is known as Medial hyperplasia. The third FMD that occurs equally in both sexes and accounts for 5% of the cases is known as intimal fibroplasia [57]. Intimal fibroplasia is focal stenosis in adults caused by the accumulation of subendothelial mesenchymal cells with a loose matrix of connective tissue [57].

Figure 2.3: A carotid fibromuscular dysplasia with typical characteristics of multiple stenosis with intervening aneurysmal outpouching dilatations. The disease involves the media, with the smooth muscle being replaced by fibrous connective tissue. [57]

In this type of FMD the media and adventitia remain normal. The fourth type of FMD is premedial dysplasia that is caused by the accumulation of elastic tissues between the media and adventitia. Forty percent of patience with FMD are likely to present with a transient ischemic attack due to embolization of platelet aggregates [57]. Fibromuscular Dysplasia with asymptomatic lesions is treated with antiplatelet medication. The recommendation of endovascular treatment is only given for lateralizing symptoms. Surgical correction is rarely needed.

2.1.10 Carotid artery aneurysms

The prevalence of carotid artery aneurysms is rare as it occurs in only 1% of all carotid-related cases. Carotid artery aneurysm occurs due to tunica media degeneration or atherosclerosis [57]. The carotid sinus is commonly involved in carotid artery aneurysms. Carotid artery aneurysm is only bilateral in 12% of cases. Usually, carotid artery aneurysm will be accompanied with a pulsatile neck mass. Carotid artery aneurysms lead to neurological symptoms resulting from embolism that form due to the aneurysm. It is rare for the carotid artery aneurysm to form thrombosis or to rupture. Injury or infection of the carotid artery aneurysm can lead to pseudoaneurysms [57]. *Staphylococcus aureus* infection, which involves peritonsillar abscesses lead to specifically mycotic aneurysms. The formation of true aneurysms or pseudoaneurysms can be caused by FMD and spontaneous dissection. Treatment of carotid artery aneurysms are typically surgery but can be treated using an endovascular approach [57].

2.1.11 Carotid body tumour

The carotid body is located in the angle of the carotid bifurcation surrounded by the tunica adventitia [5,8,9]. As the carotid body originates from the third aortic arch, it is innervated by the glossopharyngeal nerve and supplied from the external carotid artery [5]. In some case the blood supply can be derived from the vertebral arteries. Carotid body tumours originate from a rare lesion of the neuroendocrine system. Malignancy is seen in 5–7% of the carotid body tumours. There is a genetic factor, as 35% of carotid body tumours are hereditary [57]. The risk of malignancy increases if the patient is young and has a family history of carotid tumours. The endocrine products of the carotid body tumour rarely have an effect related to symptoms. Diagnosis of carotid body tumours usually occurs between 50–70 years of age when an asymptomatic lateral neck mass is visible [57]. This diagnosis is confirmed with imaging such as carotid duplex scan and for orientation CT and MR imaging is used. The carotid body tumour affects the carotid bifurcation by widening the angle of bifurcation. Tumours are classified according to Shamblin on the tumour extent as illustrated in Table 2.5. For diagnosis a CT and MRI is used but requires an arteriography. Treatment for a carotid body tumour is surgical resection [57].

Table 2.5: The Shamblin classification of tumours [57]

The Shamblin classification describes the tumour extent	
Type 1	Tumour is < 5 cm and relatively free of vessel involvement
Type 2	Tumour is intimately involved but does not encase the vessel wall
Type 3	Tumour is intramural and encases the carotid vessels and adjacent nerves

2.2 INTERNAL ANATOMICAL VARIATION

One of the main principles taught in anatomy is that only the heart and veins have valves, incomplete valves, or flow diverters in the circulatory system [5,6,7]. Valves are defined as folds or flaps in the lining of a tubular structure that obstructs or partially obstructs blood flow [59]. The presence of flow diverters in arteries has been observed in a current study by du Plessis et al. on renal arteries ostium [60]. The function of the valves was postulated to divert blood flow into the renal arteries. Flow diverters are more prominent in the native African people [60]. These flow diverters are formed by a U-shaped loop at the distal part of the renal ostium. Collagen fibres were located in the lamina media of the blood vessel where it folds to form the U-shaped loop [60]. This study highlights the need to expand the study of anatomy into the African context especially in areas of high anatomical variation.

3 CHAPTER 3: RESEARCH QUESTION, AIM, OBJECTIVE AND HYPOTHESIS

3.1 RESEARCH QUESTION

Does a Stellenbosch cadaver cohort exhibit anatomical variations in the carotid bifurcation?

3.2 AIM

The aim of the study is to determine the anatomical variations at the carotid bifurcation in a Stellenbosch cadaver cohort.

3.3 OBJECTIVES

The objectives of this protocol are therefore:

- To determine the anatomical variations of the carotid bifurcation;
- To determine the correlation between anatomical variations; and
- To compare the results of the study to previous research.

3.4 HYPOTHESIS

H_0: The Stellenbosch cadaver cohort does not exhibit anatomical variations in the carotid bifurcation.

H_A: The Stellenbosch cadaver cohort does exhibit anatomical variations in the carotid bifurcation.

4 CHAPTER 4: RATIONALE

Surgical anatomy of the carotid bifurcation is complex and has clinical and surgical applications. Carotid sinus massage is the diagnostic technique that relies on the anatomical knowledge to apply pressure on the carotid sinus which assists in clarification of the type of rhythm disturbances. In diseases such as carotid atheromatosis disease, carotid body tumours, and carotid aneurysms, the carotid bifurcation is the surgical target. Clarification of the anatomy could alter surgical interventions and assist in distinguishing subgroups of patients necessitating individualistic interventions. Detailed descriptions are still lacking for the precise height of the carotid bifurcation, morphometry of the internal and external carotid artery, and tortuosity of the common carotid artery. Further research might ameliorate available treatment options or lead to innovative treatment options.

5 CHAPTER 5: MATERIALS AND METHODS

This study was designed to determine the anatomical variation of the carotid bifurcation. This research focuses on the height, angle, general structure, and diameter of the carotid bifurcation, as well as the length and diameter of the carotid sinus. The internal anatomical variation of the carotid bifurcation was added as the study progressed.

5.1 STUDY POPULATION

One hundred and twenty-eight specimens were obtained from Stellenbosch University with ethical clearance from the Health Research Ethics Committee (S16/10/207). These cadavers formed part of the anatomy department students' dissection programmes at Stellenbosch University, Faculty of Medicine and Health Sciences during 2016 to 2018. Since the anatomical department dissection programme at Stellenbosch University does not include dissection of the carotid bifurcation, these carotid bifurcations were used for this study. The exclusion criteria included damaged carotid bifurcations and carotid bifurcations that presented pathology that severely altered their appearance or prevented removal or identification of the structures. Age and sex of each cadaver were recorded. The ages of the cadavers ranged from 19 to 96 years (Figure:5.1). The mean age was 50 years with a standard deviation of 16.6 years. Sex distribution was unequal with 76 male cadavers and 52 female cadavers.

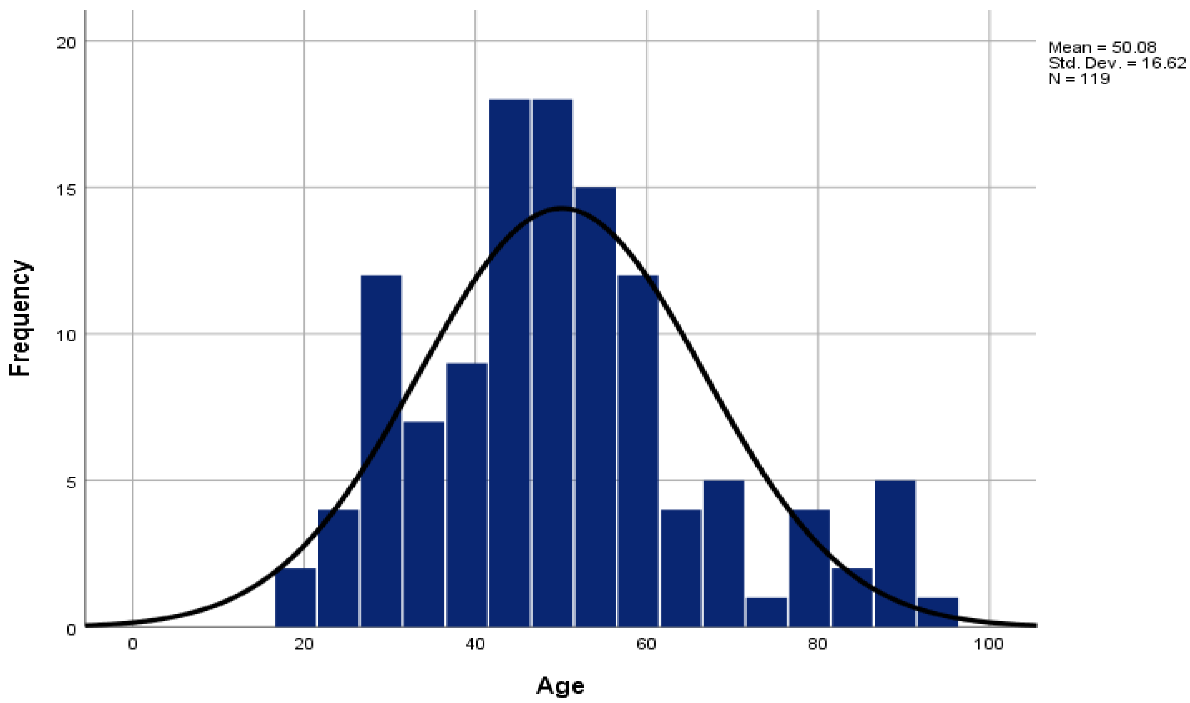


Figure 5.1: The Stellenbosch University cadaver cohort age distribution for 2016-2018.

5.2 DISSECTION

The incision was about 5 to 10 cm and was done bilaterally as illustrated in Figure 5.2. The carotid triangle was cleaned to ensure the carotid bifurcation was clearly visible. Adipose tissue and facia were removed, after which, digital images were taken (Nikon D80 with Sigma 17–70mm f/2.8-4 DC Macro OS HSM Contemporary Lens).

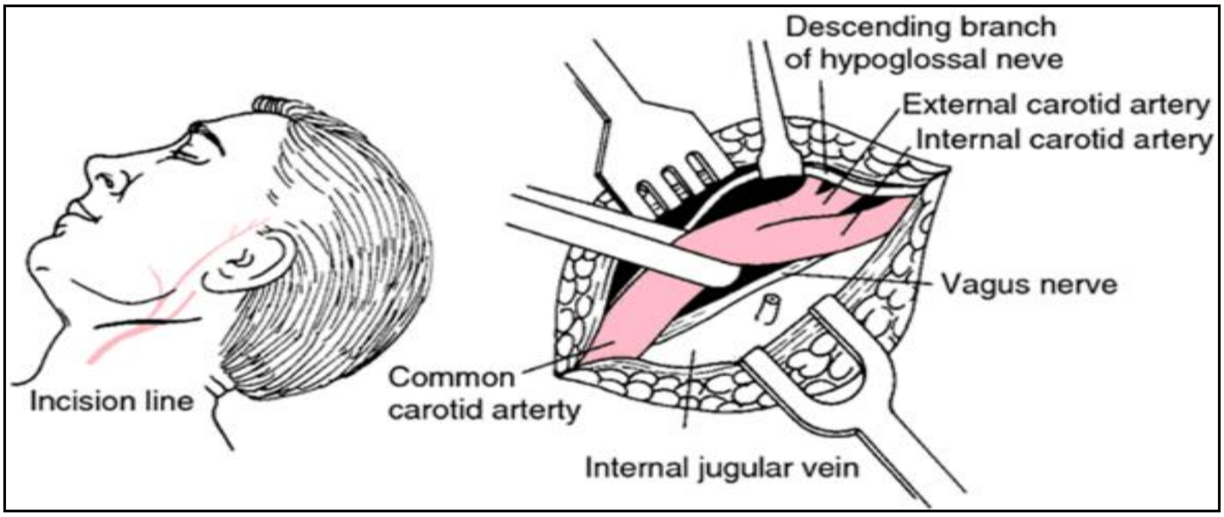


Figure 5.2: A 5 cm incision made in the carotid triangle to expose the carotid bifurcation [adapted from 61].

5.2.1 Height

The digital images were taken to illustrate how each carotid bifurcation was positioned in relation to the angle of the mandible. Measurements were taken between the angle of the mandible and the carotid bifurcation. The angle of the mandible was used as it is a bony landmark that is visible, palpable and relatively constant. Measurements were taken in anatomical position with a calliper to prevent discrepancies between measurements and to allow comparison to other similar studies. Three measurements were taken to form a complete image of the carotid bifurcation in relation to the angle of the mandible and specifically the gonion (Figure 5.3). The first measurement is the shortest distance between the gonion and carotid bifurcation. The second measurement is the perpendicular distance from the level of the mandible to the carotid bifurcation. The last measurement is the distance between the angle of the mandible and the perpendicular distance as it reaches the level mandible. The start of the measurements was the gonion as any measurements that were either more medial or superior to the gonion were recorded as negative. Any negative measurements indicated an area that was hard to access and difficult to dissect.

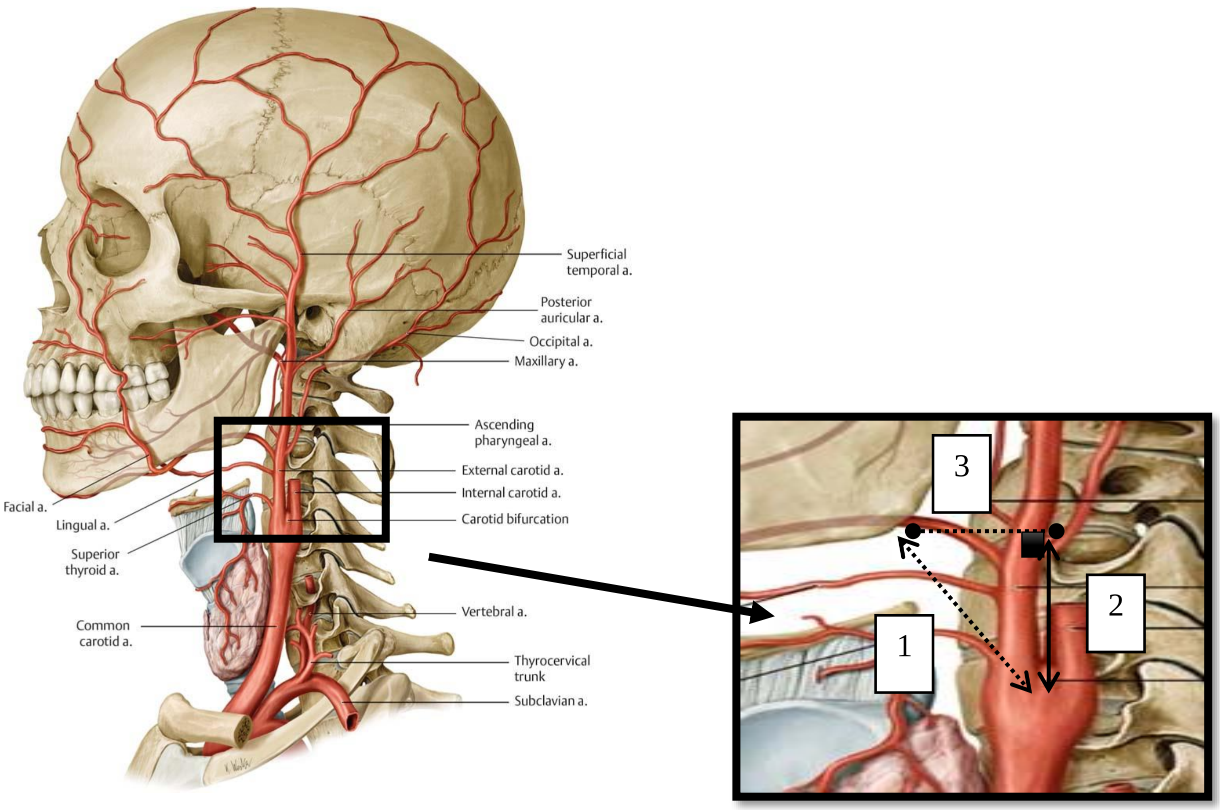


Figure 5.3:The measurements between the angle of bifurcation and the angle of the mandible [Adapted from 62]. 1: Shortest distance between the gonion and the carotid bifurcation. 2: Perpendicular distance from the level of the mandible to the carotid bifurcation. 3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible.

5.2.2 Angle and general structure

The entire carotid bifurcation was removed, and digital images were taken. The carotid bifurcation was examined for variations that were illustrated on a simple line diagram of the carotid bifurcation (Figure 12.1 in the appendix p 107). The line diagrams were analysed to identify the main features that vary in the carotid bifurcation in a quantifiable manner. These features included the position and orientation of the superior thyroid and laryngeal arteries, position of the ascending pharyngeal artery, the number of branches on the external carotid as well as their orientation, bending in either the internal or external carotid arteries. A table consisting of these features was used to simplify the process of analysing the simple line diagrams. This allowed the general structure to be compared statistically to other features of the carotid bifurcation. The angle of the carotid bifurcation, with the use of a protractor, was recorded on the simple line diagram.

5.2.3 Diameter of the carotid bifurcation and length of the carotid sinus

Measurements were taken to quantify the difference in the carotid bifurcation. The length of the carotid sinus was measured using a calliper, labelled as L1 in Figure 5.4. The diameters of the internal carotid, carotid sinus, common carotid and the external carotid was measured (labelled as M1, M2, M3 and M4 respectively) using a digital micrometer (Figure 5.4). The diameter of the carotid sinus was taken both on the x-axis and y-axis, as the cross section was oval in shape. These measurements were recorded in Table 12.4 (appendix p 106).

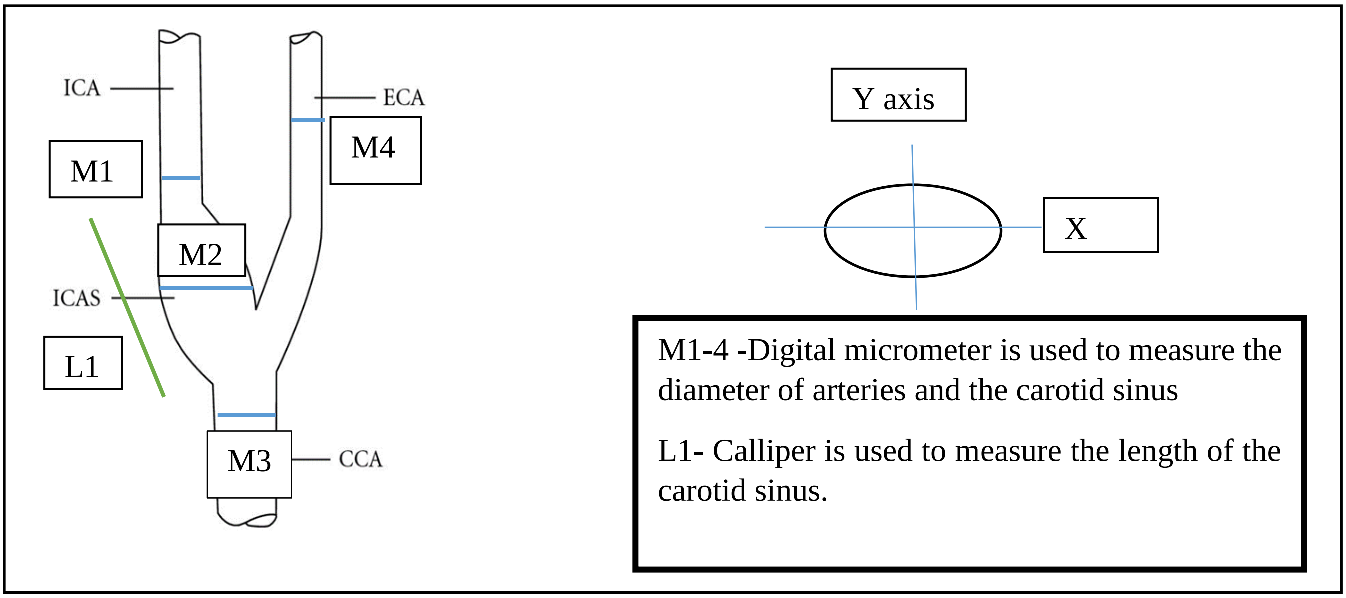


Figure 5.4: The sections of the carotid bifurcation that were measured with the use of a micrometer [adapted from 63].

5.2.4 Internal Anatomical Variations

Carotid bifurcations were observed to feature unique internal anatomical variations that were noticed externally with the primary examination. This led to the dissection of the carotid bifurcation at any point where bending of arteries was observed, or coverage was visible when observing the lumen and mainly at the flow diverter. These unique anatomical variations were captured with digital images and their position was mapped as illustrated in Figure 5.5 The orientation of the mapping section 1 to 4 represents the lateral side while sections 5 to 8 represent the medial side. The flow diverter mapping was done over the ostium of the carotid sinus as the flow diverter tended to extend in that direction.

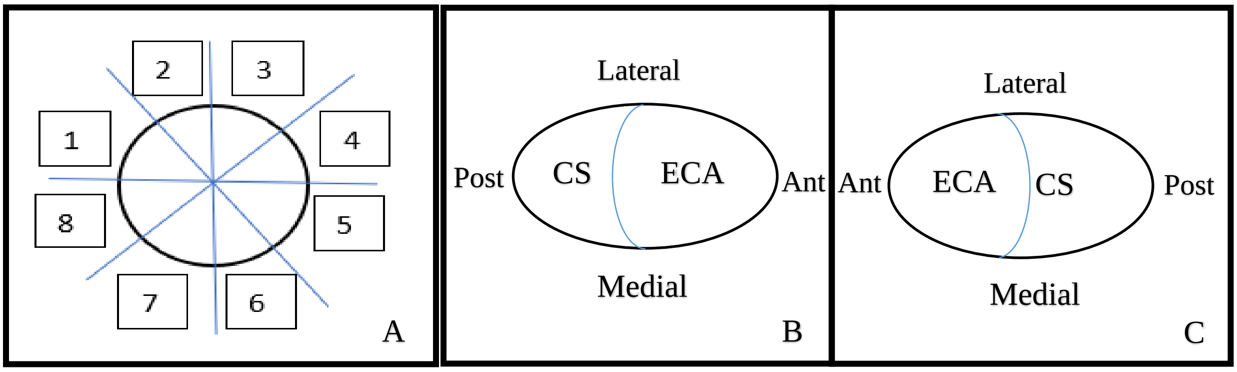


Figure 5.5: Coverage of flow diverters. A: The scale used to map the internal anatomical variations. Section 1 to 4 represents the lateral side of the arterial wall while section 5 to 8 represent the medial side. B: Left carotid bifurcation. C: Right carotid bifurcation. Post: Posterior, Ant: Anterior.

