A comparison of arterial measurements between a South African cadaver and living sample as affected by age, sex, height and weight

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Submitted in fulfilment of the requirements for the degree

Doctor of Philosophy

in

Department of Anatomy
School of Medicine
Faculty of Health Sciences
University of Pretoria
South Africa

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2020

UNIVERSITY OF PRETORIA

The financial assistance of the National Research Foundation towards this research is hereby acknowledged. Opinions expressed and conclusions arrived at, are those of the author and are not necessarily to be attributed to the National Research Foundation.

DECLARATION

I, **MARELIZE NAUDÉ**, declare that this thesis is my own work. It is being submitted for the degree of PhD in Anatomy at the University of Pretoria. It has not been submitted before for any other degree or examination at this or any other institution.

24 October 2020

ACKNOWLEDGEMENTS

This study would not have been possible without the assistance, guidance and special skills of the following people:

- Dr D Möhr, Specialist Anaesthetist and Extraordinary Lecturer in the Department of Anatomy at the University of Pretoria;
- Dr F Suleman, Clinical Head of Unit and Consultant in the Radiology Department at the University of Pretoria;
- Prof Z Lockhat, Chief Specialist and Head of the Radiology Department at the University of Pretoria;
- Dr A Musekiwa, Senior Lecturer in Biostatistics in the School of Health Systems and Public Health at the University of Pretoria;
- Prof P du Toit, Associate Professor in the Department of Physiology at the University of Pretoria.

Thank you very much. Your input, guidance and opinions are highly regarded and appreciated.

A very special word of thanks to Prof A van Schoor, a supervisor, mentor and friend who guided and supported me through this arterial journey since we first looked at the topic in the final year of my undergraduate studies.

Thank you to Mrs N Venter, whose excellent language and technical skills contributed to my immense pride in this dissertation.

To my parents, grandmother (who went to Heaven before she could see me graduate), parents-in-law and the rest of my family – thank you for your support and understanding through all the years of studying. We have completed this journey together.

Francois, my rock and partner in crime for the past 15 years – you were there for this journey from the start. I appreciate your love, guidance and words of encouragement when the journey felt too long.

I would also like to acknowledge those who volunteered to take part in this study as well as those who donated their bodies to science and research. To the families of the cadaveric donors used in this research, I would like to extend a heartfelt word of thanks. Thank you for

the selfless act of allowing us to utilise your loved ones in the search for answers. Through your contribution to science, we hope to achieve a better future for the patients to follow.

A heartfelt word of thanks to the Department of Anatomy at the University of Pretoria for allowing me to perform research and teaching me a love for the subject since I entered the Basic Medical Science building as a first year in 2009. Thank you to all the interns and other postgraduate students in the Department of Anatomy who assisted me on data collection days.

Last but not least, I would like to thank out Heavenly Father for ability and opportunity.

I can do all things through Him who strengthens me.
~Philippians 4:13~

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Abdominal aorta at level of coeliac trunk	(AC)
Abdominal aorta before terminal bifurcation	(AB)
Analysis of variance	(ANOVA)
Ascending aorta proximal to fibrous pericardium	(AA)
Body mass index	(BMI)
Chief Executive Officer	(CEO)
Computed tomography	(CT)
Digital Imaging and Communications in Medicine	(DICOM)
Infra-renal aorta	(IR)
Inner diameter	(ID)
Left brachial artery before bifurcation	(LBA)
Left common carotid artery at origin	(LCC)
Left common iliac artery at origin	(LCI)
Left coronary artery at origin	(LC)
Left femoral artery inferior to inguinal ligament	(LFA)
Left internal carotid artery distal to carotid body	(LIC)
Left popliteal artery in popliteal fossa	(LPA)
Left subclavian artery at origin	(LSC)
Magnetic resonance imaging	(MRI)
Outer diameter	(OD)
Right brachial artery before bifurcation	(RBA)
Right common carotid artery at origin	(RCC)
Right common iliac artery at origin	(RCI)
Right coronary artery at origin	(RC)
Right femoral artery inferior to inguinal ligament	(RFA)
Right internal carotid artery distal to carotid body	(RIC)
Right popliteal artery in popliteal fossa	(RPA)
Right subclavian artery at origin	(RSC)
Standard deviation	(SD)
Wall thickness	(WT)

SUMMARY

Knowledge of the normal arterial diameter at a given anatomical point is the first step towards quantifying the severity of cardiovascular diseases. According to several studies, parameters such as age, weight, height, Body Mass Index and sex, can explain morphometric variations in arterial anatomy. There is no specific differentiation point between normal age-related arterial changes and pathological changes. Therefore, it remains challenging to distinguish between physiological and pathological processes as structural changes in arteries are bound to occur with the advancement of age. There is no point at which an artery can be said to have stopped growing or developing and started to degenerate or become diseased. Hence the knowledge of changes in arterial anatomy with age is vital for understanding arterial pathology. Arterial dimensions studied by other researchers were measured on cadaveric material or diagnostic imaging methodologies such as magnetic resonance imaging, computed tomography and ultrasound. The comparability and compatibility of cadaveric and image diagnostic methodology measurements has often been fiercely debated; repeatedly raising the question on the validity of cadaveric research. The primary purpose of this study was thus to compare the measurements taken on cadaveric material with measurements taken with computed tomography and ultrasound. The aim was to establish whether there is a statistically significant difference between arterial measurements taken via these different approaches. In addition, the study also aimed to examine the effects of various demographic parameters on the arterial diameters of a South African population. Digital arterial measurements were taken on computed tomography images at selected arterial sites and the age and sex of each individual were noted. These computed tomography images, representative of a living South African population, were retrospectively selected from the database of diagnostic images at the Department of Radiology, Steve Biko Academic Hospital. The arterial diameter at the identified arterial sites was measured with the assistance of computer software. Digital measurements of arteries on ultrasound images were also measured at the selected arterial sites and the age, sex, weight, height and Body Mass Index of each individual were noted or calculated. Ultrasound images were taken on volunteers in the Department of Anatomy, University of Pretoria. Demographic information, including age, sex, weight and height, was gathered via a paper-based questionnaire. Body Mass Index was calculated. Newly available cadaveric data was added to the cadaveric database compiled during two pilot studies that took place in the Department of Anatomy at the University of Pretoria. The collected data allowed for the comparison of diameters measured with the different methodologies. The South African sample was divided into comparable age and sex groups that also allowed for the determination of correlations between the changes in arterial diameters and the changes in the demographic parameters. Analyses of these correlations answered questions such as