6 CHAPTER 6: DATA MANAGEMENT AND STATISTICAL ANALYSIS

The raw data of this study were transferred to Excel spread sheets for analysis. The data were analysed with the help of a statistician from the Centre for Evidence-based Health Care, Division of Epidemiology and Biostatistics, Stellenbosch University. The program IBM SPSS Statistics version 25 was used for statistical analyses. A Pearson's correlation analysis was used when analysing the relationship between two numerical variables. The associations between two categorical variables were analysed using Pearson's chi square test. ANOVA (analysis of variance) was used when comparing means of a numerical variable between three or more categories. Levine's test was also used when deem necessary.

7 CHAPTER 7: RESULTS

In this study, 256 carotid bifurcations were examined according to various aspects, including the height, angle, general structure, diameter, and the internal anatomical variation of the carotid bifurcation, as well as the length and diameter of the carotid sinus. Significance was deemed to be a p-value less than 0.05.

7.1 HEIGHT OF THE CAROTID BIFURCATION

The height of the carotid bifurcation was captured by three measurements as illustrated in Figure 7.1. The gonion was used as a landmark. Since carotid bifurcations can be located superior or medially to the gonion, some measurements were recoded as negative as illustrated in Figure 7.2. Table 7.1 gives a summary of the three measurements that were used to indicate the height of the carotid bifurcation.

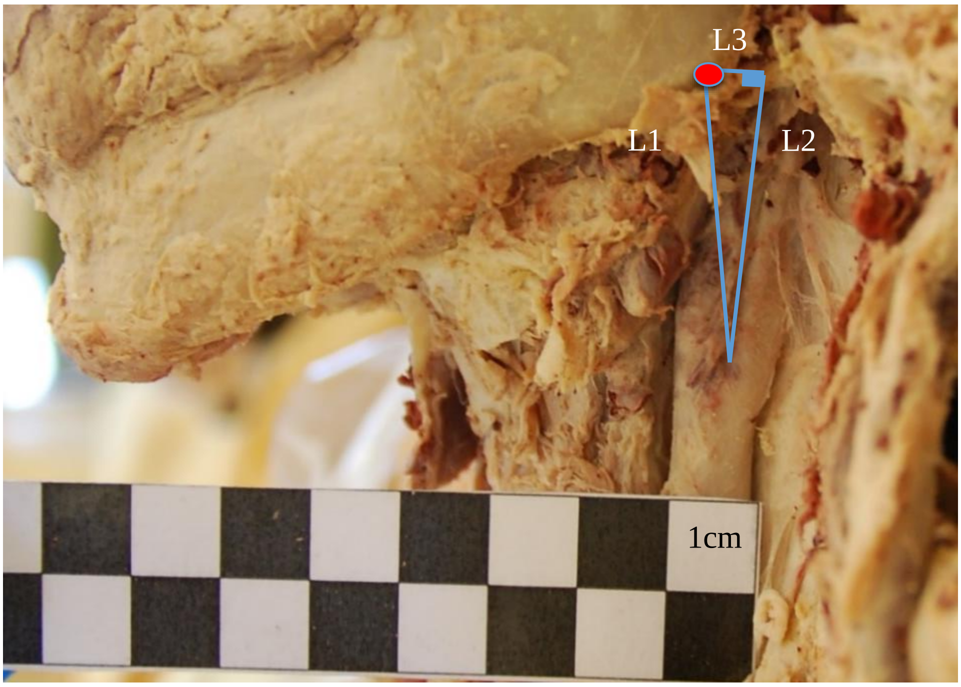


Figure 7.1: The three measurements that indicate height of the carotid bifurcation.
The red dot shows the gonion. L1: Shortest distance between the gonion and the carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side. L3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the left side. [Compare Figure 5.3 (p35)]

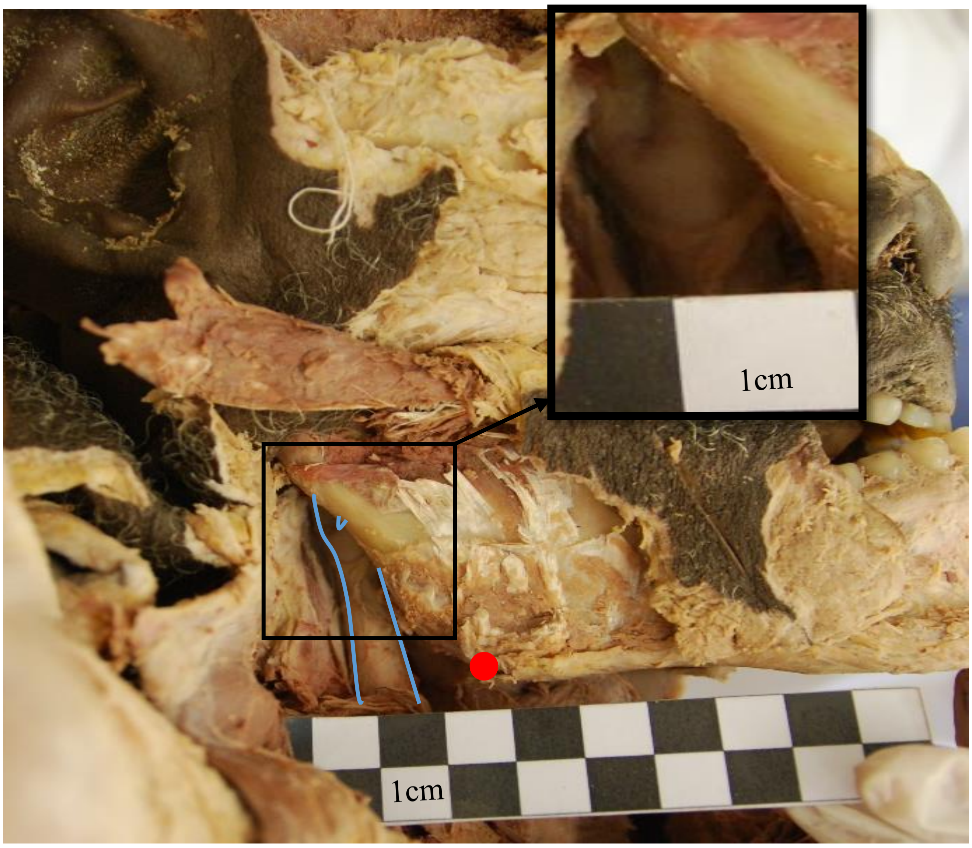


Figure 7.2: A high right carotid bifurcation.
The red dot indicates the gonion. The blue lines outline the carotid bifurcation. The insert shows a magnification of the carotid bifurcation.

Table 7.1: The height of the carotid bifurcation according to three measurements.

Measurements		1		2		3	
		Right	Left	Right	Left	Right	Left
Mean		2.1216	2.0637	1.7392	1.8049	1.5196	0.9892
Median		2.3000	2.0500	1.8000	1.8000	1.4500	1.2000
Std. Deviation		1.04802	1.27619	1.04948	1.08759	1.17145	1.37221
Skewness		-0.416	-0.748	-0.009	0.026	-0.371	-0.349
Std. Error of Skewness		0.239	.0239	0.239	0.239	0.239	0.239
Minimum		-1.20	-2.20	-0.90	-0.70	-2.20	-4.00
Maximum		4.90	4.30	4.90	5.20	4.50	4.60
Percentiles	25	1.5000	1.3000	1.1000	0.8000	0.3000	0.3000
	50	2.3000	2.0500	1.8000	1.4500	1.2000	1.2000
	75	2.8000	3.0250	2.4000	2.3250	1.8000	1.8000

1: Shortest distance between the gonion and carotid bifurcation. 2: Perpendicular distance from the level of the mandible to the carotid bifurcation. 3: The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible. [cm]

7.1.1 The correlation between left and right height for the cartid bifurcation

The shortest distance between the gonion and carotid bifurcation of the left and right carotid bifurcation had a weak Pearson postive linear correlation of 0.375; however, it was significant (p = 0.0001). The correlation between the left and right perpendicular distance from the level of the mandible to the carotid bifurcation had a moderate Pearson linear correlation 0.484 which was significant (p = 0.0001). The correlation between the distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the right and left side exhibited a moderated Pearson positive linear correlation of 0.595 and was significant (p = 0.0001). The three correlations are illustrated in Figure 7.3.

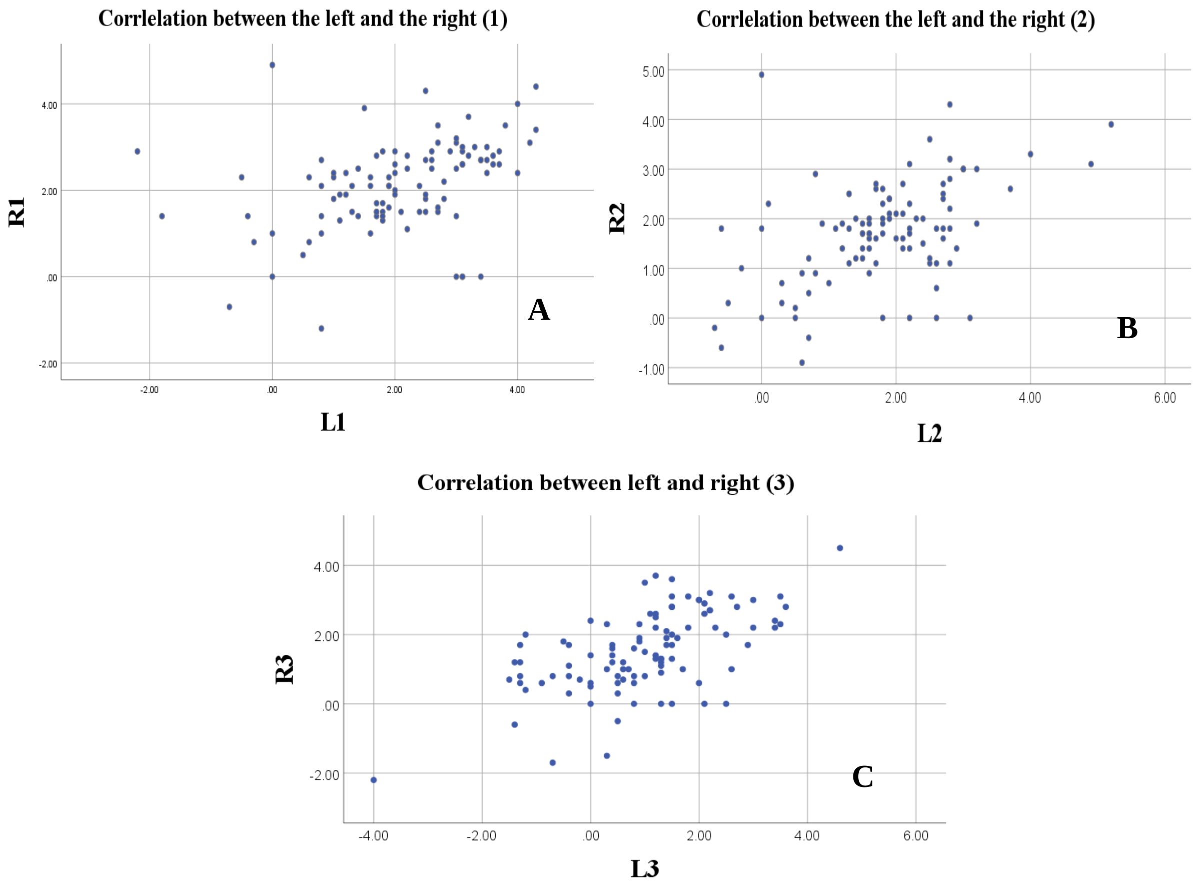


Figure 7.3: The correlation between left and right height for the carotid bifurcation. A: (R1/L1) Shortest distance between the gonion and carotid bifurcation. B: (R2/L2) Perpendicular distance from the level of the mandible to the carotid bifurcation. C: (R3/L3) The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible. [cm]

7.2 ANGLE OF THE CAROTID BIFURCATION

Angles ranged from 1° to 92°. The mean angle at the right carotid bifurcation was 18.53° and 20.20° degrees at the left carotid bifurcation (Table 7.2). The right and left angle of the carotid bifurcation were different on average as indicated by a moderate Pearson positive linear correlation of 0.502 which was significant (p = 0.0001). The correlation was stronger in the smaller angles and became weaker in the larger angles as illustrated in Figure 7.4.

Table 7.2: The angle of the carotid bifurcation according to right and left side (degrees).

		Angle of the Carotid Bifurcation	
		Right	Left
Mean		18.53	20.24
Median		15.00	15.00
Std. Deviation		16.373	17.350
Skewness		2.183	1.886
Std. Error of Skewness		0.222	0.225
Minimum		1	1
Maximum		89	92
Percentiles	25	8.00	9.00
	50	15.00	15.00
	75	24.00	24.75

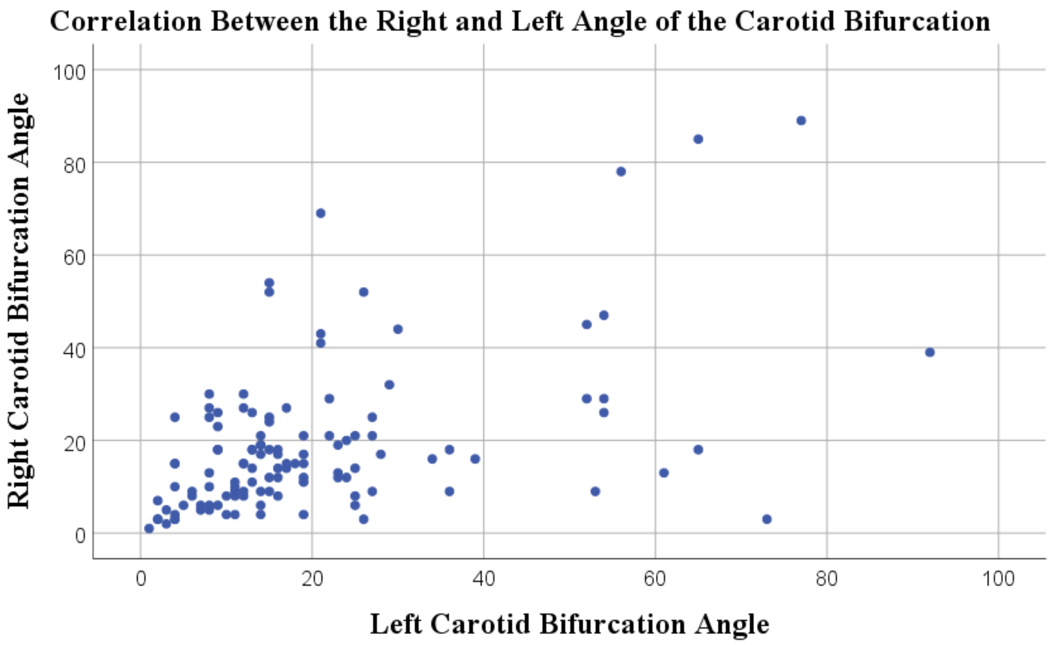


Figure 7.4: Correlation between the right angle and left angle of the carotid bifurcation (º).

7.3 GENERAL SHAPE OF THE CAROTID BIFURCATION

Certain features were investigated which included the origin and orientation of the superior thyroid artery, the origin of the ascending pharyngeal artery, the number of branches from the external carotid, the orientation of these branches, in addition to the bending in either the internal or external carotid arteries. There were various arteries that originated from the external carotid artery, namely the ascending pharyngeal, occipital, posterior auricular, superior thyroid and lingual artery. The ascending pharyngeal, superior thyroid and laryngeal arteries are described in Table 7.3. The occipital, posterior auricular and lingual artery were not specifically identified; however, these branches were referred to as general branches of the external carotid artery. In cases where the ascending pharyngeal and superior thyroid artery were not distinguishable, these branches were included in the general branching group.

Table 7.3 gives a comprehensive overview of the anatomical variation of the general shape of the carotid bifurcation. Shortly, the main findings indicated the superior thyroid artery was most commonly found on the external carotid artery proximal to the carotid bifurcation point of bifurcation. In the right carotid bifurcation, the superior thyroid artery was typically orientated superiorly or inferiorly of its origin. In the left carotid bifurcation, the superior thyroid artery was usually orientated in an inferior direction. Bifurcation occurred when the laryngeal artery originated from the carotid bifurcation instead of the superior thyroid artery. Bifurcation occurred in 18.3% on the right, and 6.7% on the left. Trifurcation of the superior thyroid artery was a rare occurrence at 0.8% on either side. General branches on the right and left external carotid artery were commonly orientated laterally and medially. Bending of either the internal and external carotid artery was rarely observed; however, the internal carotid artery most commonly bended anteriorly in 8.3% on the left and 7.5% on the right. The mean number of general branches was 2.38 on the right and 2.53 on the left. The minimum was zero and the maximum was six general branches (Table 7.4). There were only five general shapes of the carotid bifurcation that occurred in both the left and right carotid bifurcation.

Table 7.3 : Comprehensive overview of the anatomical variation of the general shape of the carotid bifurcation.

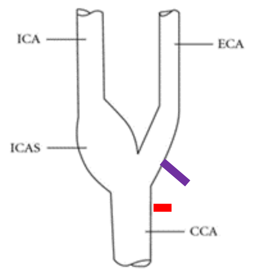
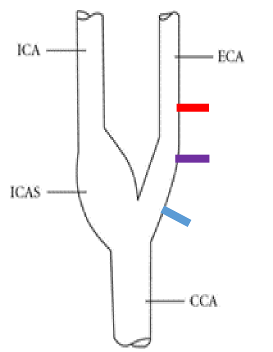
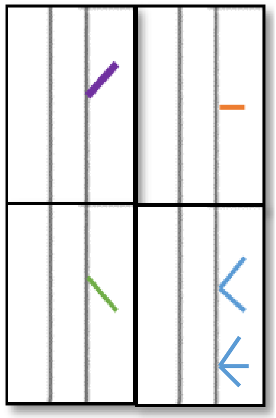
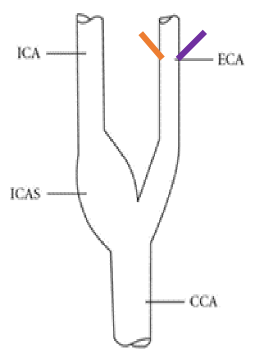
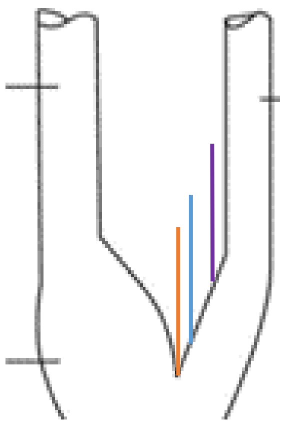
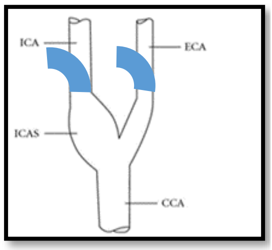
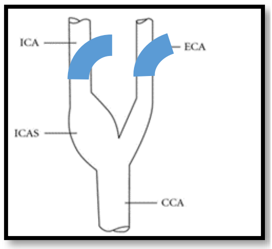
		Count	Column N %	Visual representation
Origin 1: Right Superior Thyroid and Laryngeal artery	Common carotid	3	2.5%	
	External carotid	102	85.0%	
	Absent	15	12.5%	
Origin 1: Left Superior Thyroid and Laryngeal artery	Common carotid	6	5.0%	
	External carotid	96	80.0%	
	Absent	18	15.0%	
Origin 2: Right Superior Thyroid and Laryngeal artery	Distal	29	24.2%	
	Middle	9	7.5%	
	Absent	18	15.0%	
	Proximal	64	53.3%	
Origin 2: Left Superior Thyroid and Laryngeal artery	Distal	14	11.7%	
	Middle	3	2.5%	
	Absent	24	20.0%	
	Proximal	79	65.8%	
Orientation: Right Superior Thyroid and Laryngeal artery	Bifurcation	22	18.3%	
	Inferiorly	36	30.0%	
	Trifurcation	1	0.8%	
	Transversely	10	8.3%	
	Absent	15	12.5%	
	Superiorly	36	30.0%	
Orientation: Left Superior Thyroid and Laryngeal artery	Bifurcation	8	6.7%	
	Inferiorly	52	43.3%	
	Trifurcation	1	0.8%	
	Transversely	12	10.0%	
	Absent	18	15.0%	
	Superiorly	29	24.2%	
Orientation: General Branches on the Right ECA	Medial & Lateral	63	52.5%	
	Medial	14	11.7%	
	Absent	14	11.7%	
	Lateral	29	24.2%	
Orientation: General Branches on the Left ECA	Medial & Lateral	65	54.2%	
	Medial	13	10.8%	
	Absent	11	9.2%	
	Lateral	31	25.8%	

Table 7.3 continued

		Count	Column N %	Visual representation
Position: Right Ascending Pharyngeal artery	Distal	10	8.3%	
	Median	6	5.0%	
	Absent	99	82.5%	
	Proximal	4	3.3%	
	2 Proximal arteries	1	0.8%	
Position: Left Ascending Pharyngeal artery	Distal	15	12.5%	
	Median	4	3.3%	
	2 Median arteries	1	0.8%	
	Absent	93	77.5%	
	Proximal	7	5.8%	
Bending: Right ICA/ Right ECA	Both posteriorly	2	1.7%	
	External carotid anteriorly	1	0.8%	
	External carotid posteriorly	2	1.7%	
	Internal carotid anteriorly	9	7.5%	
	Absent	106	88.3%	
Bending: Left ICA/ Left ECA	Both anteriorly	3	2.5%	
	Both posteriorly	1	0.8%	
	External carotid anteriorly	1	0.8%	
	External carotid posteriorly	4	3.3%	
	Internal carotid anteriorly	10	8.3%	
	Absent	101	84.2%	

ICA: internal carotid artery; ECA: external carotid artery.