whether arterial diameter increase or decrease with an increase in age, height or weight. This study found that age is a vital demographic parameter when assessing change in arterial dimensions. Age was also found to influence muscular and elastic arteries differently. Even though some sexual dimorphism was noted, sex had a significantly smaller effect on arterial dimensions compared to age. Weight, height and BMI correlated weakly with a change in arterial dimension. Comparisons between the different populations indicated that cadaver measurements compared well to CT measurements as well as ultrasound measurements, but that CT measurements and ultrasound measurements were significantly different. Arterial pathology is a major contributor to cardiovascular disease and mortality. Data on normal arterial dimensions for a South African population is scarce, but essential when evaluating whether a dilatation or stenosis are pathological. Studies on the arterial morphology on a cadaver sample are thus comparable to living populations and support the premise that there is an age-related increase in the dilatation of the arterial lumen. The arterial diameter is a useful indicator of the vascular ageing process. This study provided us with valuable information regarding the validity and comparability of several arterial measuring methodologies as well as vital information regarding arterial changes in a South African population.

"A man is as old as his arteries"

~ Thomas Sydenham ~

"The English Hippocrates"

1. INTRODUCTION

The human vascular tree has the daunting mission of linking all the body's organ systems to nourish the bodily tissues and sustain human life. This multifaceted network of vessels and associated cells maintains blood flow and constantly adapts to acute and chronic changes in the human body. [1] As researchers gained more insight through the years, it became clear that the physiological process that regulates arterial development also enables the human vascular tree to adapt to changes in tissue elicited by exercise, ageing, growth and pathology. Research in arterial adaptation has provided tremendous insights into vascular diseases, cancer interventions, wound repair and tissue engineering. [1]

The cardiovascular system is the first organ system to function in an embryo and it continuously changes throughout life. [1,2] The primary functions of the cardiovascular system are to facilitate gas exchange, provide nutrients and eliminate waste from body cells in order to maintain growth and viability. [1]

The cardiovascular system consists of a four-chambered heart linked to the vascular tree through the pulmonary arteries and pulmonary veins that circulate the blood to and from the lungs as well as the descending aorta that circulates the blood through the rest of the body. The vascular tree can subsequently be subdivided into three main branches. [1,2] Firstly, the arterial branch that carries blood away from the heart, with larger arteries such as the pulmonary artery and the aorta feeding into progressively smaller arteries, arterioles, and capillaries. In contrast, the venous branch transports blood back to the heart by collecting it from capillaries and transporting it through progressively larger venules and veins. Finally, the lymphatic branch transports interstitial fluid from tissues and organs and returns it to circulation through ultimate drainage into the subclavian veins. The three vascular branches described form a closed blood system (where blood is kept separated from body tissues) called the circulatory system. [1,2]

The vessels of the circulatory system are composed of several different cell layers. The inner layer is called the endothelium and is made up of endothelial cells that surround the lumen of the blood vessel. Larger arteries and veins take on a complex structure, with the endothelium or tunica intima surrounded by a thick stabilising layer of smooth muscle cells called the tunica media and an outermost layer of connective tissue, collagen, and elastic fibres, called the tunica adventitia. This complex formation grants stability to the vessels while still allowing a dynamic response to changing metabolic demands. [1,2]

The cardiovascular system undergoes continuous adaptation and change triggered by tissue growth, including adipose or fat expansion or loss, muscle addition or atrophy, cyclic remodelling of the reproductive system, wound repair as well as pathological conditions, such as diabetes or cancer. The same physiological processes that regulate vascular development thus persist throughout life to maintain one of the most dynamic organ systems within the human body. [1,2]

Research has indicated that different levels of physical exercise or manual labour, as well as height, weight, sex, nationality, ancestry and age might influence arterial diameter and wall thickness. [1-5]

Structural changes in arteries are bound to occur with the advancement of age. A loss of compliance and increased wall stiffness are typical structural changes attributable to vascular ageing. Hypertension, a thinning arterial wall and an increased luminal diameter are factors causing increased stress on the arterial wall that, in turn, lead to undesirable cardiovascular perils. [1,3-7]

There is no specific differentiation point between normal age-related arterial changes and pathological changes. Due to the difficulty to distinguish between these physiological and pathological processes, there is no point at which an artery can be said to have stopped growing or developing and started to degenerate or becoming diseased. The knowledge of age-related changes in arterial dimensions is thus vital for the understanding of arterial pathology. [8-11]

1.1 The value of knowing normal arterial diameters in a clinical setting

Researchers have found a correlation between dilated peripheral arteries and aortic aneurysmal disease. The diameters of the femoral, popliteal, brachial, common carotid and internal carotid arteries were measured in living patients with aortic aneurysms and it was found that the mean peripheral diameter was significantly higher at all measurement sites. These findings support the hypothesis that patients with aortic aneurysmal disease have a generalised arterial dilatation that may be unrelated to factors such as atherosclerosis. [12,13] The importance of screening for aneurysmal disease is well established, as is the greater risk attached to males, especially those over the age of 65 years. The relationship between generalised arteriomegaly and the formation of aneurysms is now widely accepted. [14] The availability of normal values of arterial dimensions for a South African population are thus of

clinical importance to enable South African clinicians to determine when an artery becomes aneurysmal.