Table 7.4: The number of general branches off the external carotid bifurcation.

The number of general branches off the ECA

		Right CB	Left CB
Mean		2.38	2.53
Median		2.00	3.00
Std. Deviation		1.461	1.347
Skewness		0.145	-0.187
Std. Error of Skewness		0.221	0.221
Minimum		0	0
Maximum		6	6
Percentiles	25	1.00	2.00
	50	2.00	3.00
	75	3.00	3.00

ECA: external carotid artery; CB: carotid bifurcation.

7.3.1.1 Correlation between the origin and the orientation of the superior thyroid artery

The right superior thyroid artery was commonly found proximal on the external carotid artery and oriented inferiorly. Frequently the right superior thyroid artery was orientated inferior in 43.3% (Table 7.5). An equal probability for the orientation of the left superior thyroid artery was observed to be either superior or inferior. However, the origin was commonly proximal from the external carotid (Table 7.6). In 22.5% of cases the left and right carotid bifurcation had a matching origin and orientation of the superior thyroid artery. The origins of the superior thyroid artery had no effect on the orientation of the artery.

Table 7.5: Correlation between the origin and the orientation of the right superior thyroid artery.

Origin	Orientation							
	Bifurcation	Inferiorly		Trifurcation	Transverse	Absent	Superiorly	Total
CCA	%	0.0%	2.5%	0.0%	0.8%	0.0%	1.7%	5.0%
ECA Distal	%	3.3%	3.3%	0.0%	0.8%	0.0%	4.2%	11.7%
ECA Middle	%	0.0%	1.7%	0.0%	0.8%	0.0%	0.0%	2.5%
ECA Proximal	%	3.3%	35.8%	0.8%	7.5%	0.0%	18.3%	65.8%
Absent	%	0.0%	0.0%	0.0%	0.0%	15.0%	0.0%	15.0%
Total	%	6.7%	43.3%	0.8%	10.0%	15.0%	24.2%	100.0%

CCA-Common Carotid Artery; ECA-External Carotid Artery

Table 7.6: Correlation between the origin and the orientation of the left superior thyroid artery.

Origin	Orientation							
	Bifurcation	Inferiorly	Trifurcation	Transverse		Absent	Superiorly	Total
CCA	%	0.8%	0.0%	0.0%	0.8%	0.0%	0.8%	2.5%
ECA Distal	%	3.3%	4.2%	0.0%	2.5%	0.0%	14.2%	24.2%
ECA Middle	%	2.5%	2.5%	0.8%	0.8%	0.0%	0.8%	7.5%
ECA Proximal	%	11.7%	23.3%	0.0%	4.2%	0.0%	14.2%	53.3%
Absent	%	0.0%	0.0%	0.0%	0.0%	12.5%	0.0%	12.5%
Total	%	18.3%	30.0%	0.8%	8.3%	12.5%	30.0%	100.0%

CCA-Common Carotid Artery; ECA-External Carotid Artery

7.3.1.2 Correlation between the number of general branches and the orientation of the general branches on the external carotid artery

The general branches were frequently orientated both medially and laterally on the right carotid bifurcation in 52.2% of cases as illustrated in Table 7.7. The general branches were more commonly orientated laterally when orientated to one side on the right carotid bifurcation. It was rare for right carotid bifurcations with more than two general branches to have both branches orientated medially. The orientation of the general branches on the external carotid artery on the left and right carotid bifurcation matched in 21.7% of cases. The left was slightly more likely to have general branches that were orientated both medially and laterally at in 54% of cases, as illustrated in Table 7.8. The left was slightly more likely to be lateral but had a higher chance for multiple medial general branches. The left side had fewer carotid bifurcations that showed no general branches.

Table 7.7: Correlation between the number of general branches on the external carotid artery and their orientation.

The number of general branches on the right external carotid		The Right orientation of the general branches				Total
		Both	Medial	None	Lateral	
0	Count	0	0	14	0	14
	% of total	0.0%	0.0%	11.7%	0.0%	11.7%
1	Count	0	10	0	10	20
	% of total	0.0%	8.3%	0.0%	8.3%	16.7%
2	Count	19	2	0	11	32
	% of total	15.8%	1.7%	0.0%	9.2%	26.7%
3	Count	21	1	0	4	26
	% of total	17.5%	0.8%	0.0%	3.3%	21.7%
4	Count	16	1	0	1	18
	% of total	13.3%	0.8%	0.0%	0.8%	15.0%
5	Count	6	0	0	3	9
	% of total	5.0%	0.0%	0.0%	2.5%	7.5%
6	Count	1	0	0	0	1
	% of total	0.8%	0.0%	0.0%	0.0%	0.8%
Total	Count	63	14	14	29	120
	% of total	52.5%	11.7%	11.7%	24.2%	100.0%

Table 7.8: Correlation between the number of general branches on the external carotid artery and their orientation.

The number of general branches on the external carotid		The left orientation of the general branches				Total
		Both	Medial	None	Lateral	
0	Count	0	0	11	0	11
	% of total	0.0%	0.0%	9.2%	0.0%	9.2%
1	Count	0	5	0	12	17
	% of total	0.0%	4.2%	0.0%	10.0%	14.2%
2	Count	12	3	0	9	24
	% of total	10.0%	2.5%	0.0%	7.5%	20.0%
3	Count	28	5	0	7	40
	% of total	23.3%	4.2%	0.0%	5.8%	33.3%
4	Count	20	0	0	2	22
	% of total	16.7%	0.0%	0.0%	1.7%	18.3%
5	Count	4	0	0	1	5
	% of total	3.3%	0.0%	0.0%	0.8%	4.2%
6	Count	1	0	0	0	1
	% of total	0.8%	0.0%	0.0%	0.0%	0.8%
Total	Count	65	13	11	31	120
	% of total	54.2%	10.8%	9.2%	25.8%	100.0%

7.3.1.3 Origin of the ascending pharyngeal artery correlation between left and right

The correlation between the left and right ascending pharyngeal artery position is illustrated in Table 7.9. The ascending pharyngeal artery was frequently distal to the bifurcation if not absent. There was no clear trend between the left and right ascending pharyngeal arteries.

Table 7.9: Orgin of the ascending pharyngeal artery correlation between left and right.

Right		Left					Total
		Distal	Median	2 Median	Absent	Proximal	
Distal	%	3.3%	0.0%	0.0%	5.0%	0.0%	8.3%
Median	%	0.8%	0.0%	0.8%	3.3%	0.0%	5.0%
Absent	%	8.3%	2.5%	0.0%	67.5%	4.2%	82.5%
Proximal	%	0.0%	0.0%	0.0%	1.7%	1.7%	3.3%
2 Proximal	%	0.0%	0.8%	0.0%	0.0%	0.0%	0.8%
Total	%	12.5%	3.3%	0.8%	77.5%	5.8%	100.0%

7.3.1.4 Correlation of bending in the right and left internal and external carotid arteries

The correlation of bending in the external and internal carotid artery is illustrated in Table 7.10. Bending in the external and internal carotid was not a common anatomical variation as 78.3% had no bending in either the left or right carotid bifurcation.

Table 7.10: Correlation of left and right carotid bifurcation bending in the internal and external carotid arteries

Crosstabulation									
Right			Bending: Left ICA/ Left ECA						Total
			Both Ant	Both Post	ECA Ant	ECA Post	ICA Ant	Absent	
Bending: ICA/ ECA	Both Post	%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	1.7%
	ECA Ant	%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%
	ECA Post	%	0.0%	0.8%	0.0%	0.8%	0.0%	0.0%	1.7%
	ICA Ant	%	0.0%	0.0%	0.0%	0.0%	3.3%	4.2%	7.5%
	Absent	%	1.7%	0.0%	0.8%	2.5%	5.0%	78.3%	88.3%
Total		%	2.5%	0.8%	0.8%	3.3%	8.3%	84.2%	100.0%

ECA: External carotid artery; ICA: Internal Carotid artery; Ant: Anteriorly; Post: Posteriorly

7.4 DIAMETERS OF THE CAROTID BIFURCATION

The internal carotid, carotid sinus, common carotid and the external carotid were labelled as M1–M4 respectively (Figure 5.4 p37). Since the cross section of the carotid sinus is oval, the diameters of the x-axis and y-axis were both measured. Table 7.11 provides a summary of the diameters of the left and right carotid bifurcation. The diameters ranged from 3.43 mm to 15.31 mm. The carotid sinus had the largest diameter and the external carotid artery had the smallest.

Table 7.11: Diameters of the carotid bifurcation and carotid sinus (mm).

		ICA (M1)		CS (M2 x-axis)		CS (M2 y-axis)		CCA (M3)		ECA (M4)	
		Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Mean		6.5045	6.8558	8.8570	9.3612	7.5415	7.8907	8.3757	8.6388	6.6790	6.9046
Median		6.4430	6.9180	8.7110	9.5070	7.4920	8.1180	8.3505	8.3240	6.7490	6.9085
Std. Deviation		1.30378	1.42671	1.97350	1.91710	1.62029	1.68124	1.51020	1.34986	1.45179	1.46478
Skewness		0.507	0.571	0.231	-0.116	0.226	-0.199	-0.164	1.035	0.325	0.179
Std. Error of Skewness		0.217	0.218	0.217	0.218	0.217	0.218	.223	0.218	0.217	0.219
Minimum		3.57	3.43	3.67	3.72	3.98	3.68	4.31	5.91	3.43	3.40
Maximum		11.28	11.36	15.31	14.03	11.87	11.87	12.70	13.87	10.93	10.60
Percentiles	25	7.9800	7.6370	6.7890	7.5978	7.7080	5.6915	5.7090	5.7190	5.7090	5.7090
	50	9.5070	8.7110	8.1180	8.3505	8.3240	6.7490	6.9085	6.9180	6.9085	6.9085
	75	10.5260	10.2005	8.9600	9.4058	9.3980	7.5790	7.9468	7.6910	7.9468	7.9468

ICA: internal carotid artery; CS: carotid sinus; CCA: common carotid artery; ECA: external carotid artery

Table 7.12 Diameter ratios of the carotid arterial system.

ICA/CCA			ECA/CCA			ICA/ECA		
Right	Left	Mean	Right	Left	Mean	Right	Left	Mean
0.7766	0.7936	0.7851	0.7974	0.7992	0.7983	0.9738	0.9923	0.983

ICA: internal carotid artery, CCA: common carotid artery, ECA: external carotid artery.

7.4.1.1 Correlation between the diameter of the left and right carotid bifurcation

There was a moderate positive linear Pearson correlation (0.566) between the left and right diameters of the internal carotid bifurcation (M1). Moderate positive linear Pearson correlation of 0.539 was observed between the diameter of the left and right carotid sinus x-axis (M2).

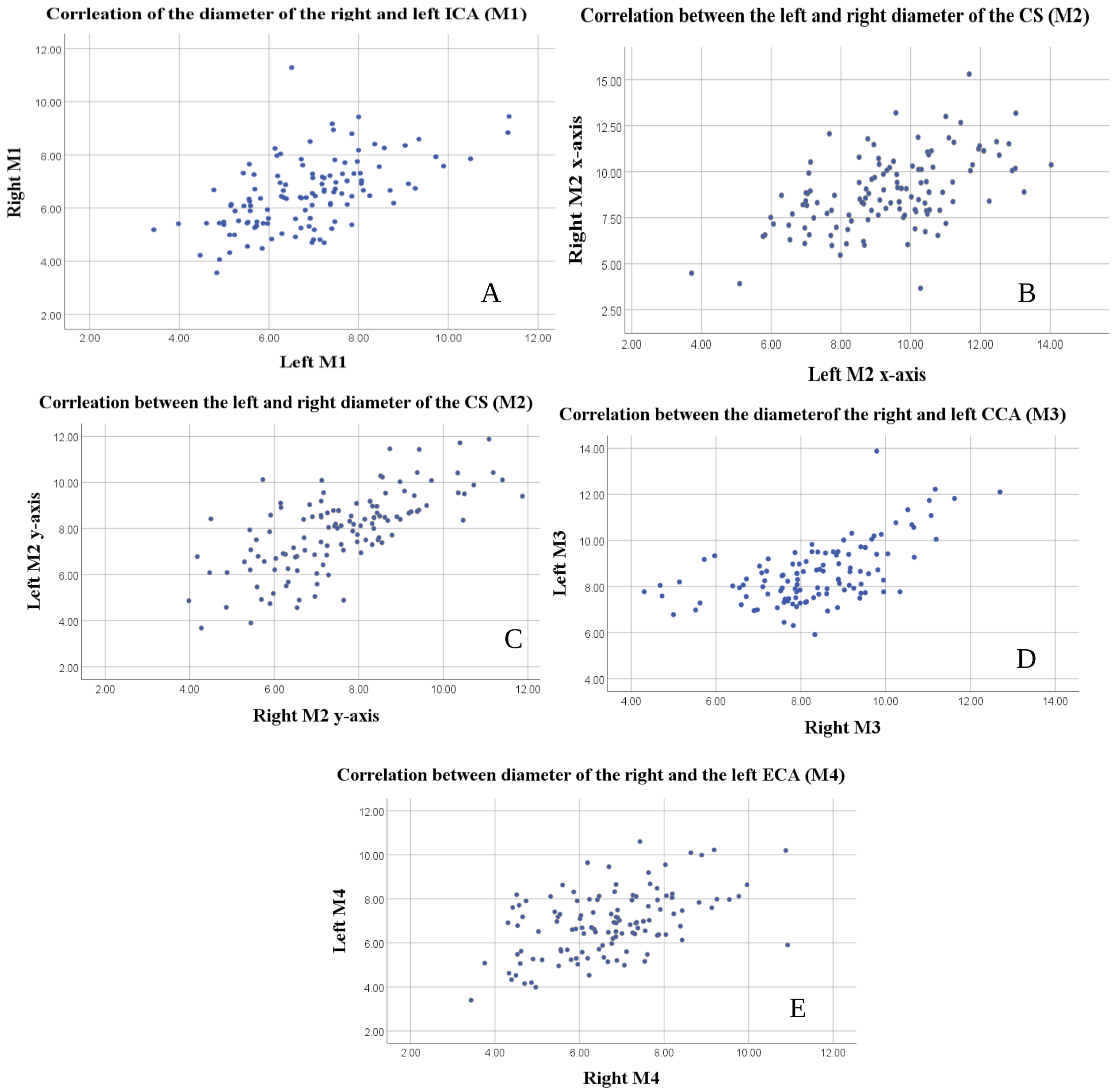


Figure 7.5 Correlation between the diameter of the left and right carotid bifurcation.
A:M1 diameters of the internal carotid bifurcation. B: M2 diameter of the carotid sinus x-axis. C: M2 diameter of the carotid sinus Y-axis. D: M3 diameter of the common carotid artery diameter. E: M4 diameter of the external carotid artery diameter.

There was a strong Pearson's positive linear correlation of 0.694 between the diameter of the left and right carotid sinus y-axis (M2). The left and right common carotid artery diameter (M3) has a moderate positive linear Pearson correlation of 0.598. The left and right external carotid artery diameter (M4) had a moderate positive linear Pearson correlation of 0.483. The correlation between left and right diameters was significant (p = 0.00001) and illustrated in Figure 7.5.

7.5 LENGTH OF THE CAROTID SINUS

The lengths of the carotid sinus ranged between 0.8 cm and 3.0 cm. The mean length of the right carotid sinus was 1.7 cm side while the left was 1.8 cm (Table 7.13). There was a moderate positive linear Pearson correlation of 0.545 between the length of the right and left carotid sinus and was significant (p = 0.0001). The positive linear Pearson correlation is illustrated in Figure 7.6.

Table 7.13 The length of the carotid sinus according to the left and right side.

		The length of the right CS (cm)	The length of the left CS (cm)
Mean		1.7448	1.8382
Median		1.7000	1.8000
Std. Deviation		0.41861	0.43936
Skewness		0.206	-.030
Std. Error of Skewness		0.217	0.218
Minimum		0.80	0.80
Maximum		3.00	2.90
Percentiles	25	1.4000	1.6000
	50	1.7000	1.8000
	75	2.0000	2.1000

CS: carotid sinus.

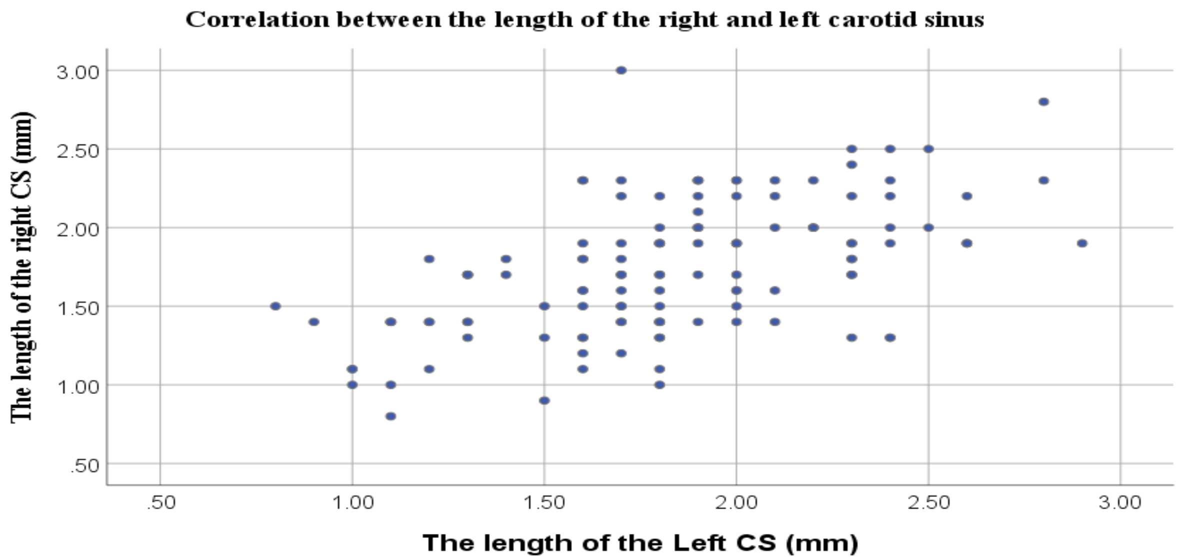


Figure 7.6: Correlation between the length of the right and left carotid sinus. CS: Carotid Sinus.

7.6 INTERNAL ANATOMICAL VARIATION OF CAROTID BIFURCATION

Carotid bifurcations were observed to feature unique internal anatomical variation that were noticed externally with the primary examination. This then led to the dissection of the carotid bifurcation at any point of interest and mainly at the flow diverter level. In 60.2% of cases the right flow diverters at the carotid bifurcation extended into the lumen beyond, as described in the literature. The left flow diverter at the carotid bifurcation showed this variation in 57.8% of the cases (Figure 7.8). Flow diverters were also found in other areas of the carotid bifurcation and were named supplementary flow diverters. The prevalence of supplementary flow diverters in the common carotid artery on the right side was 4.7%. The left common carotid artery had 2.3% of cases presenting with supplementary flow diverters. The right external carotid artery presented with 6.3% of cases having supplementary flow divers while the left had 5.5%. The right internal carotid artery only had one case (0.8%) presenting with supplementary flow diverters. The left internal carotid was the only artery that exhibited two sequential supplementary flow diverters, and this occurred in two cases (1.6%) while 3.9% had a single supplementary flow diverter. Folding in the common carotid artery was observed in 5.5% of cases on the right and 0.8% on the left. Figure 7.7 illustrates where the supplementary flow diverters and the folds occurred in relation to the carotid bifurcation. A vascular surgeon was consulted regarding the internal anatomical variation observed. The anatomical variation of the flow diverter had been observed and had no clinical applications according to the surgeon. The supplementary flow diverters were questioned as it had never been seen in patients by the vascular surgeon. It was postulated by the vascular surgeon that these abnormalities might have pathological origins (atherosclerosis or fibromuscular dysplasia) or they were artefacts caused by the embalming process.

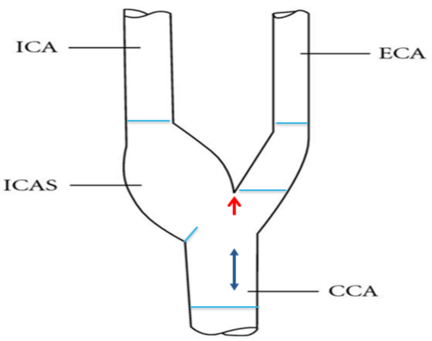


Figure 7.7: Illustration of where the supplementary flow diverters and the folds occurred in the carotid bifurcation. The blue lines indicate supplementary flow diverters. The red arrow indicates the flow diverter and where the anatomical variation of the flow diverter occurs. The double-headed dark blue arrow indicates the plane in which the folds occur, as they often line up with the flow diverter.