In aortic valve disease, the pathology leading to valve replacement can alter the annulus diameter, resulting in annular stenosis or dilatation. The aortic annulus is the diameter at the base of the aortic root. In these circumstances, an important pre-surgical decision is whether to adjust the size of the annulus to allow implantation of a normal sized valve or to use a replacement valve matching the size of the diseased valve. In both surgical scenarios, anatomical guidelines are needed for determining the correct arterial diameter. [15,16]

In 1953, Enos *et al.* made an early breakthrough in the understanding of the natural history of atherosclerotic cardiovascular disease when a 77% prevalence of coronary atherosclerosis was found among soldiers from the United States of America who were killed in the Korean War. [17-19] The study by Enos *et al*. transformed the understanding of the onset and development of cardiovascular disease by anatomically demonstrating that atherosclerosis can affect a sizable portion of young and fit individuals without clinical evidence of cardiovascular disease. [19,20] Follow-up studies during the war in Vietnam, as well as a number of autopsy studies in the civilian population, provided additional evidence that the onset of atherosclerosis may occur at an early age. [19-27]

Studies done during the more recent wars in Afghanistan and Iraq demonstrated that age-adjusted ischaemic heart disease mortality rates have declined in in the United States of America by 72% since the peak in 1968. [28,29] Ford *et al.* attributed this phenomenon to the reduction in risk factors and the expansion of therapies. [30,31] Since the publication of these studies, health policies in the United States of America for children and young adults in the general population [32,33] as well as the military population [34,35] have been aiming to reduce the risk of cardiovascular disease associated with risk factors such as hypertension, diabetes, cholesterol, and smoking. [19]

Throughout the abovementioned studies, age consistently produced the strongest correlation with atherosclerosis. Soldiers with atherosclerosis were approximately 5 years older than those without and those aged 40 years and older had about 7 times the prevalence for atherosclerosis as compared with those aged 24 years and younger. [19,36]

Pathological studies have shown a reduced arterial diameter in the early stages of atherosclerosis, although a compensatory physiological response can cause enlargement during later stages. Cardiovascular diseases cause physiological responses such as ectasia,

which is the dilatation of a tubular structure, increased myocardial demands and high-flow fistulae. [37-42] These physiological responses will result in an increased arterial diameter. This may be a widespread increase that is not limited to a specific arterial segment. It is therefore difficult to establish whether an arterial segment that appears normal, is truly normal. This highlights a problem with the conventional radiographic estimation of the severity of a cardiovascular disease. The percentage of stenosis is a ratio between the diameter of a narrowed arterial segment and the diameter of a normal arterial segment of a specific arterial site. Unfortunately, due the possible physiological responses, it becomes difficult to accurately assess normal arterial diameter in these cardiovascular patients. The clinical efficacy of the percentage of stenosis is therefore diminished. The solution to this dilemma is to find methods whereby normal arterial diameter, at a given anatomical point, may be predicted and used as normal reference to calculate the percentage of stenosis. [37-42]

Several researchers [7,14,15,37-56] have correlated arterial diameter with anatomical and demographic variables such as height, weight, age, sex, and body size. Despite differences in population groups, sample size, specimen preparation, sizing methods, and measuring techniques, all these studies have identified a correlation between growth of the body with age, increased weight and/or increased height, and arterial dimensions.

1.2 The effects of demographic variables on global populations

For a Brazilian population, Da Silva *et al*. found the diameter of the distal abdominal aorta to vary according to age, sex, height, and the amount of atherosclerosis on the aortic wall. The infra-renal aortic diameter was found to be greater in fresh (unembalmed) male cadavers than in fresh female cadavers in this Brazilian population and in both sexes the infra-renal aortic diameter increased with age. Also, in general, taller cadavers had larger aortic diameters in the Brazilian population. [37]

In a Korean study by Joh *et al.*, the infra-renal aorta was found to be 19.00 mm and 17.90 mm for male and females respectively. Measurements were done via ultrasound on a living population [57] Ouriel *et al*. studied a living American population via computed tomography (CT) and found the infra-renal diameter to be 23.00 mm in males and 19.00 mm in females. [58] For a living Turkish population studied by ultrasound, Sariosmanoglu *et al.* reported an infra-renal aortic diameter of 16.00 mm for males and 15.00 mm for females. [59] In the American population studied by Rogers *et al*., the infra-renal diameter was 19.30 mm for males and 16.70 mm for females in a CT study on a living population. [60]

The data studied by Rogers *et al.* was taken from the Framingham Heart Study – a study that was first started in 1948 and has been ongoing for more than 70 years to date. [61] In 2019 it was once again renewed for at least another 6 years. [62] Through the years, the Framingham Heart Study made important contributions to our understanding of cardiovascular disease and the associated risk factors. [61, 63-70] Studies from Framingham and other epidemiological cohorts contributed to a paradigm shift in the latter half of the 20th century - from a focus on treating individuals with established cardiovascular disease to the prevention of disease in those individuals at risk. [61]

In the 1960's, the Framingham Heart Study shed light on what we now refer to as cardiovascular risk factors, including hypertension, hyperlipidaemia, and diabetes mellitus.[61,63-70]

Patel *et al*. suggested that for an American population, weight is an important risk factor in the process of vascular ageing, as shown by enlarged abdominal aortic and common iliac artery diameters. [38] Patel *et al*. also found the common iliac arteries and abdominal aorta, before bifurcation, to be larger in males. This was especially prominent when looking at the inner diameter of each artery. [38] The study by Patel *et al*. was done on a living population via ultrasound. [38] Joh *et al.* also discovered sexual dimorphism in the Korean population and reported a right iliac artery of 12.20 mm in males and 11.70 mm in females. They reported a left iliac artery of 14.70 mm in males and 11.50 mm in females. [57]

Ilayperuma *et al*. highlighted sexual dimorphism in the diameters of the coronary arteries in a group of Sri Lankan adults. [39] The diameters were smaller in females than in males. The diameters of the coronary arteries and their branches were measured in apparently healthy hearts obtained from embalmed cadavers during routine gross anatomy dissections. [39]

In the embalmed East Indian cadaver population studied by Roy *et al.,* the left coronary artery showed a wide range of morphological variations, which could be of great clinical importance.[40] Difficulties may occur during performance of diagnostic procedures, coronary artery surgeries or prosthetic valve replacements. [40] Sass *et al*. found the correlations between age, morphologic parameters and arterial diameters to be dependent on sex and the specific arterial site in a living French population studied via ultrasound. [42]

In an ultrasound study of a living Swedish population, Sandgren *et al.* reported that the inner diameter of the popliteal artery increased with age, initially during childhood growth, but also

in adults. Demographic information was correlated with this measurement, and males were found to have larger arteries than females. [43]

The mean femoral arterial diameter of the same Swedish population was 9.80 mm in males and 8.20 mm in females. Sandgren *et al*. found no indication of sexual dimorphism for the femoral artery. Sandgren *et al.* found an increase in the diameter of the femoral artery during growth, parallel to the increase in body size. At 18 years of age, at the end of childhood growth, male subjects had larger diameters than female subjects. [44]

Considering exercise, workload, body size, sex, ancestry and age, Erbel *et al.* found the outer diameter of the elastic ascending aorta to expand by 1.30 ± 1.20 mm per year and the outer diameter of the descending aorta by 3.10 ± 3.20 mm per year in a German population. [3] This expansion results in an increased inner diameter along the entire length of the aorta. [3] Erbel and Eggebrecht notes the normal size of the aorta decreased with distance from the aortic valve in a tapering fashion. [6] This was also the case in the Korean study done by Joh *et al*. They reported a supra-renal diameter of 22.00 mm and 21.10 mm for males and females respectively and an infra-renal diameter of 19.00 mm and 17.90 mm for males and females, respectively. [57] For the German population studied by Erbel *et al*., the normal diameter of the ascending aorta has been defined as 37.10 ± 4.00 mm for males and 34.50 ± 4.00 mm for females. The normal diameter of the descending aorta has been defined as 28.20 ± 3.00 mm for males and 25.40 ± 3.00 mm for females. [6] An ascending aorta wall thickness of < 4.00 mm was regarded as normal for this German population. [6] For the American population studied by Rogers *et al*., the average ascending aorta was 34.10 mm for males and 31.90 mm for females. The average descending aorta was 25.80 mm in males and 23.10 mm in females. [60] Erbel and Eggebrecht notes that during life, the size of the aorta increases 1-2 mm/year. It involves all segments which, during childhood and in young adulthood, result in an increase of the luminal diameter of the entire aorta. In adulthood, the aortic size is related to exercise and workload. [3,6]

The phenomenon of an enlarged aorta with the advancement of age and a general increase in the size of peripheral arteries with an increase in Body Mass Index (BMI) or body size occurs in all populations studied. [4,6,37-44,57-60, 71] Joh *et al.* found the infra-renal aortic diameter to be 17.50 mm for Koreans between 50 and 60 years of age, 18.10 mm for Koreans between 60 and 70 years of age and 19.40 mm for Koreans between 70 and 80 years of age. [57] Länne *et al*. found the abdominal aorta to increase 30% between the ages of 25 and 71 years. [71] For the American population studied by Rogers *et al*., the mean aortic diameters were strongly

correlated ($p<0.0001$) with age and body surface area in age-adjusted analyses, and these relations remained significant in multivariable regression analyses. [60]

When investigating the normal diameters of an artery, textbooks and literature mostly provide diverse average values or ranges. Numerous reasons including age, ancestry, sex, viability of the subject (whether a cadaver or living individual) and measurement methodology (which could be invasive or non-invasive) may explain this discrepancy. [45-49] The differences in reported values and ranges fuelled the interest to explore the arterial variations for a South African population and establishing how the South African arterial diameters compare to the global populations studied by the above-mentioned researchers. During the current research study, the South African population studied during the pilot study (Ethical clearance: 83/2014) completed at the University of Pretoria between 2014 and 2015, was extended to include measurements done on additional imaging modalities. [51-53]

1.3 Imaging diagnostic methodology and arterial visualisation

Research on quantifying arterial diameters is of great importance, especially in a clinical setting. [16] There are various methods of measuring arterial diameter. Firstly, measurements may be done on non-invasive radiological methods such as CT or ultrasound. Secondly, measurements can be done through invasive methods using electronic or sliding callipers in theatre, during autopsy or in an embalmed cadaver. [46] In a cadaver, the arterial diameters can be measured before or after the process of filling the arterial system with silicone, latex or oxide-gelatin. [46]

The most commonly used method to quantify arterial diameters includes sliding callipers, electronic callipers, quantitative angiography, and ultrasound. Measurements may result in a certain degree of inter-observer and intra-observer variability. Using a panel of observers and the retaking of measurements can abridge these inaccuracies. Quantitative angiographic analyses require offline digitisation, a process that can be costly and time consuming. Therefore, semi-quantitative methods such as sliding callipers have been successfully used to quantify arterial diameters. [45-49] In a living patient, high-resolution ultrasound is probably the most useful and cost-effective way of obtaining arterial diameters. To establish whether a measurement perceived as normal is truly normal, a database on the normal arterial diameters at a given anatomical point should be utilised.

For arterial measurements taken during the current research, CT and ultrasound were selected as image diagnostic methodologies.