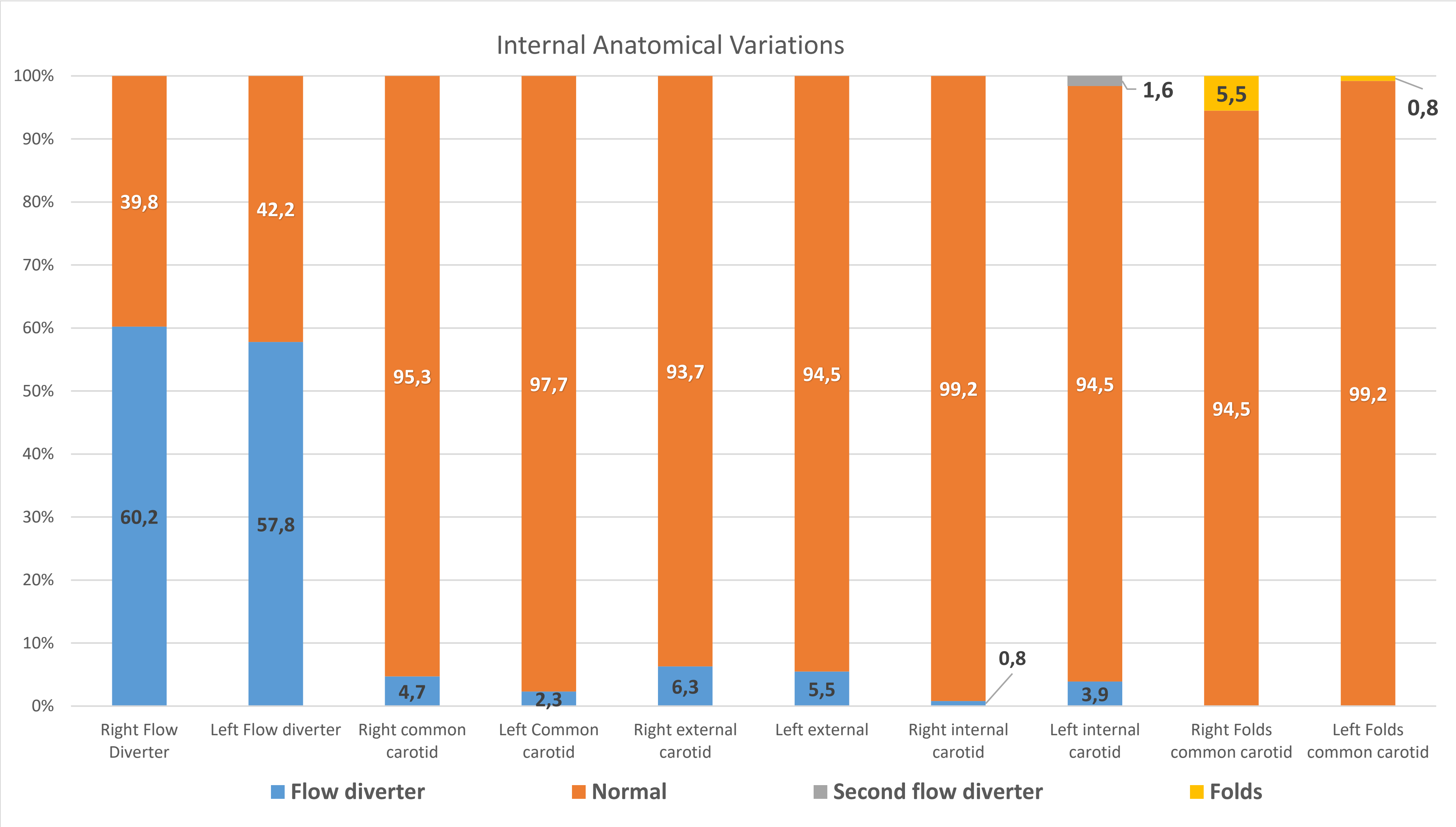


Figure 7.8: Internal variation of the carotid bifurcation.

7.6.1 Coverage of the flow diverter

The coverage of the flow diverter referred to the area that was occupied by the flow diverter, the supplementary flow diverter or the fold. The areas marked 1–4 represent the lateral side while the areas marked 5–8 represent the medial side as illustrated in Figure 5.5 p38. Right carotid bifurcation flow diverter displayed coverage mainly in areas 4 and 5 (Figure 7.10). Mapping area 1 and 8 were favoured by the left carotid bifurcation. An example of coverage in multiple mapping areas for anatomical variation of the flow diverter is illustrated in Figure 7.9.

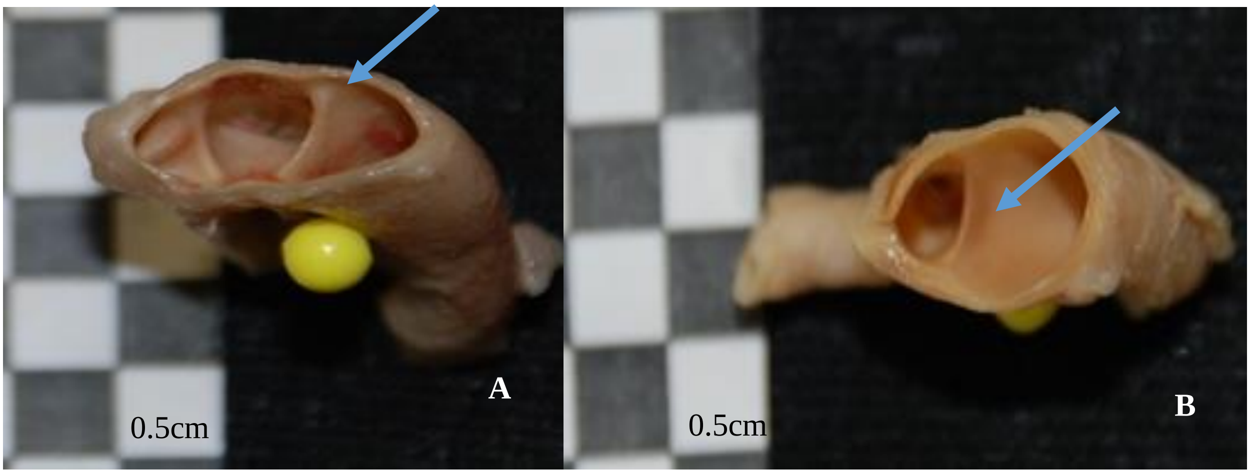


Figure 7.9: Anatomical variation of the flow diverter.
A: right carotid bifurcation with anatomical variation at the flow diverter with multiple mapping area coverage. B: left carotid bifurcation with an extension of the flow diverter creating a flap at the entrance of the external carotid artery. Arrows indicate extension of flow diverter into lumen.

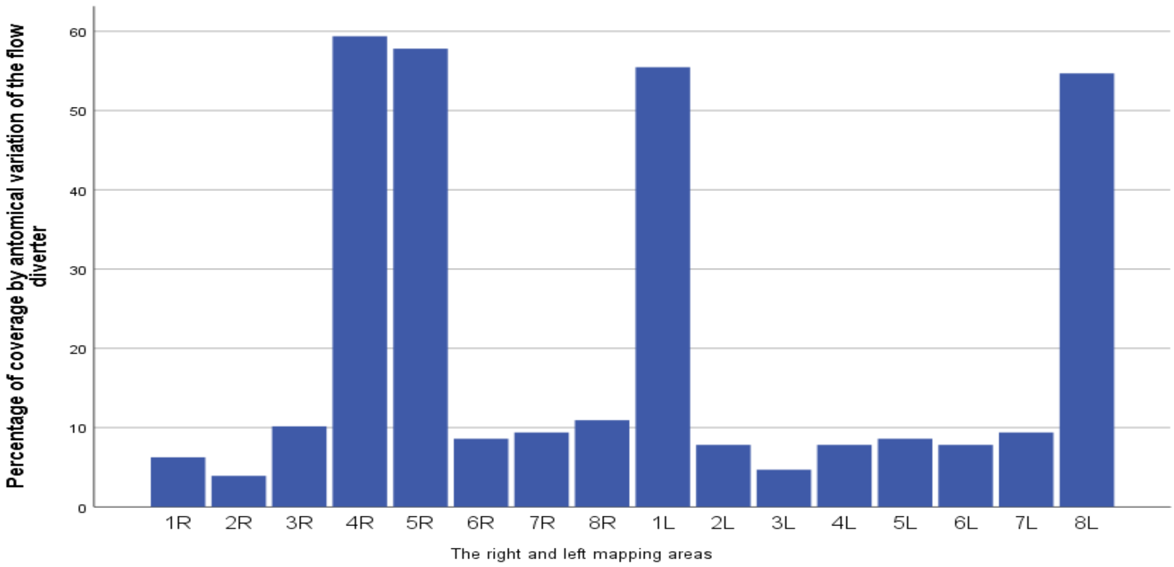


Figure 7.10: The coverage of anatomical variation observed in the right carotid bifurcation.

1R–8R indicated mapping areas in the right Carotid Bifurcation.1L–8L: mapping area in the left CB.

7.6.2 Common carotid artery

Figure 7.12 illustrates the coverage of the supplementary flow diverters in the common carotid artery both in the left and right carotid bifurcation. Figure 7.11 illustrates a supplementary flow diverter in the common carotid artery with no external carotid abnormalities.

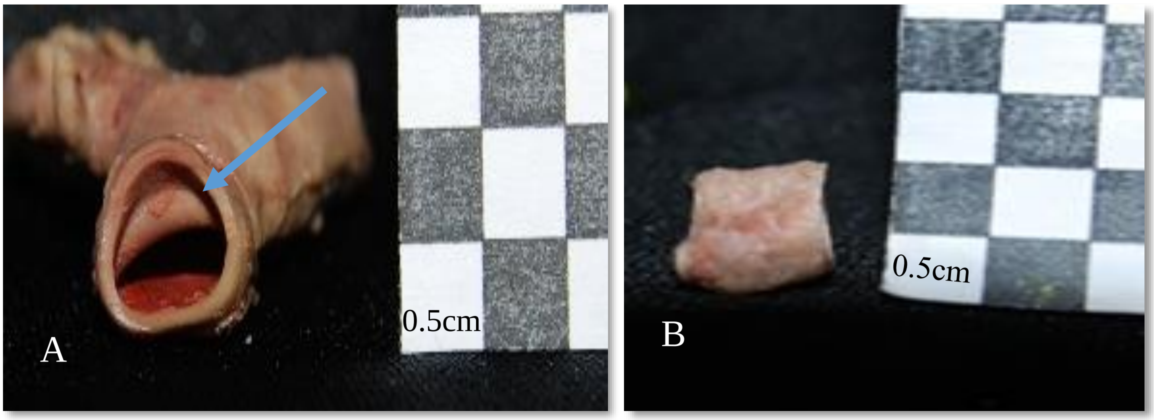


Figure 7.11: Common carotid artery.
A: Supplementary flow diverter in the common carotid artery. B: The section of the common carotid artery containing the supplementary flow diverter showing no external abnormalities. Arrows indicate supplementary flow diverter.

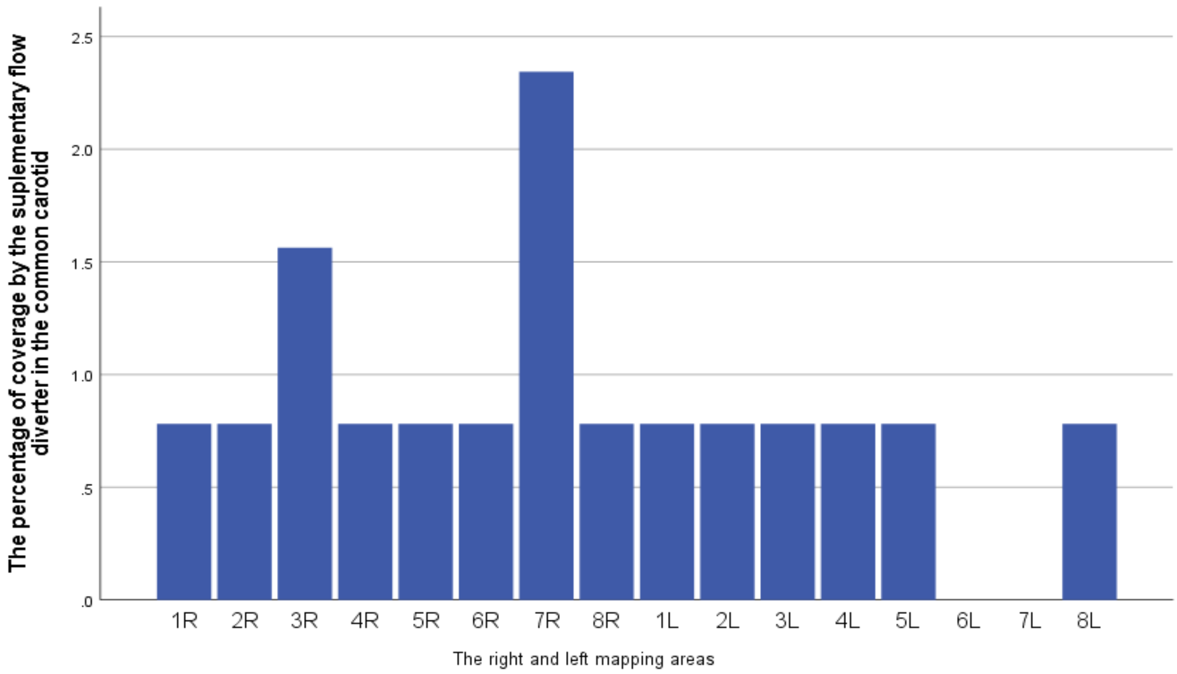


Figure 7.12: Coverage of the supplementary flow diverter in the common carotid artery.
1R–8R: mapping areas in the right CB. 1L–8L: mapping area in the left CB.

7.6.3 External carotid artery

An example of a supplementary flow diverter is illustrated in Figure 7.13; however, proximity to the bifurcation varied. The coverage of the supplementary flow diverters in the external carotid artery is illustrated in Figure 7.14. The right external carotid supplementary flow diverter favours area one and eight while the left favour mapping area seven.

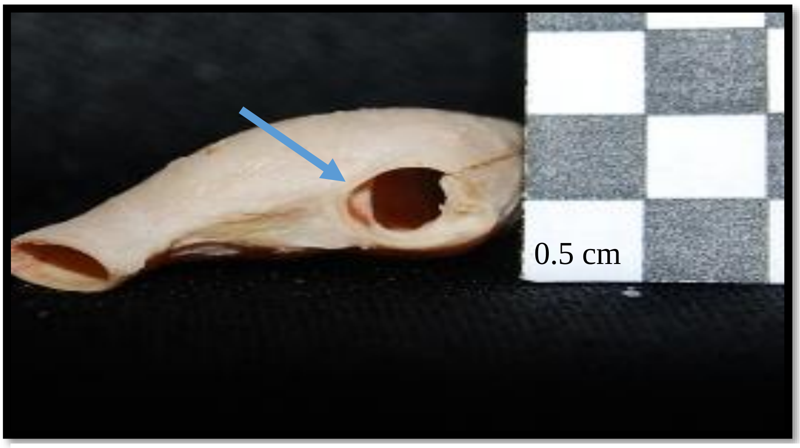


Figure 7.13: A supplementary flow diverter the external carotid artery proximal to the bifurcation. Arrows indicate supplementary flow diverter.

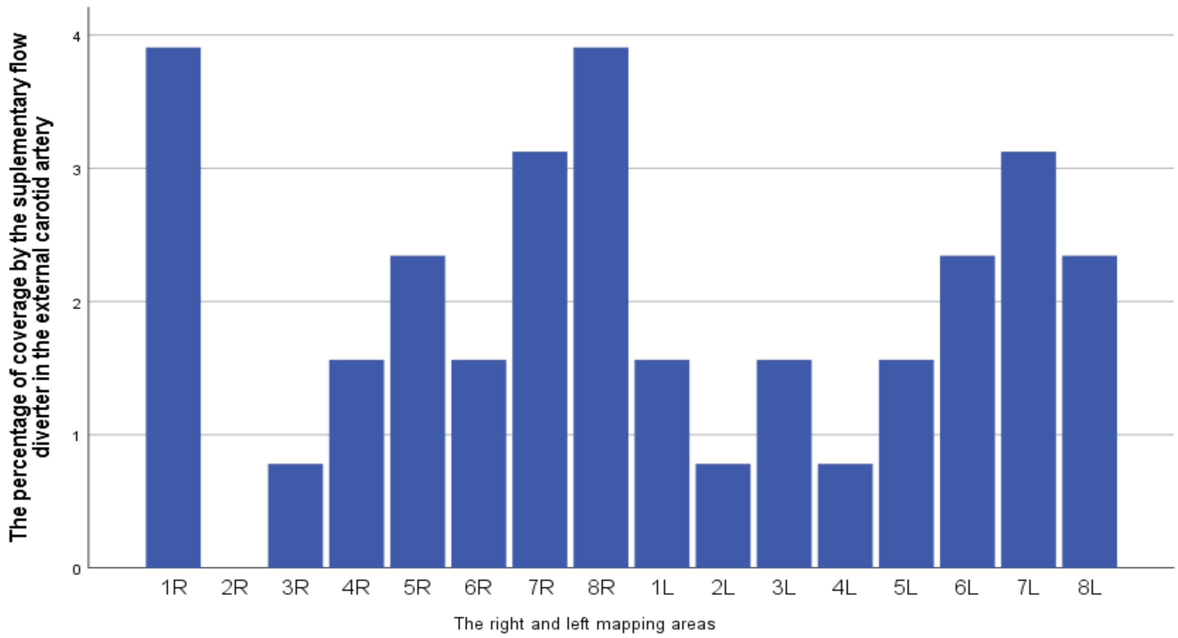


Figure 7.14: The lumen coverage of the supplementary flow diverter in the external carotid artery.

1R–8R indicated mapping areas in the right Carotid Bifurcation.1L–8L: mapping area in the left CB.

7.6.4 Internal carotid artery

The coverage of the internal carotid artery supplementary flow diverters is represented in Figure 7.15 in addition to the sequential supplementary flow diverter coverage. Figure 7.14 is an example of a supplementary flow diverter in an internal carotid artery that has a bend.

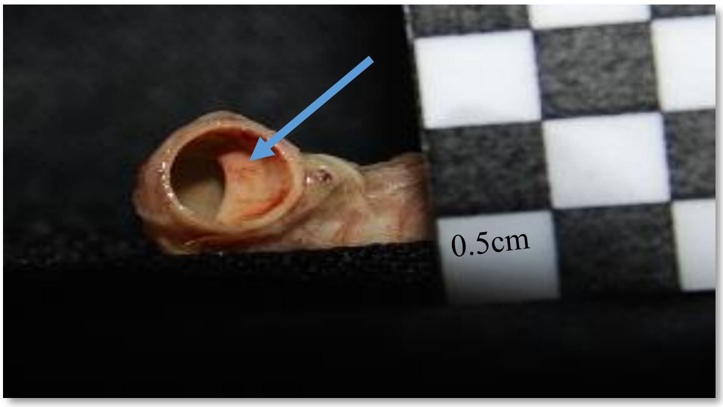


Figure 7.15: A supplementary flow diverter in the internal carotid artery which has a bend. Arrows indicate supplementary flow diverter.

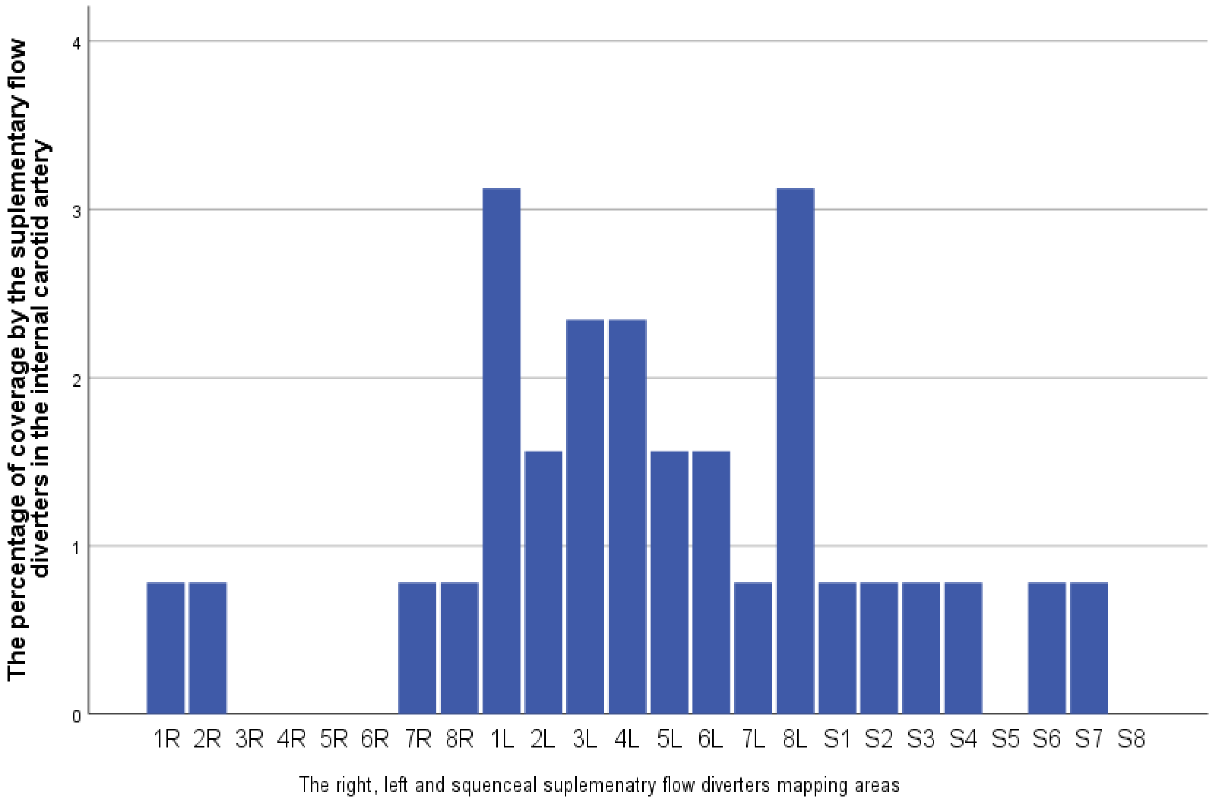


Figure 7.16: Coverage of the internal carotid supplementary flow diverters.
1R-8R indicated mapping areas in the right Carotid Bifurcation.1L–8L: mapping area in the left CB.

7.6.5 Folds in the common carotid artery

The coverage of the folds in the common carotid artery is illustrated in Figure7.17. Figure 7.16 illustrates that the folds in the common carotid artery were continuous with the flow diverter in some cases.

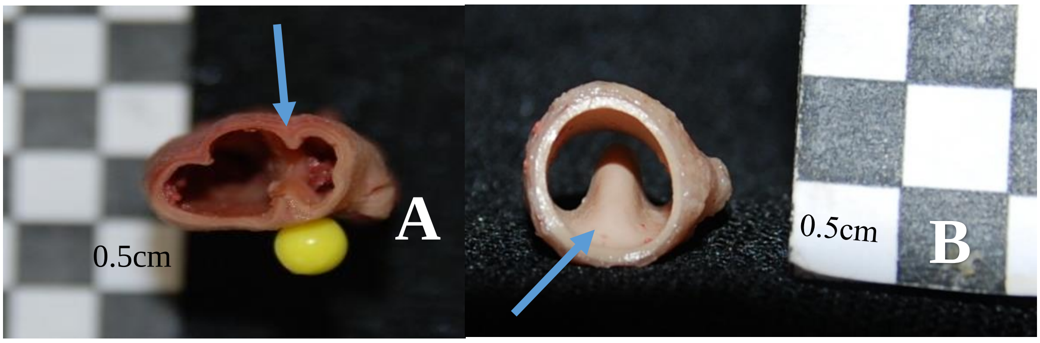


Figure 7.17: Folds in the common carotid artery. Arrow indicates folds.