1.3.1 CT

CT, often referred to as computerised axial tomography scan, is an X-ray technique that combines many X-ray images with the assistance of a computer to produce cross-sectional views and, if needed, three-dimensional images of the organs and structures of the body. [72] A CT image is used to define normal and abnormal structures in the body and assists in surgical procedures by helping to accurately guide the placement of instruments or treatments. [72]

CT is performed to analyse the internal organs and anatomical structures of the body. This includes the head, where traumatic injuries such as blood clots, skull fractures, tumours, and infections can be identified. In the spine, the bony structure of the vertebrae can be accurately defined, as can the anatomy of the intervertebral discs and spinal cord. [72] In addition, CT methods can be used to accurately measure the density of bone when evaluating osteoporosis. [72]

CT images are also used in the thorax to identify tumours, cysts, or infections. CT images of the abdomen are extremely helpful in visualising and defining body organ anatomy, including the liver, gallbladder, pancreas, spleen, aorta, kidneys, uterus, and ovaries. CT images of the thorax and abdomen are used to verify the presence or absence of tumours, infection, abnormal anatomy, or effects of trauma. [72]

The technique is painless and can provide extremely accurate images of body structures in addition to guiding the medical specialist in performing certain procedures, such as biopsies of suspected cancers, removal of internal body fluids for various tests, and the draining of abscesses deep in the body. Many of these procedures are minimally invasive and have markedly decreased the need to perform extensive surgery to accomplish the same goal. [72]

Modern CT scanners have the ability to completely assess the entire vascular tree and have been demonstrated by several studies to have good diagnostic accuracy for the identification of anatomically important coronary artery disease or peripheral artery disease - generally defined as arterial stenosis with a lumen reduction of at least 50%. [73-77]

The CT was chosen as image methodology for this study because it is less operator-dependent and more objective than ultrasound. CT-based measurements are not affected by gastrointestinal gas or other body features.

1.3.2 Ultrasound

All diagnostic ultrasound applications are based on the detection and display of acoustic energy reflected from interfaces within the body. These interactions provide the information needed to generate high-resolution, grey-scale images of the body as well as display information related to blood flow. The unique imaging attributes of ultrasound have made it an important and versatile medical imaging tool. The amplitude of reflected energy is used to generate ultrasound images, and frequency shifts in the backscatter ultrasound provide information relating to moving targets such as blood. [78-83]

Ultrasound has provided an incredible wealth of knowledge in diagnostic medicine. Few would be willing to deny the impact this imaging modality has had on medical practice. Ultrasound examination is an integral part of routine abdominal scans, and it is prudent to at least survey the aorta during limited abdominal scans performed for other indications. [79-83]

Various research studies indicate that monitoring small abdominal aortic aneurysms, with a diameter of less than 55 mm, with ultrasound is as effective as early surgery in preventing mortality and carries a lower morbidity and cost. There is increasing evidence that it is valid, worthwhile and cost effective to screen selected populations for aortic aneurysms with ultrasound examinations. [79]

Several studies conclude that ultrasound imaging represents a useful and valid tool for the detection and monitoring of changes in arterial diameters, allowing for the evaluation of changes in the arterial wall in areas without localised plaques. The non-invasive nature of ultrasound is recommended for its use in pre-clinical diagnosis and follow-up of patients with atherosclerosis. [84-87]

Ultrasound was chosen as an image methodology for this study due to advantageous practicality, ease of use, low cost and the absence of radiation.

1.4 Comparing imaging modalities

The detection and quantification of arterial pathology such as carotid stenosis is typically done from MRI or CT which guides the decision for the need for surgical intervention of the patient.[88,89] Ultrasound has also been applied clinically as a standard method for atherosclerosis diagnoses. Compared to other imaging modalities such as MRI, CT and

positron emission tomography, ultrasound provides a less expensive, more portable and real-time imaging modality to help quantify and visualise arterial stenosis and arterial diameter. [88,89]

Since the 1970's, CT has evolved into an imaging technology that permits visualisation of arteries and assessment of vascular function; therefore, it presents a non-invasive alternative for identification of arterial diameter. CT angiography has good diagnostic performance for the detection of significant arterial stenosis. [90-92]

To the researcher's knowledge, South African studies analysing the comparability between CT and ultrasound are limited and scarce. A study comparing these modalities will determine whether results that are defined as normal, that are measured with different modalities on patients with similar demographic parameters, are significantly similar. Knowledge of the normal arterial diameter as a specific arterial site could thus assist in effective screening and can contribute to early diagnosis of cardiovascular complications. Apart from the 2014/2015 pilot study (Ethical clearance: 83/2014) done at the University of Pretoria, South African data on the normal diameter of human arteries are not available in a methodical format. [51-53]

1.5 Pilot study

The 2014/2015 pilot study explored and evaluated the influence of variables associated with an increased risk of cardiovascular complications on the morphometric variations in arterial diameters at a variety of arterial sites. For the South African cadaver and CT population studied, it was found that compared to height, weight, BMI and sex, it is age that contributed the most to the differences seen in the wall thickness of the arteries in the neck and trunk. This contribution was statistically significant. Age contributed nearly 28% to the variation in wall thickness of the left brachial artery, more than 30% to the variation in the right brachial artery, almost 30% to the left popliteal artery, about 27% to the right popliteal artery, almost 33% to the left femoral artery and 26% to the right femoral artery. [52,53]

Age showed a significant influence on 63% of the wall thickness measurements, on 47% of the outer diameter measurements and on 26% of the inner diameter measurements. In the South African population studied, age also showed a positive linear relationship with the outer diameter of these arteries – an age-related increase thus exists in the dilatation of the arterial lumen. [52,53]

It is often stated that females have worse outcomes than men following a myocardial infarction and coronary revascularisation. The reason for this is multifactorial and includes the

dimensional differences of the coronary artery where females have smaller arteries than males - as also confirmed by the pilot study. [39,52,53] In addition, there is evidence linking the smaller diameter of the female coronary artery to adverse cardiovascular events. [39] In percutaneous revascularisation, coronary arterial diameter is a strong predictor of re-stenosis. Furthermore, in coronary artery bypass surgery, target vessel size correlates with long-term graft patency. It is also known that in the event of atherosclerotic plaque rupture, a smaller inner diameter will increase the risk of total occlusion and myocardial infarction. [39]