A: fold in the common carotid which connects with the flow diverter. B: fold in the common carotid. that did not connect with flow diverter.

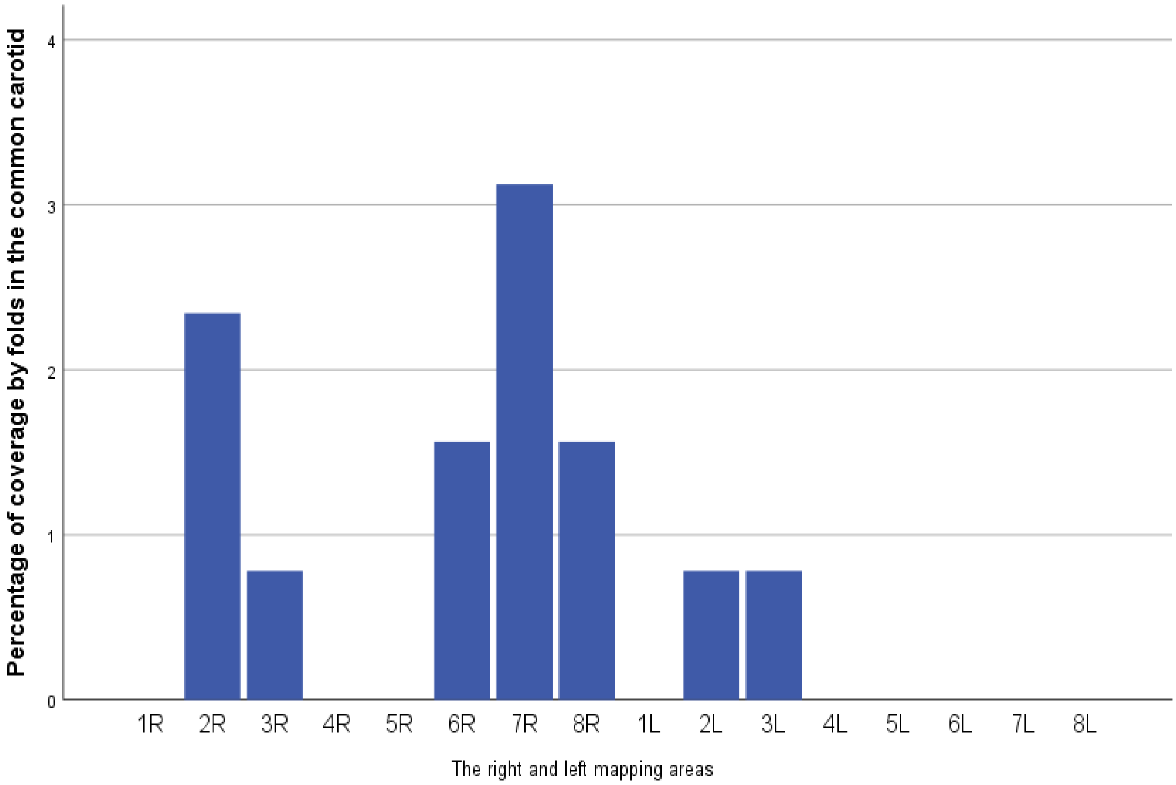


Figure 7.18: Coverage of the folds in the common carotid artery.

1R–8R indicated mapping areas in the right Carotid Bifurcation.1L-8L: mapping area in the left CB.

7.7 RELATIONSHIPS BETWEEN ANATOMICAL VARIATION

7.7.1 Correlation between the angle of the carotid bifurcation and the three measurements of height in addition to the correlation between the three measurements

7.7.1.1 The right carotid bifurcation

The angle of the carotid bifurcation is compared to the three different measurements used to determine the height of the bifurcation. The correlation between the three measurements was analysed. There was no significant correlation between the angle of the right carotid bifurcation and any of the three measurements related to the height of the carotid bifurcation. There was a significant correlation between the three measurements for the right CB. R1 and R2 had a significant correlation with a p = 0.0001 and a Pearson correlation of 0.706 indicating a positive linear correlation. R2 and R3 significant factor was p = 0.001 which indicates a significant correlation but has a Pearson correlation of 0.332 which indicates a weak positive linear correlation. R1 and R3 mirror this correlation with a p = 0.001 significant factor and a Pearson correlation factor 0.333. The Pearson positive linear correlations can be visually observed in Figure 7.19

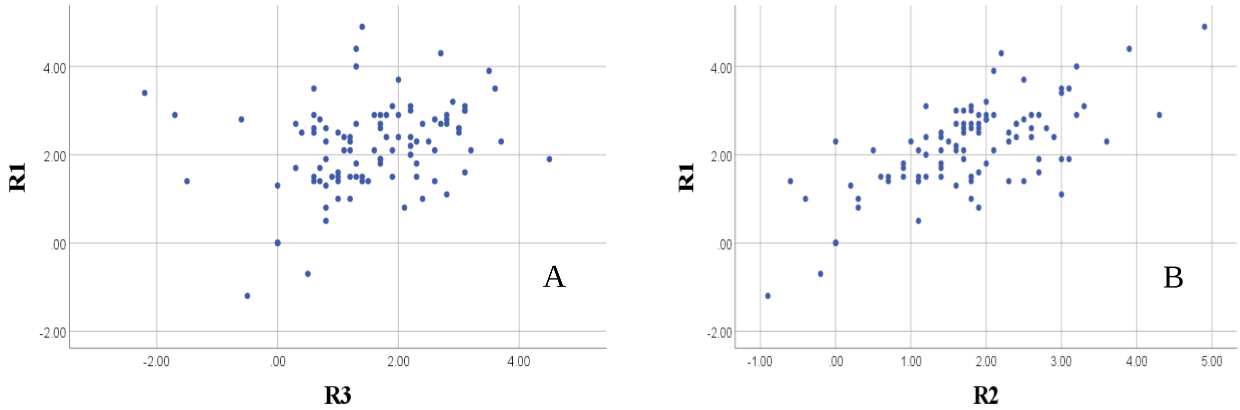


Figure 7.19: Correlation between height measurements.
A: R1 vs R2 Strong Pearson positive correlation. B: R1 vs R3 Weak Pearson positive correlation graph. R1: Shortest distance between the gonion and carotid bifurcation of the right side. R2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the right side. R3: The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the right side.

7.7.1.2 The left carotid bifurcation

The left carotid bifurcation displayed the same pattern as the right side. The angle of the left carotid bifurcation had no significant correlation with any of the three measurements related to the height of the carotid bifurcation. L1, L2 and L3 had a significant correlation with each other which was stronger on the left than on the right as each correlation has a significant factor of $p = 0.0001$. Pearson correlation factor however, played the main role in this analysis. The L1 and L2 Pearson correlation factor was 0.696 which indicated a positive linear factor. L1 and L3 Pearson correlation factor 0.382 indicating a weak positive trend. The Pearson correlation factor between L2 and L3 was 0.415, indicating a moderate positive linear correlation. This was visually represented in Figure 7.20.

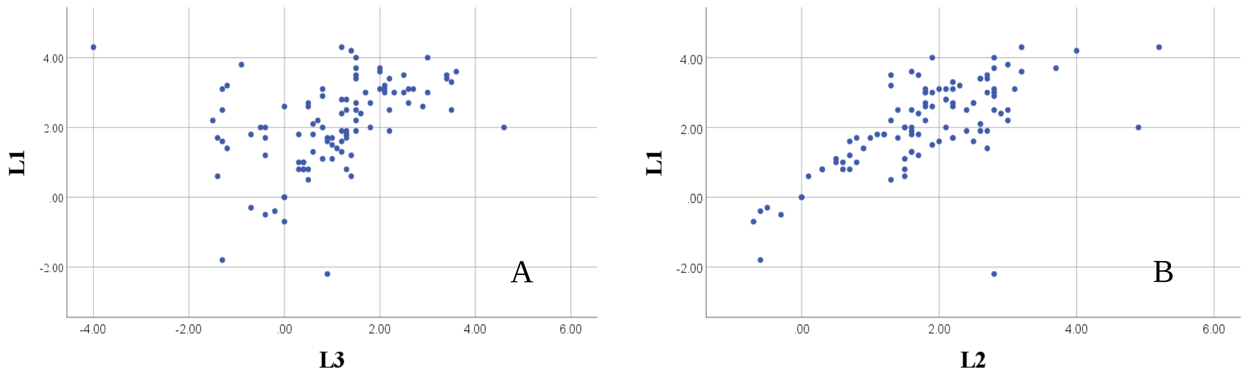


Figure 7.20: Correlation between height measurements.
A: L1 vs L3 Weak Pearson positive linear correlation. B: L1 vs L2: Strong Pearson positive linear correlation L1: Shortest distance between the gonion and carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side. L3: The distance between the angle of the mandible and the perpendicular distance as it reaches the level mandible on the left.

7.7.2 Correlation of the angle of the carotid bifurcation and the length of Carotid sinus

There was no significant correlation between the angle of the carotid bifurcation and the length of the carotid sinus. The Pearson correlation indicates no linear trend.

7.7.3 Correlation between the angle of the carotid bifurcation and the diameters of the carotid bifurcations in addition to the correlation between diameters

7.7.3.1 Right carotid bifurcation

There was no significant correlation between the angle of the right carotid bifurcation and any of the diameters of the right carotid bifurcation (Table 7.14). There was no linear correlation according to Pearson correlation factor for the angle of the right carotid bifurcation and any of the diameters of the right carotid bifurcation. There was however a significant correlation between all the diameters, but the Pearson correlation factor provided a more accurate depiction of the relationship between the diameters. The Pearson correlation also indicated that there was a link between the diameters which were positive linear correlations, however the strength varied. The diameter of the right external carotid artery (M4) had a weak positive linear correlation to other diameters. The diameter of the right internal carotid artery (M1) had a moderate positive linear correlation to the diameters of the carotid sinus both in the y-axis and x-axis, however, it favours the x-axis. The carotid sinus diameter of the right carotid bifurcation had a strong positive linear correlation between its y-axis and x-axis (M2). The diameter of the carotid sinus had a moderate positive linear correlation with both the diameter of the right internal carotid artery (M1) and the diameter of the right common carotid artery (M3). A weak linear correlation factor was found between the diameter of the right common carotid artery (M3) and the diameter of the right internal carotid artery (M1).

Table 7.14: Correlation between the angle of the right carotid bifurcation and the diameters of the right carotid bifurcations in addition to the correlation between diameters

		Angle	ICA (M1)	CS on the x-axis (M2)	CS on the y-axis (M2)	CCA (M3)	ECA (M4)
Angle	Pearson Correlation	1	0.112	0.037	-0.072	0.060	-0.034
	Sig. (2-tailed)		0.229	0.687	0.441	0.529	0.713
	N	119	118	118	118	112	118
ICA (M1)	Pearson Correlation	0.112	1	0.625**	0.542**	0.345**	0.304**
	Sig. (2-tailed)	0.229		0.000	0.000	0.000	0.001
	N	118	125	125	125	118	125
CS on the x-axis (M2)	Pearson Correlation	0.037	0.625**	1	0.655**	0.499**	0.289**
	Sig. (2-tailed)	0.687	0.000		0.000	0.000	0.001
	N	118	125	125	125	118	125
CS on the y-axis (M2)	Pearson Correlation	-0.072	0.542**	0.655**	1	0.508**	0.319**
	Sig. (2-tailed)	0.441	0.000	0.000		0.000	0.000
	N	118	125	125	125	118	125
CCA (M3)	Pearson Correlation	0.060	0.345**	0.499**	0.508**	1	0.383**
	Sig. (2-tailed)	0.529	0.000	0.000	0.000		0.000
	N	112	118	118	118	118	118
Diameter of the right *ECA (M4)	Pearson Correlation	-0.034	0.304**	0.289**	0.319**	0.383**	1
	Sig. (2-tailed)	0.713	0.001	0.001	0.000	0.000	
	N	118	125	125	125	118	125

**Correlation is significant at the 0.01 level (2-tailed). ICA: internal carotid artery; CS: carotid sinus, CCA: common carotid artery; ECA: external carotid artery; CB: carotid bifurcation.

7.7.3.2 Left carotid bifurcation

The angle of the carotid bifurcation and any of the diameters of the left carotid bifurcation had no significant correlation or linear correlation according to Pearson correlation factor (Table 7.15). There was a significant correlation between all the diameters, however the Pearson correlation factor provided a more accurate depiction of the relationship between the diameters. The Pearson correlations also indicated that there was a link between the diameters which were positive linear correlations, however the strength varied. The Pearson correlation for the left carotid bifurcation was stronger than the right carotid bifurcation although similar trends were observed in both. The diameter of the left external carotid artery (M4) had a weak positive linear correlation to other the diameters. The left carotid sinus both in the y-axis and x-axis, had a moderate positive linear correlation to the diameter of the left internal carotid artery (M1), however, x-axis Pearson correlation factor was stronger. A strong positive linear correlation was observed between the diameter on the y-axis and x-axis (M2) of the left carotid sinus. The diameter of the left internal carotid artery (M1) and the diameter of the right common carotid artery (M3) had a moderate positive linear correlation with the diameter of the carotid sinus (M2). A weak linear correlation factor was found between the diameter of the left internal carotid artery (M1) and the diameter of the left common carotid artery (M3).

Table 7.15: Correlation between the angle of the left carotid bifurcation and the diameters of the left carotid bifurcations in addition to the correlation between diameters.

		Angle	ICA (M1)	*CS on the x-axis (M2)	*CS on the y-axis (M2)	CCA (M3)	ECA (M4)
Angle	Pearson Correlation	1	0.007	00.086	0.019	-0.075	0.197*
	Sig. (2-tailed)		0.942	0.357	0.836	0.422	0.035
	N	116	116	116	116	116	115
*ICA (M1)	Pearson Correlation	0.007	1	0.631**	0.590**	0.587**	0.411**
	Sig. (2-tailed)	0.942		0.000	0.000	0.000	0.000
	N	116	123	123	123	123	122
CS on the x-axis (M2)	Pearson Correlation	0.086	0.631**	1	0.788**	0.606**	0.451**
	Sig. (2-tailed)	0.357	0.000		0.000	0.000	0.000
	N	116	123	123	123	123	122
CS on the y-axis (M2)	Pearson Correlation	0.019	0.590**	0.788**	1	0.588**	0.375**
	Sig. (2-tailed)	0.836	0.000	0.000		0.000	0.000
	N	116	123	123	123	123	122
CCA (M3)	Pearson Correlation	-0.075	0.587**	0.606**	0.588**	1	0.387**
	Sig. (2-tailed)	0.422	0.000	0.000	0.000		0.000
	N	116	123	123	123	123	122
ECA (M4)	Pearson Correlation	0.197*	0.411**	0.451**	0.375**	0.387**	1
	Sig. (2-tailed)	0.035	0.000	0.000	.000	00.000	
	N	115	122	122	122	122	122

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). ICA: internal carotid artery; CS: carotid sinus; CCA: common carotid artery; ECA- external carotid artery; CB- carotid bifurcation.

7.7.4 The angle of the carotid bifurcation compared to the general structure of the carotid bifurcation

The angle of the carotid bifurcation had no significant correlation with the general shape of the carotid bifurcation. This applied for both the left and right carotid bifurcations. The angle of the carotid bifurcation compared to bends in the internal and external carotid arteries was examined separately. There was no significant correlation between the angle of the carotid bifurcation and the bends in the internal and external carotid arteries. Although a mean for each type of bending could be calculated and the standard deviation was too large to be significant.

7.7.5 The general shape of the carotid bifurcation compared to the diameter and height of the carotid bifurcation

There was no significant correlation between the general shape of the carotid bifurcation, the length of the carotid sinus, the diameters of the carotid bifurcation and carotid sinus. The height of the carotid bifurcation determined by the three measurements was uninfluenced by the general shape of the carotid bifurcation.

7.7.6 Correlation between the length of the carotid sinus and the height of the carotid bifurcation

There was a significant trend between the length of the carotid sinus and the shortest distance between the gonion and the carotid bifurcation on both sides. It was a weak Pearson positive linear correlation; however, it was significant. The perpendicular distance from the level of the mandible to the carotid bifurcation and the distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible were uninfluential factors on the length of the carotid sinus. (Figure 5.3 p 35)

7.7.7 Correlation between the height and the diameter of the carotid bifurcation

There was a slight Pearson positive linear correlation of shortest distance between the gonion and carotid bifurcation (R1) of the right side and perpendicular distance from the level of the mandible to the carotid bifurcation (R2) on the right side with (M2 y-axis) diameter of the right carotid sinus on the y-axis (Table 7.16). There was a weak Pearson positive linear correlation between the diameter of the left common carotid artery (M3) and the shortest distance between the gonion and carotid bifurcation of the left side (L1) as illustrated in (Table 7.17).

Table 7.16: Correlation between height and diameter of the right carotid bifurcation.

		Right carotid Bifurcation							
		R1	R2	R3	M1	M2(x)	M2(y)	M3	M4
R1	Pearson Correlation	1	0.706**	0.333**	0.148	0.003	0.297**	0.078	0.032
	Sig. (2-tailed)		0.000	0.001	0.143	0.976	0.003	0.455	0.749
	N	102	102	102	100	100	100	94	100
R2	Pearson Correlation	0.706**	1	0.332**	0.082	-0.005	0.201*	0.047	0.074
	Sig. (2-tailed)	0.000		0.001	0.415	0.962	.045	0.652	0.464
	N	102	102	102	100	100	100	94	100
R3	Pearson Correlation	0.333**	0.332**	1	0.021	0.025	0.188	0.104	0.169
	Sig. (2-tailed)	0.001	0.001		0.838	0.803	0.061	0.316	0.092
	N	102	102	102	100	100	100	94	100
M1	Pearson Correlation	0.148	0.082	0.021	1	0.625**	0.542**	0.345**	0.304**
	Sig. (2-tailed)	0.143	0.415	0.838		0.000	0.000	0.000	0.001
	N	100	100	100	125	125	125	118	125
M2(x)	Pearson Correlation	0.003	-0.005	0.025	0.625**	1	0.655**	0.499**	0.289**
	Sig. (2-tailed)	0.976	0.962	0.803	0.000		0.000	0.000	0.001
	N	100	100	100	125	125	125	118	125
M2(y)	Pearson Correlation	0.297**	0.201*	0.188	0.542**	0.655**	1	0.508**	0.319**
	Sig. (2-tailed)	0.003	0.045	0.061	0.000	0.000		0.000	0.000
	N	100	100	100	125	125	125	118	125
M3	Pearson Correlation	0.078	0.047	0.104	0.345**	0.499**	0.508**	1	0.383**
	Sig. (2-tailed)	0.455	0.652	0.316	0.000	0.000	0.000		0.000
	N	94	94	94	118	118	118	118	118
M4	Pearson Correlation	0.032	0.074	0.169	0.304**	0.289**	0.319**	0.383**	1
	Sig. (2-tailed)	0.749	0.464	0.092	0.001	0.001	0.000	0.000	
	N	100	100	100	125	125	125	118	125

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed). M1: Diameter of the Internal Carotid Bifurcation. M2(x): Diameter of the Carotid Sinus on the x-axis. M2(y): Diameter of the Carotid Sinus on the y-axis. M3: Diameter of the Common Carotid artery. M4: Diameter of the External Carotid Artery. R1: Shortest distance between the gonion and carotid bifurcation of the right side. R2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the right side. R3: The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the right side.

Table 7.17: Correlation between the height and the diameter of the left carotid bifurcation.

Left carotid bifurcation

		L1	L2	L3	M1	M2(x)	M2(y)	M3	M4
L1	Pearson Correlation	1	0.696**	0.382**	0.180	0.109	0.099	0.228*	0.034
	Sig. (2-tailed)		0.000	0.000	0.076	0.286	0.330	0.024	0.743
	N	102	102	102	98	98	98	98	97
L2	Pearson Correlation	0.696**	1	0.415**	0.051	-0.026	0.015	0.176	-0.174
	Sig. (2-tailed)	0.000		0.000	0.621	0.802	0.886	0.083	0.089
	N	102	102	102	98	98	98	98	97
L3	Pearson Correlation	0.382**	0.415**	1	-0.044	-0.129	-0.098	0.071	-0.052
	Sig. (2-tailed)	0.000	0.000		0.668	0.205	0.337	0.484	0.612
	N	102	102	102	98	98	98	98	97
M1	Pearson Correlation	0.180	0.051	-0.044	1	0.631**	0.590**	0.587**	0.411**
	Sig. (2-tailed)	0.076	0.621	0.668		0.000	0.000	0.000	0.000
	N	98	98	98	123	123	123	123	122
M2(x)	Pearson Correlation	0.109	-0.026	-0.129	0.631**	1	0.788**	0.606**	0.451**
	Sig. (2-tailed)	0.286	0.802	0.205	0.000		0.000	0.000	0.000
	N	98	98	98	123	123	123	123	122
M2(y)	Pearson Correlation	0.099	0.015	-0.098	0.590**	0.788**	1	0.588**	0.375**
	Sig. (2-tailed)	0.330	0.886	0.337	0.000	0.000		0.000	0.000
	N	98	98	98	123	123	123	123	122
M3	Pearson Correlation	0.228*	0.176	0.071	0.587**	0.606**	0.588**	1	0.387**
	Sig. (2-tailed)	0.024	0.083	0.484	0.000	0.000	0.000		0.000
	N	98	98	98	123	123	123	123	122
M4	Pearson Correlation	0.034	-0.174	-0.052	0.411**	0.451**	0.375**	0.387**	1
	Sig. (2-tailed)	0.743	0.089	0.612	0.000	0.000	0.000	0.000	
	N	97	97	97	122	122	122	122	122

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). M1: Diameter of the Internal Carotid Bifurcation. M2(x): Diameter of the Carotid Sinus on the x-axis. M2(y): Diameter of the Carotid Sinus on the y-axis. M3: Diameter of the Common Carotid artery. M4: Diameter of the External Carotid Artery. L of CS: The length of the Carotid Sinus. L1: Shortest distance between the gonion and carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side. L3: The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the left side.

7.7.8 Correlation between the length of the carotid sinus and the diameters of the carotid bifurcation and carotid sinus

There was a significant moderate Pearson positive linear correlation between the diameters of the carotid bifurcation and the length of the carotid sinus (Table 7.18). The correlation was strongest for the diameter of the carotid sinus and the diameter of the internal carotid artery.