Sex, the second demographic parameter studied, showed a significant influence on 63% of the inner diameter measurements, on 58% of the outer diameter measurements and only on 0.05% of wall thickness measurements. [52,53]

The abdominal aorta before bifurcation, left and right internal carotid arteries, right common carotid artery, right brachial artery, left and right subclavian arteries, left and right femoral arteries and left and right common iliac arteries showed significant sexual dimorphism where female arteries were found to have smaller outer diameters. The outer diameters of the ascending aorta, aorta at the level of the coeliac trunk, left common carotid artery, left brachial artery, left popliteal artery, right popliteal artery and left and right coronary arteries were also found to be smaller in females although not statistically significant. [52,53]

The inner diameter of the abdominal aorta before bifurcation, left and right internal carotid arteries, right common carotid artery, right brachial artery, left and right subclavian artery, left popliteal artery, left and right femoral artery, and left and right common iliac arteries were found to be significantly smaller in females. Although not significant, the inner diameters of the aorta at the level of the coeliac trunk, left common carotid artery, left brachial artery, right popliteal artery and right coronary artery are also smaller in females. [52,53]

The wall thickness in females is significantly smaller in only the left internal carotid artery. The wall thickness is smaller, but not significantly, in the female ascending aorta, aorta at the level of the coeliac trunk, abdominal aorta before bifurcation, right internal carotid artery, left and right common carotid artery, left brachial artery, right subclavian artery, right popliteal artery, left and right femoral artery, left common iliac artery and left and right coronary artery. [52,53]

Vascular surgeries may be more difficult in patients with a smaller BMI who may have proportionally smaller arteries. Smaller patients are likely to have shorter necks, which may limit surgical access to the common carotid or internal carotid arteries. [50] As parameters of

body size, the effect of height, weight and BMI on arterial diameters was investigated in the pilot study.

Height, the third demographic parameter studied, showed a significant influence on 32% of the outer diameter measurements, on 32% of the inner diameter measurements and on none of the wall thickness measurements. Weight, the fourth demographic parameter, showed a significant influence on 58% of the outer diameter measurements, on 53% of the inner diameter measurements and on 16% of the wall thickness measurements. As a function of both height and weight, BMI, the fifth demographic parameter, showed a significance influence on 37% of the outer diameter measurements, on 32% of the inner diameter measurements and on 21% of the wall thickness measurements. [52,53]

In retrospective studies such as the pilot study, one would not be able to isolate the reason for any differences in ancestry, as the differences could possibly be accounted for by other socio-economic and socio-demographic factors – demographic information that were not available in the cadaver records and one that the researcher could not assume. [52]

For the outer diameter, the only arterial pair that showed a significant difference in size between the left and right side was the coronary arteries, with the left coronary artery being larger. This supports the finding of another cadaveric pilot study at the University of Pretoria (97/2013) in 2013. The inner diameter of the coronary arteries was also found to be significantly larger on the left. The thicker trunk and immediate bifurcation of the left coronary artery might explain this phenomenon. [51,52]

The wall thickness of the femoral and common iliac arteries shows a statistically significant difference between the left and right side of the body. The wall thickness of the right femoral artery and the wall thickness of the left common iliac artery are thicker. [52,53] The femoral – and common iliac arteries are prone to atherosclerosis, and this could possibly explain the thicker wall found here. [54] If not indicated in the records, it is impossible to determine whether the cadavers or CT patients suffered from atherosclerosis that could have accelerated age-related changes in the structure and function of arterial anatomy.

The knowledge that the central, elastic arteries have a large percentage of elastin components, larger diameter and are located closer to the heart, and the peripheral, muscular arteries contain a higher proportion of collagen and smooth muscle cells than elastic fibres and have medium-sized diameters, fuelled interest in other possible differences between the two groups of arteries. [55]

Research has shown that an abdominal aortic aneurysm is associated with abnormalities in the central, elastic arteries. [56] A variance in the rate of dilatation over time in muscular and elastic arteries was considered as a likely explanation.

A two-sided *t*-test revealed no significant difference in the increase in the arterial diameter of the two groups of arteries over time, and the null hypothesis of no significant difference was accepted. There is thus no significant difference in the rate of dilatation over time between the elastic and muscular arteries in the South African population studied that could help explain the prevalence of undesirable clinical outcomes in certain arteries. [52,53]

The primary purpose of the 2014/2015 pilot study was to establish whether cadaveric measurements are an accurate reflection of measurements on a living population. [51-53] The null hypothesis of no significant difference was accepted since the *P*-value indicated no significant difference for 87% of the measurements - the exception being the left common carotid and the left subclavian arteries. These arteries are found on the left side of the neck and branches from the arch of the aorta. The origin of these two arteries differs from the origin of the same arteries on the right side of the neck, and only these two arteries show a significant difference between cadaver and CT measurements which were taken at origin. [51-53] It is possible that when comparing the cadaver measurements with a larger CT sample, the differences might not be significant anymore.

An original article on the results from the pilot study were published in Surgical and Radiologic Anatomy, an international journal (Appendix C).

1.6 Research rationale

Arterial pathology is a major contributor to cardiovascular disease and mortality. Data on normal arterial diameters for a South African population is scarce, but essential when evaluating whether a dilatation or stenosis are pathological. Several studies, including the pilot studies for the current research, indicated an age-related increase in the dilatation of the arterial lumen. [37-56,93-98] The arterial diameter is therefore a useful indicator of the vascular ageing process. As also found in other populations studied, the principle dimensional changes that occur with vascular ageing in a South African population are arterial dilatation and an increase in wall thickness. [42,99,100]

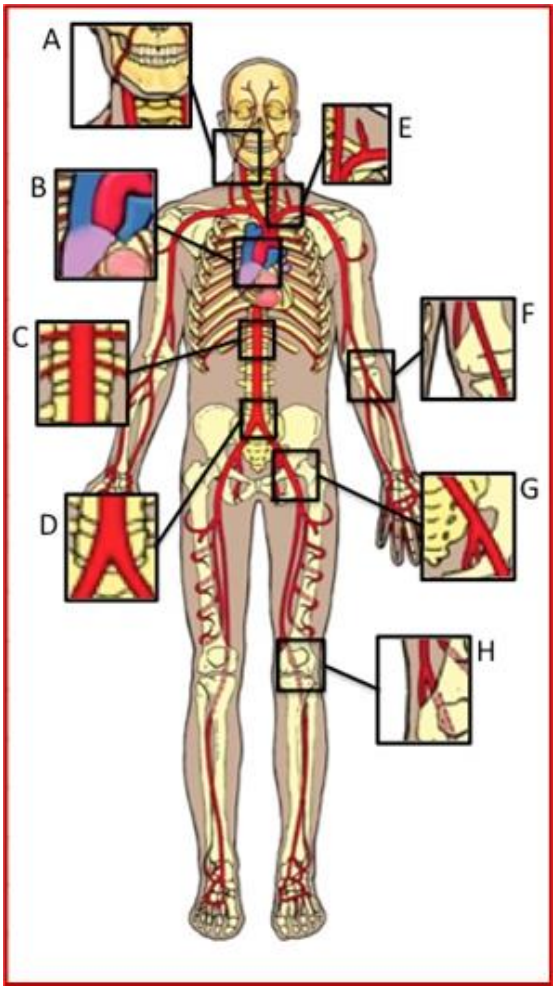


Figure 1.1: Measured arterial sites

An arterial diameter database based on the arterial regions in Figure 1.1 can function as a quantitative estimate of the severity of cardiovascular diseases in a South African population. The chosen arterial sites should be representative of the whole body. Such a database will aid in the assessment of arterial changes with age, as well as arterial diameter within groups with different body sizes. The database can provide better insight into the normal and abnormal diameters of the different arteries affected by cardiovascular disease. This knowledge can contribute to early diagnosis of various cardiovascular diseases and arterial abnormalities, specifically if the contribution or influence of the patient's demographic parameters such as age, weight, height, BMI and sex can be correlated.

Arterial measurements obtained from CT images as well as ultrasound measurements allowed the researcher to compare and correlate the accuracy of measurements taken on these diagnostic imaging techniques with measurements taken on a cadaver sample.

2. AIM AND OBJECTIVES

2.1 Aim

The primary purpose of this study was to compare the measurements taken on cadaveric material with measurements taken with imaging diagnostic methodology such as CT and ultrasound. The aim was to establish whether there is a statistically significant difference between measurements taken on different approaches in individuals with similar demographic variables. The study also aimed to examine the effects of various demographic parameters such as age, sex, weight, height and BMI on the arterial diameters of a South African population.

The reference data set compiled during the 2014/2015 pilot study was extended into a database of arterial measurements from cadaver, CT (retrospective data), and ultrasound (living volunteers) populations - sorted according to the abovementioned demographic parameters.

2.2 Research objectives

1. To determine whether the results for the arterial dimensions from the CT and ultrasound populations are comparable.
2. To determine whether the results for the arterial dimensions from the imaging populations are comparable with the cadaveric measurements.
3. To determine the mean arterial diameter of the aorta and several other peripheral arteries in a South African adult population using cadaveric measurements, CT images and ultrasound analysis.
4. To correlate the mean arterial diameters with changes in the relevant demographic factors that could affect arterial anatomy of a South African population.
5. To compile a reference database regarding the range of the mean arterial diameters for a South African population.

3. MATERIALS AND METHODS

3.1 Study Design

The study had a quantitative approach with a correlational design.

3.2 Setting

3.2.1 Cadaver study

Cadaveric measurements were taken in the dissection halls in the Department of Anatomy, University of Pretoria.

3.2.2 CT study

With the help of a consultant radiologist, CT images were retrospectively selected for analyses from the imaging database at the Department of Radiology, Steve Biko Academic Hospital. Images were analysed using the RadiAnt Digital Imaging and Communications in Medicine (DICOM) software.

3.2.3 Ultrasound study

Ultrasound images were taken of healthy volunteers by a consultant anaesthesiologist, and measurements were taken in the Department of Anatomy, University of Pretoria.

3.3 Population groups

For the purpose of this research, the following population groups were identified[101]:

- Adult males (18-60 years of age)
- Adult females (18-60 years of age)
- Older males (61+ years of age)
- Older females (61+ years of age)

3.4 Sample Size

Each population group comprised of at least 40 measurements of each arterial site. This did not necessarily translate to 40 individuals as all 20 arterial sites could not be measured on each individual – whether cadaver, ultrasound or CT (see Discussion: Limitations). For the purpose of this research measurements were taken on 615 individuals from South Africa.

Sample sizes were calculated by doing power analyses in conjunction with a bio-statistician.

3.4.1 Cadaver study

The cadaver sample comprised of 321 individuals. Table 3.1 indicates the distribution of the cadaver sample between the population groups:

Table 3.1: Distribution of cadaver sample

Population group	Sample size
Adult males (18-60 years of age)	98
Adult females (18-60 years of age)	59
Older males (61+ years of age)	106
Older females (61+ years of age)	58

3.4.2 CT study

The CT sample comprised of 213 individuals. Table 3.2 indicates the distribution of the CT sample between the population groups:

Table 3.2: Distribution of CT sample

Population group	Sample size
Adult males (18-60 years of age)	54
Adult females (18-60 years of age)	79
Older males (61+ years of age)	41
Older females (61+ years of age)	39

3.4.3 Ultrasound study

The ultrasound sample comprised of 81 individuals. Table 3.3 indicates the distribution of the ultrasound sample between the population groups:

Table 3.3: Distribution of ultrasound sample

Population group	Sample size
Adult males (18-60 years of age)	40
Adult females (18-60 years of age)	41

3.5 Research subject selection

3.5.1 Cadaver study

The cadavers were randomly selected from the Department of Anatomy, University of Pretoria. Each cadaver's demographic information was obtained from the cadaver records at the Department of Anatomy. These records are compiled with information retrieved from the hospital records or from the deceased family.