Table 7.18: Correlation between the length of the carotid sinus and the diameters of the carotid bifurcation and right carotid sinus.

		Right	Left
		The length of the CS	The length of the CS
M1	Pearson Correlation	0.533**	0.540**
	Sig. (2-tailed)	0.000	0.000
M2(x)	Pearson Correlation	0.630**	0.643**
	Sig. (2-tailed)	0.000	0.000
M2(y)	Pearson Correlation	0.579**	0.521**
	Sig. (2-tailed)	0.000	0.000
M3	Pearson Correlation	0.443**	0.478**
	Sig. (2-tailed)	0.000	0.000
M4	Pearson Correlation	0.438**	0.341**
	Sig. (2-tailed)	0.000	0.000

M1: Diameter of the Internal Carotid Bifurcation. M2(x): Diameter of the Carotid Sinus on the x-axis. M2(y): Diameter of the Carotid Sinus on the y-axis. M3: Diameter of the Common Carotid artery. M4: Diameter of the External Carotid Artery. L of CS: The length of the Carotid Sinus.

7.7.9 Correlation of flow diverters and supplementary flow diverters with the angle of the carotid bifurcation

7.7.9.1 Correlation between the angle of carotid bifurcation and the presence of the flow diverter with anatomical variation.

There was no significant correlation between the angle of carotid bifurcation and the presence of the flow diverters with anatomical variation. There was, however, a trend in the right carotid bifurcation to present with an anatomical variation of the flow diverter when a small angle was present (Figure 7.21 and 7.22).

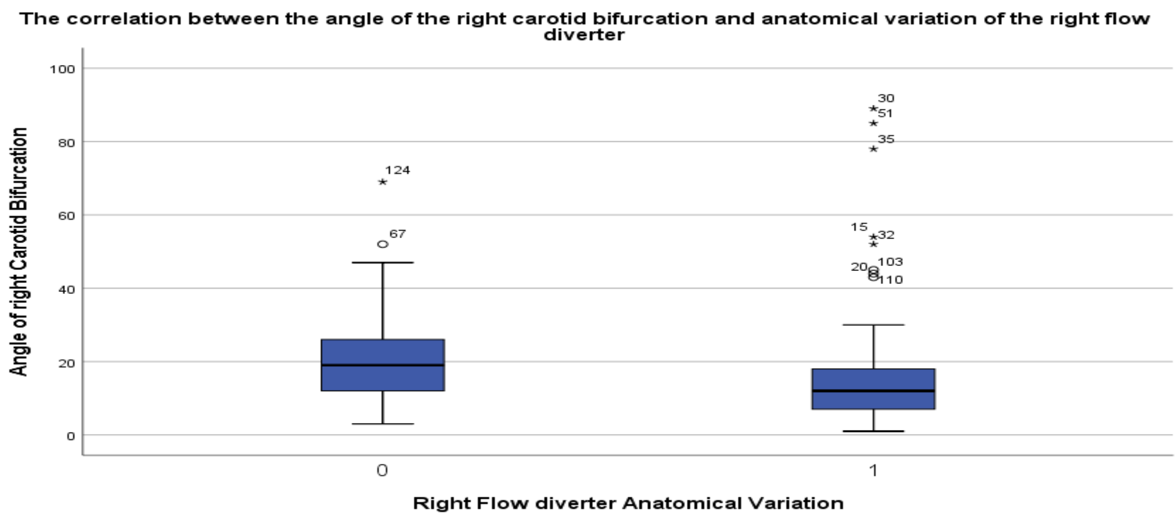


Figure 7.21: Box and whiskers diagram illustrating the correlation between the angle of the right carotid bifurcation and anatomical variation of the right flow diverter.

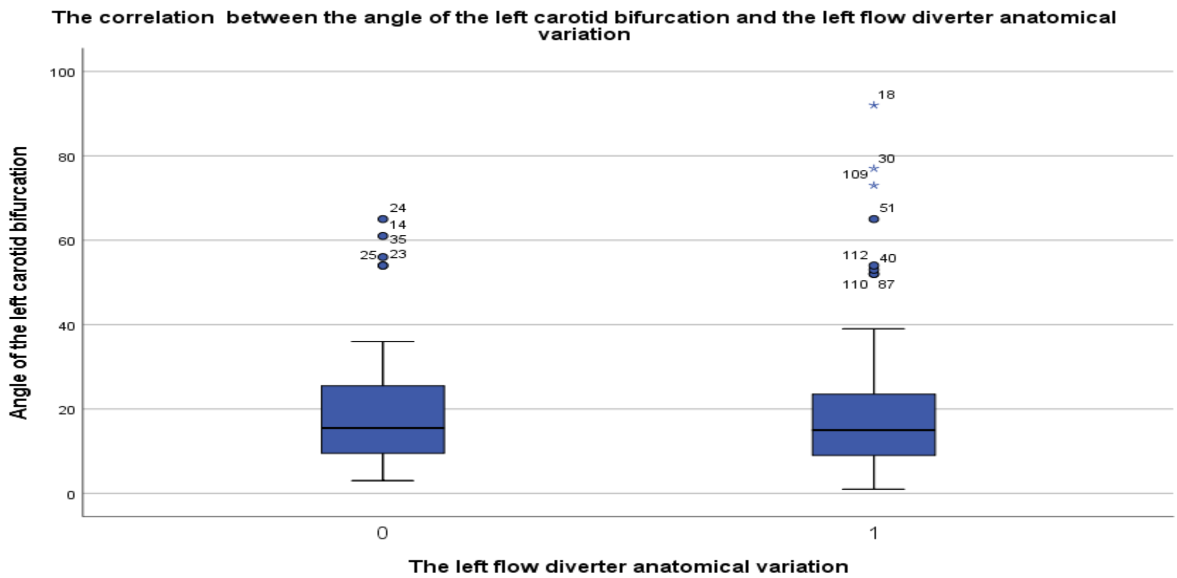


Figure 7.22: Box and whiskers diagram illustrating the correlation between the angle of the left carotid bifurcation and anatomical variation of the left flow diverter.

7.7.9.2 Correlation between the bends in the external carotid artery regarding supplementary flow diverters in the external carotid artery

The bends in the external carotid artery had an insignificant effect on the probability of a supplementary flow diverter in the external carotid artery. There was, however, a greater possibility for a supplementary flow diverter to occur when no bending occurred in the internal and external carotid arteries.

7.7.9.3 Correlation between the bends in the internal carotid artery regarding supplementary flow diverters in the internal carotid artery

The right carotid bifurcation with bends in the internal carotid artery exhibited supplementary flow diverters in the internal carotid artery, however this was not significant. The presence of secondary flow diverter was not influenced by the bending in the internal carotid artery. The bends in the internal carotid artery had no significant effect on the probability of a supplementary flow diverter in the internal carotid artery.

7.7.9.4 Correlation between the flow diverter anatomical variation and the supplementary flow diverter in the common carotid

The chance of a supplementary flow diverter presenting in the right common carotid if there was anatomical variation was not significant as determined by Fisher's Exact Test. Supplementary flow diverters in the common carotid were only found in left carotid bifurcations that exhibited an anatomical variation of the flow diverter. This trend, however, was not significant.

7.7.9.5 Correlation of external carotid artery presenting a supplementary flow diverter regarding the flow diverter presenting anatomical variation

There was a slight trend to suggest that there was an increased likelihood of a supplementary flow diverter in the external carotid if the right flow diverter presented with an anatomical variation. Left external carotid artery supplementary flow diverters were commonly found in the left carotid bifurcation with an anatomical variation in the flow diverter. Neither of these trends were significant.

7.7.9.5.1 Correlation of right internal carotid artery presenting a supplementary flow diverter regarding the right flow diverter presenting anatomical variation

Supplementary flow diverters were only found in the internal carotid artery when there was no anatomical variation in the right flow diverter, however, this was not significant.
The occurrence of a supplementary flow diverter in the internal carotid artery did not depend on the presence of anatomical variations at the carotid bifurcation. A secondary supplementary flow diverter in the internal carotid only occurred if there were anatomical variations in the flow diverter, however, this correlation was not significant.

7.7.9.5.2 Correlation of right common carotid artery presenting a fold regarding the right flow diverter presenting anatomical variation

Folds in the common carotid artery were found in the right carotid bifurcation with anatomical variation. This correlation between the two factors was significant with a Fishermen exact

P=0.041. The left carotid bifurcation presented folds in the common carotid artery only if there were anatomical variations, however, this was not significant.

7.8 The influence sex has on the anatomical variations

The angle of the carotid bifurcation was larger in females and was significant in accordance with Table 7.19 and 7.20. Males had longer carotid sinuses and this difference was significant. The diameter of the internal carotid artery was significantly larger in males and this difference was significant. Larger diameters were observed in all male carotid bifurcations for the M1 to M4 measurements of diameter. Males thus had a significantly lager carotid bifurcations compared to females. There was a trend for females to have a higher carotid bifurcation as their three measurements of height was smaller compared to male subjects; however, this trend was not significant.

Table 7.19: Characteristics of carotid bifurcations in males and females

Group Statistics

	Sex	N	Mean	Std. Deviation	Std. Error Mean
Angle of the Right CB	M	71	15.90	13.233	1.570
	F	48	22.42	19.655	2.837
Angle of the Left CB	M	69	15.88	10.078	1.213
	F	47	26.64	23.068	3.365
The length of the right CS (mm)	M	75	1.8133	0.42246	0.04878
	F	50	1.6420	0.39491	0.05585
M1 Right CB	M	75	6.7930	1.23562	0.14268
	F	50	6.0717	1.29512	0.18316
M2(x) Right CB	M	75	9.3577	1.98284	0.22896
	F	50	8.1059	1.72019	0.24327
M2(y) Right CB	M	75	7.9573	1.60308	0.18511
	F	50	6.9178	1.44955	0.20500
M3 Right CB	M	71	8.8024	1.50230	0.17829
	F	47	7.7311	1.28881	0.18799
M4 Right CB	M	75	6.9612	1.45840	0.16840
	F	50	6.2557	1.34794	0.19063
The length of the right CS (mm)	M	73	1.9548	0.42428	0.04966
	F	50	1.6680	0.40780	0.05767
M1 Left CB	M	73	7.2339	1.41318	0.16540
	F	50	6.3038	1.26869	0.17942
M2(x) Left CB	M	73	9.9782	1.80697	0.21149
	F	50	8.4604	1.71979	0.24322
M2(y) Left CB	M	73	8.3717	1.59782	0.18701
	F	50	7.1886	1.56158	0.22084
M3 Left CB	M	73	9.0465	1.43054	0.16743
	F	50	8.0437	0.95950	0.13569
M4 Left CB	M	73	7.0532	1.34976	0.15798
	F	49	6.6833	1.61006	0.23001
R1	M	64	2.1766	1.15164	0.14395
	F	38	2.0289	0.85200	0.13821
L1	M	64	2.0859	1.35317	0.16915
	F	38	2.0263	1.15142	0.18679
R2	M	64	1.7953	1.19926	0.14991
	F	38	1.6447	0.73694	0.11955
L2	M	64	1.8969	1.17702	0.14713
	F	38	1.6500	0.91141	0.14785
R3	M	64	1.6000	1.14504	0.14313
	F	38	1.3842	1.21800	0.19759
L3	M	64	1.0266	1.23587	0.15448
	F	38	0.9263	1.59148	0.25817

M1: Diameter of the Internal Carotid Bifurcation; M2(x): Diameter of the Carotid Sinus on the x-axis; M2(y): Diameter of the Carotid Sinus on the y-axis; M3: Diameter of the Common Carotid artery; M4: Diameter of the External Carotid Artery; L of CS: Length of the Carotid Sinus. L1: Shortest distance between the gonion and carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side ; L3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level mandible on the left side R1: Shortest distance between the gonion and carotid bifurcation of the right side R2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the right side R3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level mandible on the right side. M:Males ; F:Females.

Table 7.20:Results comparison between males and females.

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Right Angle	EV assumed	7.548	0.007	-2.162	117	0.033	-6.515	3.013	-12.482	-0.548
	EV not assumed			-2.009	75.462	0.048	-6.515	3.243	-12.974	-0.056
Left Angle	EV assumed	34.054	0.000	-3.427	114	0.001	-10.754	3.138	-16.971	-4.538
	EV not assumed			-3.007	58.075	0.004	-10.754	3.577	-17.914	-3.594
Length CS	EV assumed	0.201	0.655	2.279	123	0.024	0.17133	0.07517	0.02255	0.32012
	EV not assumed			2.311	109.921	0.023	0.17133	0.07415	0.02438	0.31829
M1 Right CB	EV assumed	0.496	0.483	3.137	123	0.002	0.72135	0.22998	0.26611	1.17658
	EV not assumed			3.107	101.711	0.002	0.72135	0.23217	0.26082	1.18187
M2(x) Right CB	EV assumed	1.292	0.258	3.642	123	0.000	1.25175	0.34372	0.57139	1.93212
	EV not assumed			3.747	114.675	0.000	1.25175	0.33407	0.59000	1.91350
M2(y) Right CB	EV assumed	0.089	0.766	3.688	123	0.000	1.03948	0.28185	0.48158	1.59738
	EV not assumed			3.763	112.123	0.000	1.03948	0.27620	0.49222	1.58674
M3 Right CB	EV assumed	0.976	0.325	4.008	116	0.000	1.07125	0.26730	0.54182	1.60067
	EV not assumed			4.135	108.357	0.000	1.07125	0.25909	0.55770	1.58479
M4 Right CB	EV assumed	0.177	0.675	2.730	123	0.007	0.70553	0.25842	0.19400	1.21705
	EV not assumed			2.774	110.685	0.007	0.70553	0.25436	0.20148	1.20957
The length of the right CS (mm)	EV assumed	0.171	0.680	3.740	121	0.000	0.28679	0.07667	0.13500	0.43859
	EV not assumed			3.768	108.138	0.000	0.28679	0.07610	0.13594	0.43765
M1 Left CB	EV assumed	0.206	0.651	3.735	121	0.000	0.93014	0.24902	0.43714	1.42314
	EV not assumed			3.812	112.418	0.000	0.93014	0.24403	0.44666	1.41363
M2(x) Left CB	EV assumed	0.050	0.823	4.666	121	0.000	1.51785	0.32532	0.87379	2.16192
	EV not assumed			4.709	108.787	0.000	1.51785	0.32231	0.87904	2.15667
M2(y) Left CB	EV assumed	0.256	0.613	4.071	121	0.000	1.18310	0.29064	0.60771	1.75850
	EV not assumed			4.088	107.020	0.000	1.18310	0.28938	0.60943	1.75678
M3 Left CB	EV assumed	6.239	0.014	4.331	121	0.000	1.00280	0.23152	0.54445	1.46115
	EV not assumed			4.653	120.963	0.000	1.00280	0.21551	0.57613	1.42947
M4 Left CB	EV assumed	0.798	0.373	1.372	120	0.173	0.36990	0.26953	-0.16376	0.90356
	EV not assumed			1.326	90.537	0.188	0.36990	0.27904	-0.18441	0.92421
R1	EV assumed	2.084	0.152	0.686	100	0.494	0.14762	0.21519	-0.27932	0.57455
	EV not assumed			0.740	95.095	0.461	0.14762	0.19956	-0.24856	0.54379
L1	EV assumed	1.159	0.284	0.227	100	0.821	0.05962	0.26259	-0.46136	0.58060
	EV not assumed			0.237	87.864	0.814	0.05962	0.25199	-0.44117	0.56041
R2	EV assumed	8.193	0.005	0.699	100	0.486	0.15058	0.21548	-0.27692	0.57807
	EV not assumed			0.785	99.850	0.434	0.15058	0.19174	-0.22984	0.53099
L2	EV assumed	2.031	0.157	1.110	100	0.270	0.24687	0.22248	-0.19451	0.68826
	EV not assumed			1.184	93.001	0.240	0.24687	0.20858	-0.16733	0.66108
R3	EV assumed	0.000	0.983	0.899	100	0.371	0.21579	0.24013	-0.26063	0.69221
	EV not assumed			0.884	74.045	0.379	0.21579	0.24398	-0.27035	0.70193
L3	EV assumed	1.800	0.183	0.355	100	0.723	0.10025	0.28224	-0.45972	0.66021
	EV not assumed			0.333	63.461	0.740	0.10025	0.30086	-0.50089	0.70139

M1: Diameter of the Internal Carotid Bifurcation. M2(x): Diameter of the Carotid Sinus on the x-axis. M2(y): Diameter of the Carotid Sinus on the y-axis. M3: Diameter of the Common Carotid artery. M4: Diameter of the External Carotid Artery. L of CS: Length of the Carotid Sinus. L1: Shortest distance between the gonion and carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side. L3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the left side. R1: Shortest distance between the gonion and carotid bifurcation of the right side. R2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the right side. R3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the right side. EV: Equal variance.

7.8.1 Internal anatomical variation compared to sex

Internal anatomical variations of the flow diverter in the right carotid bifurcation were more likely to occur in males than in females at a ratio of 3:2. This was a significant correlation with a p-value of 0.021. The left carotid bifurcation mirrors the right with a trend of males being more likely to present with anatomical variation of flow diverters at the carotid bifurcation; however, this trend was not significant in the left carotid bifurcation as it had a p-value of 0.452.

7.8.2 Supplementary flow diverter compared to sex

Females were more likely to exhibit supplementary flow diverters in the common carotid artery at the right carotid bifurcation; however, this trend was not significant. The left carotid bifurcation exhibited no significant difference between males and females presenting with supplementary flow diverters in the common carotid artery.

There was no significant difference in the probability of males and females presenting with supplementary flow diverters in the external carotid artery. At the right carotid bifurcation, males had a higher prevalence. However, at the left carotid bifurcation females had a higher prevalence.

There was no significant difference in the probability of male and female presenting with supplementary flow diverters in the internal carotid artery. It was equally possible to present with sequential/secondary supplementary flow diverters regardless of sex. However, this was a rare occurrence which was only observed in the left internal carotid artery.

7.8.3 Folds of the common carotid artery compared to sex

There was a trend that males were more likely to present with folds in the common carotid artery when compared to females. This trend was approaching significance on the right, however, neither side was significant.

7.8.4 General shape compared to sex and age

Sex and age had no significant influence on the general shape of the carotid bifurcation. This included examining individual factors such as the origin and orientation of the superior thyroid artery, origin of the ascending pharyngeal artery, the number of branches from the external carotid, orientation of these branches, in addition to the bending in either the internal or external carotid arteries. Trends were, however, observed in the origin of the superior thyroid artery.

7.8.4.1 Origin of the superior thyroid artery

There was no significant difference between male and female subjects' position of the right superior thyroid artery regarding the origin of the right superior thyroid artery (Table: 7:21). In both sex the superior thyroid was most commonly originating from the external carotid artery, proximal to the carotid bifurcation point of division. There was a non-significant trend that suggested that females were more likely to have the superior thyroid originating from the common carotid artery (Table7:21,Table: 7:22).

Table 7.21: Position of the right superior thyroid artery in males compared to females.

			Position: Right Superior Thyroid and Laryngeal artery						
			Absent	CCN	ECD	ECMID	ECP	NN	Total
Sex	F	Count	4	3	10	3	27	5	52
		% within Sex	7.7%	5.8%	19.2%	5.8%	51.9%	9.6%	100.0%
	M	Count	4	0	19	6	37	10	76
		% within Sex	5.3%	0.0%	25.0%	7.9%	48.7%	13.2%	100.0%
Total		Count	8	3	29	9	64	15	128
		% within Sex	6.3%	2.3%	22.7%	7.0%	50.0%	11.7%	100.0%

Table 7.22: Position of the left superior thyroid and laryngeal artery compared to sex

Crosstab

			Position: Left Superior Thyroid and Laryngeal artery						
			Absent	CCN	ECD	ECMID	ECP	NN	Total
Sex	F	Count	4	3	10	0	27	8	52
		% within Sex	7.7%	5.8%	19.2%	0.0%	51.9%	15.4%	100.0%
	M	Count	4	3	4	3	52	10	76
		% within Sex	5.3%	3.9%	5.3%	3.9%	68.4%	13.2%	100.0%
Total		Count	8	6	14	3	79	18	128
		% within Sex	6.3%	4.7%	10.9%	2.3%	61.7%	14.1%	100.0%

7.9 The influence of age on anatomical variation

7.9.1 Correlation between age and the three measurements used to describe the height of the carotid bifurcation

There was a weak Pearson positive linear correlation for R1, L1, R2 and L2 compared to age; however, this was not significant. The measurement R3 an L3 had very weak negative linear Pearson correlation with age which was not significant (Table:7.23).

Table 7.23: Correlation between age and the three measurements used to describe height of the carotid bifurcation.

Correlations

		R1	L1	R2	L2	R3	L3	Age
R1	Pearson Correlation	1	0.375**	0.706**	0.336**	0.333**	0.040	0.227*
	Sig. (2-tailed)		0.000	0.000	0.001	0.001	0.690	0.026
	N	102	102	102	102	102	102	96
L1	Pearson Correlation	0.375**	1	0.311**	0.696**	0.167	0.382**	0.172
	Sig. (2-tailed)	0.000		0.001	0.000	0.093	0.000	0.093
	N	102	102	102	102	102	102	96
R2	Pearson Correlation	0.706**	0.311**	1	0.484**	0.332**	0.112	0.192
	Sig. (2-tailed)	0.000	0.001		0.000	0.001	0.263	0.062
	N	102	102	102	102	102	102	96
L2	Pearson Correlation	0.336**	0.696**	0.484**	1	0.293**	0.415**	0.125
	Sig. (2-tailed)	0.001	0.000	0.000		0.003	0.000	0.223
	N	102	102	102	102	102	102	96
R3	Pearson Correlation	0.333**	0.167	0.332**	0.293**	1	0.595**	-0.035
	Sig. (2-tailed)	0.001	0.093	0.001	0.003		0.000	0.738
	N	102	102	102	102	102	102	96
L3	Pearson Correlation	0.040	0.382**	0.112	0.415**	0.595**	1	-0.100
	Sig. (2-tailed)	0.690	0.000	0.263	0.000	0.000		0.333
	N	102	102	102	102	102	102	96
Age	Pearson Correlation	0.227*	0.172	0.192	0.125	-0.035	-0.100	1
	Sig. (2-tailed)	0.026	0.093	0.062	0.223	0.738	0.333	
	N	96	96	96	96	96	96	119

**Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). L1: Shortest distance between the gonion and carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side. L3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the left side. R1: Shortest distance between the gonion and carotid bifurcation of the right side. R2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the right side. R3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the right side.

7.9.2 Correlation between age and angle, height and diameters of the carotid bifurcation, as well as the length and diameter of the carotid sinus

There was a very weak Pearson positive linear correlation between the length of the carotid sinus and the age of the person. This correlation was only significant at the right carotid bifurcation. The diameter measurements M1-M4 had a similar very weak Pearson positive linear correlation at both the left and right carotid bifurcations with age, as illustrated in Table 7.24. The age of the person in comparison to the angle of the carotid bifurcation exhibited the very weak Pearson positive linear correlation. The correlation of diameters and angle of the carotid bifurcation with age was significant.

Table 7.24: Correlation between age and angle, height and diameters of the carotid bifurcation, as well as the length and diameter of the carotid sinus.

		Right						
		CSL	M1	M2(x)	M2(y)	M3	M4	Angle
Age	Pearson Correlation	0.270**	0.295**	0.348**	0.471**	0.332**	0.247**	0.228*
	Sig. (2-tailed)	0.003	0.001	0.000	0.000	0.000	0.007	0.016
	N	117	117	117	117	110	117	110
		Left						
		CSL	M1	M2(x)	M2(y)	M3	M4	Angle
Age	Pearson Correlation	0.172	0.273**	0.384**	0.470**	0.362**	0.201*	0.434**
	Sig. (2-tailed)	0.066	0.003	0.000	0.000	0.000	0.032	0.000
	N	115	115	115	115	115	114	108

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed). CSL: Carotid Sinus Length. M1: Diameter of the Internal Carotid Bifurcation. M2(x): Diameter of the Carotid Sinus on the x-axis. M2(y): Diameter of the Carotid Sinus on the y-axis. M3: Diameter of the Common Carotid artery. M4: Diameter of the External Carotid Artery. L of CS: Length of the Carotid Sinus. L1: Shortest distance between the gonion and carotid bifurcation of the left side. L2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the left side. L3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the left side. R1: Shortest distance between the gonion and carotid bifurcation of the right side. R2: Perpendicular distance from the level of the mandible to the carotid bifurcation on the right side. R3: Distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible on the right side.

7.10 Internal anatomical variation compared to age

7.10.1 Anatomical variation of flow diverter at the carotid bifurcation compared to age

Age had no significant influence on the anatomical variation of the flow diverter in the right or left carotid bifurcation. The average age however was slightly older in specimens that presented with the anatomical variation of the flow diverter.

7.10.2 Supplementary flow diverter compared to age

Age had no significant influence on supplementary flow diverter presenting in the common carotid artery. The presence of a supplementary flow diverter was observed in a mean age group of 61 years on the right; however, on the left, the mean age group was 37 years. The age of patients presenting with supplementary flow diverters on the right side seems to be older and the left side younger.

There was a trend suggesting that being older increased the probability of the presence of supplementary flow diverters in the external carotid artery. This trend was significant ($p = 0.003$) for the right carotid bifurcation however the left carotid bifurcation was only approaching significance.

There was no significant correlation between age and the presentation of a supplementary flow diverter in the internal carotid artery. The mean age of cadavers with supplementary flow diverters was older than those that did not present with any supplementary flow diverters.

7.10.3 Folds of the common carotid artery compared to age

There was no significant correlation between age and folds presenting in the common carotid artery. The carotid bifurcation presenting with folds had a younger mean age (42 years on the right and 29 years on the left) than those that did not present with any folds in the common carotid.

8 CHAPTER 8: DISCUSSION

8.1 HEIGHT OF THE CAROTID BIFURCATION

The importance of the height of the carotid bifurcation lies in its proximity to the gonion as this affects the operative area. Previous studies have used a single measurement to illustrate the relationship between the carotid bifurcation and a gonion [17,34]. It can be argued that this method unreliable, as there was no indication other than distance to indicate the relationship with the gonion as a landmark. In a few studies, however, it was indicated that carotid bifurcation was superior, inferior or on the same plane as the gonion [1]. When it comes to the carotid bifurcation, the location is of high importance as it can affect the choice of approach and the risks involved. This study chose to make use of three measurements to clarify the position of the carotid bifurcation and to account for carotid bifurcations that were too difficult to access. Any negative measurements indicated an area that was difficult to access, and hence that could complicate surgery and increases the risk involved. The three measurements thus gave a complete picture of the relationship between the bony landmark (gonion) and the carotid bifurcation.

The Stellenbosch cadaver cohort had a higher carotid bifurcation when compared to the previous studies. The shortest distance between the gonion and carotid bifurcation was used as the standard measurement in previous studies [1,17,34,]. The height of the carotid bifurcation in the present study was 2.12 cm on the right side and 2.06 cm on the left. Mc Namara et al. [1]in an Irish population report an average height of 2.5 cm between the gonion and the carotid bifurcation. This was the closest report to the Stellenbosch study [1]. The Stellenbosch cadaver cohort had a smaller average distance between the gonion and carotid bifurcation than reports by Querry et al., Ozgur et al. and Mc Namara et al. [1,17,34]. Mc Namara et al. [1], however, did an angiographic study which could have led to misinterpretations when compared to a cadaveric study.

In the literature review, the height of the bifurcation was estimated at 1.79 cm inferior to the gonion. Thus, a third measurement of height was used here to determine if the carotid bifurcation was high, normal or low. In the current study, this distance was 1.74 cm on the right side and 1.80 cm on the left. Thus, in the Stellenbosch cadaver cohort a tendency of high bifurcation was observed as the average perpendicular distance between the gonion and the carotid bifurcation was smaller.

A study by Woldeyes et al. [4] suggested that the height of the carotid bifurcation occurs due to a genetic factor as the study had a large incidence of high carotid bifurcations in their Ethiopian population. The findings of the present study add weight to the suggestion that there is a genetic factors influencing the carotid bifurcation pattern as was suggested in the Ethiopian study [4]. However, the diversity in the present study population group can also account for the proximity to the McNamara et al. [1] study as there is an overlap in the population groups. More specific population group studies are needed to confirm or deny this claim. Hayashi et al. observed similar trends to Woldeyes et al. [4] with a larger incidence rate of high carotid bifurcations in a Japanese population group. This strengthens the suggestion that specific population groups have different heights of carotid bifurcations. The height of the Stellenbosch cadaver population being relatively high can be postulated to be affected by genetic factors that could be similar to those seen in the Woldeyes et al. [4] study.

The perpendicular distance from the level of the mandible to the carotid bifurcation gives an idea of how the carotid bifurcation is located superiorly or inferiorly to the gonion. The carotid bifurcation in the current study ranged between 0.9 cm superiorly and 5.2 cm inferiorly. In this study, carotid bifurcations that were superior to gonion were observed. These were, however, still accessible as they were located lateral to the gonion. This emphasized the need to measure the distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible, because this provided a more comprehensive picture on how accessible the carotid bifurcation was.

The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible gives an idea whether the carotid bifurcation is located anterior or posterior to the gonion. This measurement ranged from 4 cm anterior to 4.6 cm posterior. The cases where the carotid bifurcation was 4.6 cm posterior to the gonion, could indicate a high carotid bifurcation still being accessible for surgical intervention; however, this is risky due to the nerves in this area, there is still high-risk factor.

The height of the carotid bifurcation measured in the current study varied between left and right side. The height difference seen between left and right side was similar to that reported by

Klosek et al. [15] and could be attributed to the origin difference of the common carotid artery [5,8,9]. The smallest difference (0.07 cm) between left and right measurements were observed in perpendicular distance from the level of the mandible to the carotid bifurcation. Anterior and posterior variation in the position of the bifurcation in relation to the gonion was observed between the left and right sides (0.53 cm). This would indicate that the difference seen in the first measurement (0.06 cm) correspondenced to the superior and inferior height difference, however, anterior and posterior differences were greatest between sides. These differences in positions of the carotid bifurcation could be accounted to origins from the common carotid artery.

The correlation of the three measurements between left and right side was weak to moderate, however, it was significant. The three measurements had a Pearson positive linear correlation which, according to the measurement, would increase on both the left and the right side. The shortest distance between the gonion and carotid bifurcation's correlation between left and right was the strongest when the values were positive, however, the correlation for the other two measurements remained constant. The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible had the strongest correlation between left and right side. This would indicate a moderate Pearson positive linear correlation that influences the position of the carotid bifurcation being anterior or posterior to the gonion as it increases on both the right and left side. All three measurements increase both on the left and right sides, however, the relationship of the increase depends on the correlation.

The correlation between the three measurements was significant as indicated by Pearson positive linear correlations. A strong correlation existed between R1 and R2, however, a weak correlation existed between R2 and R3, and R1 and R3. This was mirrored in the left carotid bifurcation. These correlations indicate that the height of the bifurcation is mainly determined by the superior and inferior distances and is minimally affected by the anterior and posterior location.

The influence of sex on the height of the carotid bifurcation was not significant. However, there was a trend that females had higher carotid bifurcations compared with the males

Age had a weak Pearson correlation suggesting that measurements of the height of the carotid bifurcation slightly increase over time as the blood vessels elastic fibre weaken and elongate.

This would mean that the height of the bifurcation lowers with age, but only slightly and over a long period of time.

8.2 ANGLE OF THE CAROTID BIFURCATION

The increase in the angle of the carotid bifurcation affects various factors. The risk of plaque development increases with the tortuous and angled vessels due to the turbulent flow [43]. The current study observed a mean angle for the right carotid bifurcation of 18.53° and 20.20° for the left carotid bifurcation. This would suggest that the left carotid bifurcation had a higher risk of plaque development. Left and right side had a moderate Pearson linear correlation which was significant. However, the correlation was stronger in smaller angle and became weaker as the angle increased. This suggested that the variation between left and right side increased. The increase of the angle of the carotid bifurcation affects the correlation and increases the risk of plaque to development.

De Syo et al. [35] observed a correlation between the angle of bifurcation and the height of the bifurcation. A high bifurcation had smaller angles and a low bifurcation had larger angles. The present study did not confirm this correlation, as height had no significant influence on the angle of the carotid bifurcation regardless of which measurement was used. Females of the Stellenbosch cadaver cohort had a larger angle of bifurcation (24.53°) compared to males (15.89°) and this was significant. However, females had higher bifurcations than males and this corresponded to De Syo et al.'s [40] findings regarding the effect of height on the angle of bifurcation. This could indicate that sex has an influence on the relationship between height and angle of the carotid bifurcation. Males had a minimal difference (0.02°) between left and right side compared to females (4.42°). Thus, the angle of carotid bifurcation in females was more asymmetrical compared to males. This contradicts Goubergrits et al. [41] who observed a larger angle of bifurcation in males (67°) compared to females (51°). Therefore, the Stellenbosch cadaver cohort does not conform to previous findings and is highly influenced by sexual dimorphism.

The angle of the carotid bifurcation increased with age. The weak Pearson positive linear correlation suggests the angle of bifurcation slightly increase over time as the blood vessel elastic fibres weakens and stretches. Thus, a slight increase in the angle of the bifurcation could be observed over a long period of time.

8.3 GENERAL SHAPE

The current study provided insights on specific aspects of the general shape at the carotid bifurcation. The carotid bifurcation was analysed in a table format to allow a more in-depth look at how the individual features of the carotid bifurcation interact with each other and in additional to the interaction of these features with other aspects of the carotid bifurcation. The use of these more specific criteria showed that carotid bifurcation was very diverse and that very little correlation to the general shape occurred. Thus, this criterion was too specific to make general analyses; however, it provided an insight on individual features and their interactions.

The description of the Stellenbosch cadaver cohort of the superior thyroid artery matches the standard description in medical textbooks. The superior thyroid artery was most commonly originating from the external carotid artery proximal to the carotid bifurcation. This corresponded with the general description of the origin of the superior thyroid artery as illustrated in clinically-oriented anatomy text books [5,8,9]. The right carotid bifurcation of the superior thyroid artery was typically orientated superiorly or inferiorly; however, the left was commonly orientated in an inferior direction. The standard orientation of the superior thyroid artery was described to run anteroinferiorly [5]. The left carotid bifurcation corresponded to this orientation; however, the right was found to be equally as likely to have a superior orientation which could be due to the height difference observed in carotid bifurcation or be a population-specific variation. Bifurcation of the superior thyroid artery was observed on both the left and right side where the superior laryngeal artery originates from the carotid bifurcation instead of the superior thyroid artery. This occurred three times more often on the right side and could possibly be due to the height differences of the carotid bifurcation. Trifurcation of the superior thyroid at its origin was a rare occurrence (0.8%). This could be due to the lingual artery sharing an origin with the bifurcation of the superior thyroid artery. The superior thyroid artery displayed minor asymmetry on the left and right side; however, the origin and orientation for the most part corresponded to the standard description in literature.

Left and right superior thyroid artery had matching origins and orientation in 22.5% of cases in this study. This would indicate that the carotid bifurcation is asymmetrical in regard to the superior thyroid artery. The asymmetry could be due to the difference in origin between of the left and right common carotid arteries which influences the height [5,8]. The correlation of the origin and orientation of the superior thyroid artery yielded no clear trends. This could be due to the variation in height, a variation of surrounding structures, and the artery being variable in itself. There was no significant correlation seen in the superior thyroid artery.

The branches from the external carotid artery provide a picture of how the carotid bifurcation lies in relation to the surrounding structures. The general branches were located distally on the external carotid artery. The mean number of general branches from the external carotid was 2.38 on the right side and 2.53 on the left. This could be because the sections of carotid bifurcation removed were the same size; however, the location of the carotid bifurcation was variable. Thus, there was a greater area on the right external carotid bifurcation for the branches to originate from, leading to the branches being identifiable or branching off in a more distal region from the external carotid artery and therefore not recorded as ‘general’ branches. The minimum quantity of branches was zero and the maximum was six. This variability of general branches occurred due to the location of the carotid bifurcation. Low carotid bifurcations had fewer branches in the area of the carotid bifurcation that were removed, and the superior thyroid and ascending pharyngeal artery were identifiable, thus zero general branches recorded. A high carotid bifurcation had a smaller area for the general branches to branch from, thus more general branches were observed on the removed external carotid artery. This corresponds with what is reported in literature. The general branches were frequently orientated both medial and laterally. This corresponds to the description regarding the orientation of the branches of the external carotid artery in previous studies [5,8,9]. It is suggested that location affect the number of general branches and thus the orientation of the general branches.

Left and right general branches had matching orientation and numbers from the external carotid artery in 21.7% of cases in this study. Asymmetry is thus suggested in the general branches from the external carotid artery. The correlation between the orientation and numbers of branches was not significant. As the number of general branches increased, so did the chances of the orientation of these branches being both medial and lateral in terms of the carotid bifurcation. The general branches were frequently facing laterally when it was only on one side. This occurred when the general branches came off the distal part of the external carotid bifurcation, and where laterally orientated [5]. It was rare for carotid bifurcations with more than two general branches just to be orientated medially. This is due to general structure of the carotid bifurcation having only two branches that branches off anteriorly [5,8,9]. The left carotid bifurcation had an increased probability of multiple medial general branches in addition to an increase in posterior facing branches. This could be due the difference between …the left and right side as there is less of an area for the same arteries to branch off the external carotid artery. There was no significant correlation; however, there was a trend to suggest that a difference between left and right sides affected the number of general branches.

The ascending pharyngeal artery in this study did not originate on the proximal part of the external carotid artery but frequently originated on the distal part of the external carotid artery. It was indistinguishable between the general branches. Distal origins of ascending pharyngeal corresponded to standard descriptions in other studies [5,67]. There were two rare occurrences of duplications of the ascending pharyngeal artery and, according to literature [5,8,13], this occurs during embryological development as it interacts with the corresponding area of vascularization. These variations are frequently asymptomatic and go unnoticed [13]. Proximal and median origins of the ascending pharyngeal arteries occur due to the interaction with surrounding structures [13] and this changes as the location of the carotid bifurcation changes. The origin of the ascending pharyngeal artery in the present study predominately corresponds to the standard description [5,6,7].

The ascending pharyngeal artery had a 67.5% correlation between left and right side in this study when originating with the general branches. In addition, there were only 26.6% of asymmetry in the origin of the ascending pharyngeal artery. Thus, it can be concluded that there is was strong correlation between the origins of the left right ascending pharyngeal artery in this study.

Bending of the carotid bifurcation was not frequently observed. There were four different types of bending that occurred in this study in terms of which artery bends and the orientation of the bend as illustrated in Table 7.3 on p45. These bends are referred to as kinks in the literature, however their aetiology is still up for debate. The kinks described by Togay-Isikay [58] were seen in the internal carotid artery, however this study observed them in the external carotid artery as well. This corresponds with Cvetko et al. [48] who observed cases of kinks in the external carotid artery. The most frequently observed bend was in the internal carotid artery and this corresponds with literature [58]. This could be due to the high bifurcation site seen in the Stellenbosch cadaver cohort or due to the population group. Togay provided criteria, which were a modification of the Metz and Weibel-fields as shown in Table 2.4 on p27. According to these criteria, the kinks in this study were all classified as mild to moderate and ranged between grade one and two according to severity, with the tortuosity being described as C-shaped. The Stellenbosch cadaver cohort exhibited kinks in the external and internal carotid artery.

Kinks in the external and internal carotid were not a common anatomical variation as 78.3% of the specimen had no kinks on either side. There was only 21.7% of carotid bifurcations that showed signs of kinks and of that only 7.5% corresponded with the same type of kink bilaterally. Only 3.4% had kinks unilaterally. This means, that although kinks were rare, they were most frequently found bilaterally; however, the types of kinks only corresponded in 34.5% of the carotid bifurcations with kinks. Thus, there was a strong correlation between bilateral kinks, however a weak correspondence to the type of kinks.

The general shape of the carotid bifurcation had no significant correlation with the angle of bifurcation. Even when the individual factors were compared to the angle of bifurcation. This lack of correlation could be due to the branches on the carotid bifurcation being influenced by the surrounding vascularization and the kinks being pathology [41,57]. The kinks observed in the present study were not significantly influenced by angle of the carotid bifurcation. This was contrary to De Syo et al. [35] who observed that a larger angle is accompanied with increased frequency of elongation and kinking. This contradiction may be caused by differences in the study population. De Syo et al. [35] describe a mean angle at the bifurcation of 40.3° compared to an angle of 19.4° in this study.

Sex had no significant influence on the general shape of the carotid bifurcation in the present study. This included examining individual factors such as the origin and orientation of the superior thyroid artery, origin of the ascending pharyngeal artery, the number of branches on the external carotid, orientation of these branches, in addition to the bending in either the internal or external carotid arteries. A trend was, however, observed in the origin of the superior thyroid artery.

There was no significant difference between male and female subjects regarding the origin of the superior thyroid artery. In both sexes the superior thyroid was most commonly originating from the external carotid artery proximal to the carotid bifurcation. However, a non-significant trend suggested that females were more likely to have the superior thyroid originating from the common carotid. This could be due to females having higher bifurcations, thus shifting the location of the carotid bifurcation.

Age had no significant influence on the general shape of the carotid bifurcation. The general shape of the present study was not a factor that could be influenced by the weakening of elastic fibre associated with age. However, the kinks are postulated to be caused by age-related degeneration [58]. There were no trends in this study to support an association kinks with age-related degeneration.

8.4 DIAMETERS AT THE CAROTID BIFURCATION

The diameter at the carotid bifurcation in this study corresponded with previous reports in literature [17,43,44,45]. The carotid sinus was larger on the x-axis than the y-axis. This would indicate that the carotid sinus dilation is larger on the x-axis. The common carotid artery had the largest diameter and the diameter of the internal carotid was the smallest. This corresponded with the literature [17,43,44,45]. The left carotid bifurcation diameters were larger in this study. This would suggest that the left carotid bifurcation was slightly bigger than the right carotid bifurcation. A difference in origin may explain the size difference. Ozgur et al. [17] reported smaller diameters in the internal, external and common carotid artery than this study. Goubergrits et al. [41] reported smaller diameters in the external and common carotid artery, however, a larger diameter in the internal carotid artery compared to this study. The difference between the diameter of the internal and the external carotid artery in the study by Goubergrits et al. [41] was large and did not seem to correspond to any other studies. This might be due to the population group or the site of measurement of the internal carotid. Previous studies [18,48,50,52] chose to use diameter ratios to describe the distribution of the blood flow. The current study had smaller diameter ratios than Thomas et al. [42] and Ozgur et al. [17], however, larger diameter ratios than Shirli et al. [45] and Schulz and Rothwell [44]. Thus, it can be concluded that this study falls within the average range when regarding diameter ratios as an indication of blood flow. The study lies in the average range of diameters at the carotid bifurcation.

The correlation between left and right diameters of the carotid bifurcation in this study was significant. Each diameter illustrated moderate positive linear Pearson correlation, except the carotid sinus diameter on the y-axis which had a strong positive linear Pearson correlation. This can be due to the dilation of the carotid sinus expanding along the y-axis thus leading to a stronger correlation. This means that the diameters corresponded between left and right side.

Significant correlations were observed in this study between all diameters, however, the Pearson correlation factor provided a more accurate depiction. Each correlation observed was a Pearson positive linear correlation. The diameter of the external carotid artery (M4) had a weak positive linear correlation to other diameters. This was due to the external carotid artery having a different embryonic origin and being perceived as a branch [5,8,9,13]. The internal carotid artery was seen as continuation of the common carotid [5,8,9,13]; however, it had a weak correlation between diameters. This could be due to carotid sinus being located between the continuation of arteries. The carotid sinus diameters had a moderate positive linear correlation between both the internal and external carotid artery. The strongest correlation was observed between the x-axis and y-axis of the carotid sinus. Thus, the carotid sinus x-axis influenced the y-axis diameter, illustrating that dilation of the carotid sinus expanded on both axes in positive linear correlation.

The angle of the carotid bifurcation had no significant influence on the diameters of the carotid bifurcation. In the current study the diameters of the right and left carotid bifurcation relationship with height of the bifurcation differs. The right side had a significant correlation between R1 and R2 with carotid sinus y-axis diameter; however, this was a weak positive linear correlation. The left side had a weak positive linear trend between diameter of the left common carotid artery (M3) and the shortest distance between the gonion and carotid bifurcation on the left side (L1). Both these trends seen on the left and right did not give a clear illustration how the height interacted with the diameters. Possible reasons for the difference might lie in differences of their origin [13] resulting in height difference affects the diameter.

Regarding the influence of sex in this study, a trend was observed that the males had a larger diameters in the carotid bifurcation than females. The carotid bifurcation was larger in males compared to females. The sex difference in diameter ranged from 0.3699–1.5178 cm. The left side illustrating larger differences. The smallest difference was recorded in the external carotid artery; however, this could be associated with embryological origin [13]. The largest difference was observed in the carotid sinus diameters and more so in the x-axis than y-axis. This would suggest that the x-axis of the carotid sinus was influenced by sex and measuring a 1.37 cm difference between the sexes; however, this was not significant.

Age only had a weak Pearson positive linear correlation suggesting that the diameter of the carotid bifurcation slightly increased over time as the blood vessels’ elastic fibre weakened and elongated. This could mean that the diameter of the carotid bifurcation slightly increases over long periods of time, as the subject gets older.

8.5 LENGTH OF THE CAROTID SINUS

The length of the carotid sinus was larger on the left than on the right side in this study. This corresponded to the diameter of the left carotid bifurcation being larger than on the right. Thus, it could be postulated that as the diameter of the carotid sinus increased, so did its length. The length of the carotid sinus had a moderate positive linear Pearson correlation which was significant. This would mean that the length of the carotid sinus stays relatively similar on both sides.

The length of the carotid sinus was not influenced by the angle of the carotid bifurcation. The height of the bifurcation did not influence the length of the carotid sinus. A trend, however, was seen only between the first measurement and length of the carotid sinus in the left carotid bifurcation. This could be due to the height difference between the left and the right side due to the origin from the common carotid artery [13].

The present study illustrated a moderate Pearson positive linear correlation between the diameters of the carotid bifurcation and the length of the carotid sinus. The diameter of the carotid sinus on both axes increased as the length of the carotid sinus increased. Furthermore, the diameters of the internal, external and common carotid arteries affected the length of the carotid sinus. Thus, the diameters of the carotid bifurcation also determined the size of the carotid sinus.

There was a trend in the present study that males had a longer carotid sinus than females. This could be due to males having a larger carotid bifurcation in general as illustrated by the diameters at the carotid bifurcation. The difference of length of carotid sinus regarding sex was 0.17 cm on the right side and 0.29 cm on the left. Thus, the average difference in length on both two sides was 0.23 cm. The male and female carotid sinus lengths were asymmetrical; however, the left was slightly larger. This was due to the larger diameters seen on the left which influence the length of the carotid sinus, however, the difference was not significant.

Age had a weak Pearson positive linear correlation suggesting that length of the carotid sinus slightly increased over time as the elastic fibres weakened and elongated. This would mean that the length of the carotid sinus increases with age but only slightly and over a long period of time as the person ages.

8.6 INTERNAL ANATOMICAL VARIATION AT THE CAROTID BIFURCATION

The flow diverter at the carotid bifurcation naturally divide blood flow [41]; however, the risk of plaque development increases with turbulent flow [43]. The anatomical variation observed in the present study was an extension of the flow diverter into the lumen which could increase turbulent flow. This extension into the lumen frequently provided coverage of the ostium of the carotid sinus. A vascular surgeon who was consulted, observed this phenomenon in patients and regarded this as a normal variation. The Stellenbosch cadaver cohort presented with this extension of the flow diverter with a frequency of 60.2% on the right side and 57.8% on the left. This would mean that the extension in the flow diverter was a normal anatomical variation in the Stellenbosch cadaver cohort. This is similar to a report by du Plessis et al. [60] on flow diverters that provided partial coverage on the renal arteries ostium. They also reported that these flow diverters were more prominent in native African people. Thus, it can be postulated that flow diverters could be a population-specific phenomenon.

The coverage of the extension of the flow diverters observed in this study could affect the haemodynamics at the bifurcation. The coverage provided by flow diverters was often area-specific. An extension of this coverage was observed right around the ostium of the carotid sinus, however, at a low frequency. In some cases, the coverage was disjointed with an extension on the flow diverter and on the opposite wall of the carotid sinus. This could affect turbulence, blood distribution and the blood interaction with the stretch receptors in the carotid sinus.

The presence of anatomical variation of the flow diverter at the carotid bifurcation was not influenced by the angle of the bifurcation. There was an insignificant correlation between the angle of carotid bifurcation and the presence of the flow diverter with anatomical variation. There was, however, a trend in the right carotid bifurcation to present with anatomical variation of the flow diverter when a smaller angle was present. External factors did not affect the probability of anatomical variation at the carotid bifurcation. However, there was no previous reports on this matter found.

This study observed that males were more likely to present with an anatomical variation of the flow diverter than females; however, this trend was only significant on the right side. The reason is unclear. However, it could be postulated that the size difference between left and right may have contributed to the difference.

Age did not influence the presence of the anatomical variation of the flow diverter in this study. The average age, however, was slightly older in specimens that presented with the anatomical variation of the flow diverter. This observation was not significant.

Abnormal flow diverters were observed in the common, internal and external carotid arteries. Their presence ranged between 0.8–6.3% in the Stellenbosch cohort; however, no reports were found on these supplementary flow diverters. Abnormal flow diverters were reported to occur in the renal ostium [60] and incomplete valve structures were found between the IVP and the azygous veins [64]. Both studies [60,64] were done on an African population group, however no correlating information was reported in other population groups. The lack of information seen on these supplementary flow diverters could be due to rarity of this condition or it could be a a population specific phenomenon. The presence of these supplementary flow diverters was clearly visible as illustrated in Figure 7.11–7.16. However, supplementary flow diverters were never observed in patients at Tygerberg Hospital, whose population group correlates to the present studies, according to the consulting vascular surgeon. It has been speculated that the cause of these abnormalities: It was postulated that they might have pathological origins (atherosclerosis or Fibromuscular dysplasia) or that they might be artefacts caused by the embalming process. The embalming process, however, was highly unlikely to have caused the development of structures. Atherosclerosis provides a possible explanation; however, no literature was found to support this argument and histology will be needed to prove this. Fibromuscular dysplasia can cause the development of structures into the arteries however without histology this cannot be confirmed. Fibromuscular dysplasia, however, has only been reported in the internal carotid artery and the presence of these supplementary flow diverters in the external and common carotid, cannot be explained based on reports in the literature.

The right common and external carotid arteries were more likely to present with supplementary flow diverters than those on the left side. However, the internal carotid artery presented with supplementary flow diverters with a higher frequency on the left than the right side. The left internal carotid was the only artery that exhibited two sequential supplementary flow diverters and it occurred in two cases (1.6%), while 3.9% of cases had only a single supplementary flow diverter. Left and right bifurcation differ due to common carotid origins. This difference may favour the formation of supplementary flow diverters in the internal carotid artery on the left due to the higher bifurcation. Additionally, the common and external carotid artery formation may favour a slightly lower bifurcation as seen on the right side. The external carotid artery had the highest probability to present with supplementary flow diverters, while the internal carotid had the lowest. This could be due to branches on the external carotid artery; however, the reason behind their origins is still up for debate.

Coverage of supplementary flow diverters is highly variable. In the common carotid artery, the supplementary flow diverter favoured sections three and seven on the right and avoided section six and seven. On the left there, no section was favoured. The reasoning for a preference for certain sections is still unclear. The external carotid supplementary flow diverters favoured the medial side; however, the right anterior medially (section 1,8,7) and the left was posterior medially (section 6,7,8) as seen in Fig7.14 p 57. This could be caused by branches that originate from the external carotid artery. The internal carotid artery supplementary flow diverters favoured the anterior side on the right; however, the left favoured the posterior side for supplementary flow diverters. The sequential flow diverter coverage depended on the first flow diverter. A different section will then be covered sequential flow diverter with minimal overlap. Sequential flow diverters were proximal to the primary supplementary flow diverter.

The presence of supplementary flow diverters or sequential supplementary flow diverter presence was not influenced by kinks in the internal or external carotid arteries. There was, however, a greater probability for a supplementary flow diverter to be present when no bending occurred in the internal and external carotid arteries. The presence of supplementary flow diverter presence in the common carotid artery was not influenced by the presence of an anatomical variation of the flow diverter on the right side. However, flow diverters on the left were only present when anatomical variation of the flow diverter was observed but not really significant. This could be due to the rare occurrence of a supplementary flow diverter.

The external carotid artery exhibited a slightly increased likelihood for a supplementary flow diverter in the external carotid if a flow diverter with anatomical variation was present. This could suggest that the supplementary flow diverter in the external carotid artery is a response to changes caused by blood flow due to the anatomical variation; however, it was not significant. The internal carotid artery only had supplementary flow diverters when there was no anatomical variation in the flow diverter; however, this was not significant. Because this situation is the opposite of the external carotid artery, it could suggest that these supplementary flow diverters are in adaption to increased blood flow in a specific artery. This is due to the anatomical variation of the flow diverter changing the hemodynamic of the area as has been suggested by du Plessis et al. [60]. A secondary or sequential supplementary flow diverter in internal carotid only occurred if there was anatomical variation of the flow diverter; however, this was not significant.

Sex did not have a significant effect on the presence of supplementary flow diverters. This could be due to a number of causes. The presence of supplementary flow diverter was not sex-specific.

Age did not have a significant correlation with the presence of the supplementary flow diverters in the internal and common carotid arteries in the present study. The common carotid artery illustrated asymmetry when it came to the mean age of subjects with supplementary flow diverters. The mean age of the internal carotid arteries with supplementary flow diverters were older than those that did not present with supplementary flow diverters. Age was significantly correlated with the presence of an external carotid artery suggesting an increase in the probability of supplementary flow increases with age.

Folding in the common carotid artery was observed in 5.5% of cases on the right side and 0.8% of cases on the left. Folds occurred when the common carotid artery folded into the lumen and this could affect the haemodynamics. The coverage of folds favoured the section that proximally lined up with the flow diverter. Frequently it was observed that these folds could run in line with the flow diverter. No reports in the literature were found on this topic. This could be due to the embalming process when there is a weakening in the arterial wall of the common carotid artery.

Folds had a significant correlation with the presence of anatomical variation of the flow diverters on the right side; however, this was not significant on the left due to low frequency. This correlation was further accentuated by folds acting as a continuation of the flow diverter. Overall the presence of folds was dependent on the presence of anatomical variation of the flow diverter.

The influence of sex on folds was exemplified by a trend that females had a higher probability to present with folds in the common carotid compared to males. This trend was approaching significance on the right side but did not reach significance on either side. The lack of significance on the left could be due to low frequency of cases seen with this phenomenon.

Age had no influence on the probability of the common carotid presenting with folds. However, younger specimens had a higher probability to present with folds. Thus, the suggested weakening of the walls that was postulated to occur to create folds in the common carotid was not due to age-related degeneration.

9 CAPTER 9 LIMITATIONS

In cadaver studies the external diameter of the arteries are measured, while in MRA studies the internal diameters are measured. This can lead to discrepancies between reported diameters seen in literature. Therefore, these studies results were predominately compared to cadaveric studies to limit discrepancies.

The sex distribution in our experimental group was unequal with male cadavers accounting for 76 and females only 52. The biostatistical unit advised that the female group were large enough to be compared to the male specimens.

Cadavers were part of the anatomy department dissection programmes at Stellenbosch University during 2016 to 2018. A small incision on the neck was made to remove the carotid bifurcation prior to the start of dissections, to minimise damage to this area. However, in order not to interfere with the dissection programme, only a small opening in the carotid triangle was made. This made it difficult to accurately identify general branches from the external carotid. The identification process was further hindered by the proximity to the mandible and the high frequency of high bifurcations in this study. Thus, the main branches were identified better by comparing the distal branches of the external carotid as a group to avoid misidentification. Additionally, misrepresentation of the Stellenbosch cadaver cohort was avoided, without omitting features of the carotid bifurcation.

There were no previous reports on internal anatomical variation at the carotid bifurcation. However, this study identified a gap which will initiate research on this topic.

Previous studies used various landmarks to describe the height of the bifurcation. Thus, the landmarks were examined to determine the reliability of each of them. Additional measurements were added in this study to aid in understanding the exact location of the carotid bifurcation in relation of the gonion. This, however, limited comparison to some of the previous studies.

10 CHAPTER 10: CONCLUSION

The carotid bifurcation is an area of interest for various medical reasons. Diagnosis, prognosis and treatment rely on the precise anatomical knowledge of this area. A literature search exhibited gaps in certain features pertaining to knowledge on the carotid bifurcation and specifically on the South African population group. The aim of the study was to determine the anatomical variations at the carotid bifurcation in a Stellenbosch cadaver cohort. It was observed that the Stellenbosch cadaver cohort exhibited certain variations that correlated to what is reported in the literature.

This study illustrated that Stellenbosch cadaver cohort had a high prevalence of high bifurcation A trend was observed that females had a higher bifurcation compared to males and the left bifurcation was higher than on the right side. Age slightly increased the distance between gonion and the bifurcation over a long period of time as the elasticity of the arterial wall decreases and stretches with age.

The angle of bifurcation in this study was relatively small compared to previous findings [13,34,] and illustrated correlation between left and right angles; however, the correlation weakened as the angle increased. Female subjects and left carotid arteries of both sexes had larger angles of bifurcation and age the angle only increased with age over time. De Syo et al. [35] observed a correlation between the angle of bifurcation and the height of the bifurcation, in which high bifurcations had smaller angles and low bifurcations had larger angles. The current study only reflects the relationship between the angle and the height that was described in the literature [35] when the sex was considered. This could be due to a more pronounced sex dimorphism in the South African population.

The general shape of the carotid bifurcation in this study was asymmetrical and was not influenced by any other factors of the carotid bifurcation, sex or age. The description of the superior thyroid artery in the Stellenbosch cadaver cohort was in agreement with the literature. The superior thyroid artery commonly originated from the external carotid artery proximal to the carotid bifurcation and the orientation was inferiorly.

There was a trend the general branches exhibited a trend where the left carotid bifurcation had more branches. This suggested the distribution of branches proximal to the carotid bifurcation was affected by the height of the carotid bifurcation. The ascending pharyngeal artery in this study did not originate on the proximal part of the external carotid artery; rather, it frequently originated on the distal part of the external carotid artery and was often indistinguishable from the general branches. Kinks were observed in the internal and external carotid arteries and were not influenced by other factors. Arteries could kink in an anterior or posterior direction. Kinking in one artery did increase the probability of kinking in another artery. Kinking was rare and asymmetrical and ranged from mild to moderate with a c-shape. However, kinking occurred frequently bilaterally. Height did not influence the probability of kinks in the Stellenbosch cadaver cohort and this was contrary to a report by De Syo et al. [35].

The diameters of the internal carotid, external carotid and common carotid artery in addition to the diameter of the carotid sinus were larger on the left side in both sexes and in male subjects. The blood flow distribution ratio in this study corresponded on average with reports in the literature [17,41,44,45]. The external carotid had the weakest correlation with the other diameters, but this was due to the embryological origin of this vessel. The diameter was not influenced by angle or height, however, it slightly increased with age over time.

The length of the carotid sinus was larger on the left side in both sexes and in male subjects. The length of the carotid sinus correlated with the diameter. However, the main correlation was with the diameter of the carotid sinus in both axes. Height, angle and general shape of the carotid bifurcation did not affect the length of the carotid sinus. Age slightly increased the length of the carotid sinus over time.

Research on the internal anatomical variation at the carotid bifurcation is lacking. The Stellenbosch cadaver cohort presented with an anatomical variation of the flow diverter in addition to presenting with supplementary flow diverters and folds at the carotid bifurcation. Anatomical variation was observed as an extension of the flow diverter into the lumen, partially covering the internal carotid artery and occurred in 59% of cases. This anatomical variation correlated with what was observed in patients at Tygerberg Hospital in South Africa. The supplementary flow diverters occurred in the internal, external and common carotid arteries but this was a rare observation. The reason for the carotid bifurcation to present with supplementary flow diverters is still up for debate; however, pathological origins (atherosclerosis or fibromuscular dysplasia) was suggested. Folds were a rare occurrence in the common carotid artery and often acted as a continuation of the anatomical variation of the flow diverters. Internal anatomical variation was not influenced by any external anatomical variations observed at the carotid bifurcation. Males seem to have a higher prevalence of internal anatomical variations, but age did not affect the probability of any internal anatomical variation.

The importance of this study is to provide information of the Stellenbosch population group with regard to carotid bifurcation and how these variations interact and differ with regard to previous studies. It was observed that diameters of the carotid bifurcation and the length of the carotid sinus corresponded with each other. The angle and the height of the carotid bifurcation correlated with each other, but this correlation was sex specific whereas previous studies were not sex specific. This study provided novel information on the internal anatomical variations at the carotid bifurcation.

Further studies are needed on the internal anatomical variations and their effect on haemodynamics. Additionally, the reason why the carotid bifurcation presents with internal anatomical variation and what these flow diverters consist of, should be examined. A study should be done on why supplementary flow diverters have not been detected previously . How the embalming process affects arteries should also be investigated. Additionally, carotid bifurcation variations and genetic factors should be investigated in different population groups. The sexual dimorphism that affects the relationship between the angle and height of the carotid bifurcation in a South African population group should also be investigated further.

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12 APPENDIX

12.1 The basic format for worksheets

12.2 The worksheets for measurements height of the bifurcation

Table 12.1:

The perpendicular distance from bifurcation to the mandible		
Ref nr	Right	Left

Table 12.2

The distance between the angle of the mandible and bifurcation		
Ref nr	Right	Left

Table 12.3

The distance between the angle of the mandible and the perpendicular distance as it reaches the level of the mandible		
Ref nr	Right	Left

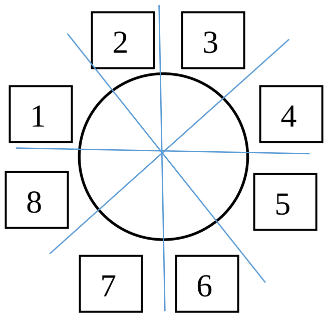
12.3 The worksheet for the measurements of the diameters of the arteries and carotid sinus as well as the length.

Table 12.4

Ref nr	Sex	Age	Race	Right						Left					
				L1	M1	M2 (x)	M2(y)	M3	M4	L1	M1	M2(x)	M2(y)	M3	M4

12.4 The mapping of coverage diagram and worksheet

Table 12.5



Ref nr.	L/R	1	2	3	4	5	6	7	8

12.5 Simple Sketch

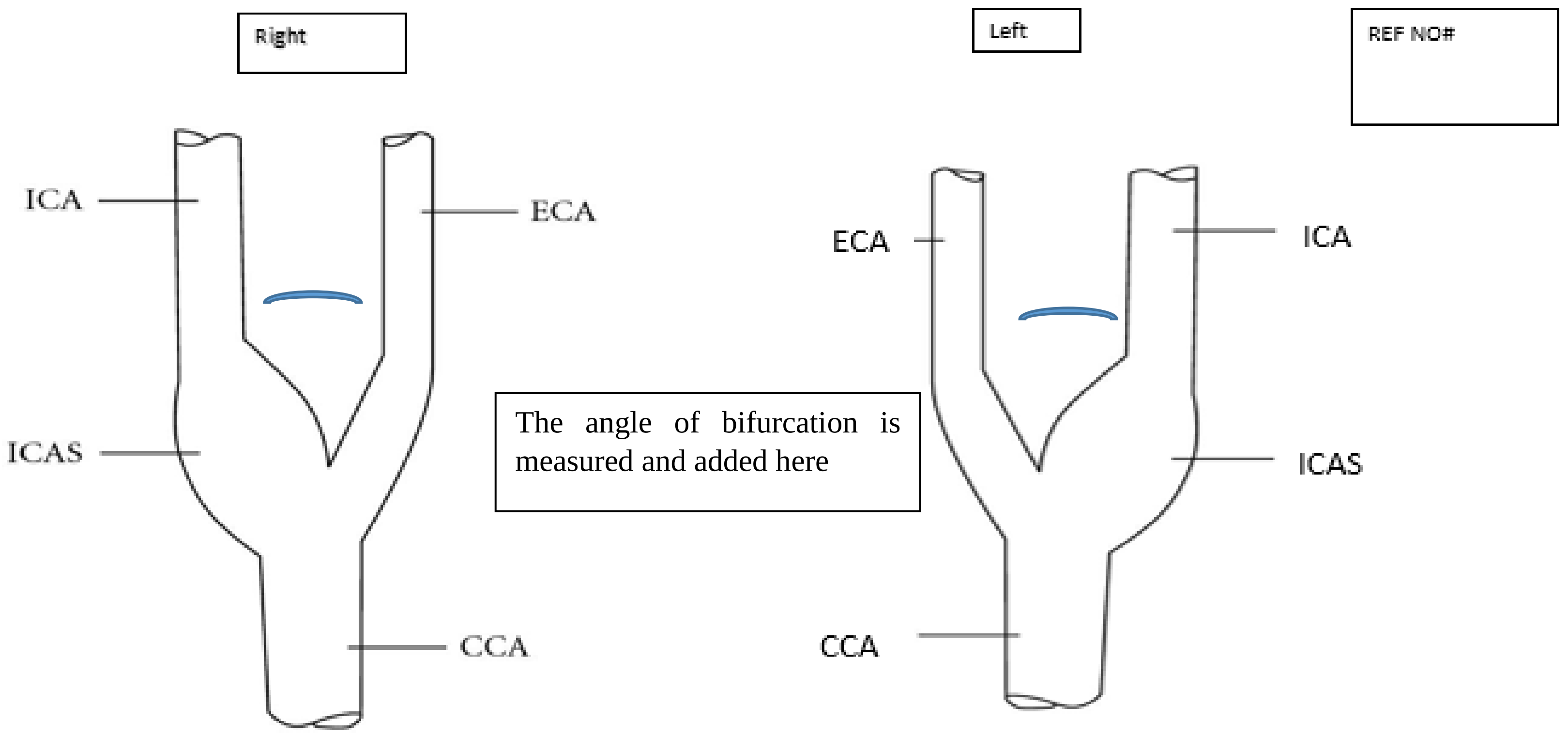


Figure 12.1: The simple sketch to draw variations, angle of bifurcation and variations observed.