3.5.1.1 Inclusion criteria

Only cadavers between the ages of 18 and 100 years were used in order to allow for comparisons with a similar age group from the living (CT and ultrasound) population. Cadavers of all BMI's were included.

3.5.1.2 Exclusion criteria

Cadavers were excluded if they were known smokers or suffered from any known cardiovascular conditions e.g. hypertension or hypercholesterolaemia. Cadavers with known aortic aneurysms, aortic dissections or those who have undergone previous vascular surgery were also excluded from this study.

3.5.2 CT study

The CT images were retrospectively selected from the database of radiographic images at the Department of Radiology, Steve Biko Academic Hospital. The demographic parameters relating to each patient was readily available on the scan. Medical records were perused by the primary investigator to investigate possible exclusion criteria.

3.5.2.1 Inclusion criteria

Only images of patients between the ages of 18 and 100 years were used to allow for comparisons with a similar age group from the cadaver and ultrasound population. Patients of all BMI's were included.

3.5.2.2 Exclusion criteria

Patients were excluded if they were known smokers or suffered from any known cardiovascular conditions e.g. hypertension or hypercholesterolaemia. The diagnostic images of patients with known aortic aneurysms, aortic dissections or those who have undergone previous vascular surgery were also excluded from this study.

3.5.3 Ultrasound study

The ultrasound images were taken on healthy, living volunteers studying in the Department of Anatomy, University of Pretoria. The volunteers provided their demographic information via questionnaires (see Table 3.4).

3.5.3.1 Inclusion criteria

Only images of volunteers between the ages of 18 and 60 years were used in order to allow for comparisons with a similar age group from the cadaver and CT population. Patients of all BMI's were included.

3.5.3.2 Exclusion criteria

The older male and female population groups (above 60 years old) were excluded the ultrasound study. Volunteers were excluded if they were known smokers or suffered from any known cardiovascular conditions e.g. hypertension or hypercholesterolaemia. The diagnostic images of volunteers with known aortic aneurysms, aortic dissections or those who have undergone previous vascular surgery were excluded from this study.

3.6 Demographic information

Table 3.4 summarises the demographic parameters obtained in relation to the research subjects of the three studies.

Table 3.4: Demographic parameters

Study	Demographic parameters
Cadaver	Age Sex Height Weight BMI
CT	Age Sex
Ultrasound	Age Sex Height Weight BMI Handedness

3.7 Measurements and procedure

Table 3.5 indicates the different arterial dimensions measured at each relevant arterial site (see Table 3.6) for the three different studies. Also indicated are the abbreviations for each measurement that will be used for reporting purposes.

Table 3.5: Measurements taken in different studies

Study	Arterial dimensions measured	Measurement abbreviation
Cadaver	Outer diameter (OD)	M1
	Inner diameter (ID)	M2
	Wall thickness (WT)	M3
CT	Outer diameter (OD)	M1
Ultrasound	Outer diameter (OD)	M1

Table 3.6 indicates the arterial sites measured in the three different studies. Also indicated are the abbreviations for each arterial site that will be used for reporting purposes. These abbreviations will be used in conjunction with those indicated in Table 3.5. All measurements are in millimetres.

Table 3.6: Measured arterial sites used in different studies

#	Arterial site	Abbreviation
1	Ascending aorta proximal to fibrous pericardium	AA
2	Abdominal aorta at level of coeliac trunk	AC
3	Abdominal aorta before terminal bifurcation	AB
4	Left internal carotid artery distal to carotid body	LIC
5	Right internal carotid artery distal to carotid body	RIC
6	Left common carotid artery at origin	LCC
7	Right common carotid artery at origin	RCC
8	Left brachial artery before bifurcation	LBA
9	Right brachial artery before bifurcation	RBA
10	Left subclavian artery at origin	LSC
11	Right subclavian artery at origin	RSC
12	Left popliteal artery in popliteal fossa	LPA
13	Right popliteal artery in popliteal fossa	RPA
14	Left femoral artery inferior to inguinal ligament	LFA
15	Right femoral artery inferior to inguinal ligament	RFA
16	Left common iliac artery at origin	LCI
17	Right common iliac artery at origin	RCI
18	Left coronary artery at origin	LC
19	Right coronary artery at origin	RC
20	Infra-renal aorta	IR

Key:

Cadaveric and ultrasound measurements
Cadaveric and CT measurements
Cadaveric measurements
Cadaveric, ultrasound and CT measurements

When considering Table 3.5 and Table 3.6, AAM1 (as example) will thus refer to the outer diameter of the ascending aorta proximal to fibrous pericardium.

3.7.1 Cadaver study

The arterial sites were exposed during the dissection sessions of medical and medical science students within the Department of Anatomy. In cases where an arterial site was not exposed, a basic dissection was done. Once the arterial site was identified, careful measurements were taken of the outer diameter using a standard stainless-steel mechanical dial sliding calliper (accuracy 0.01 mm).

Measurement was taken without compressing arteries in order to avoid confounding the results. Once the outer diameter was measured, the arteries were sectioned, and the wall thickness was measured at the same location. A simple mathematical formula (OD – 2WT) gave an indication of the inner diameter. Figure 3.1 and Figure 3.2 serve as example of cadaveric measurements taken.

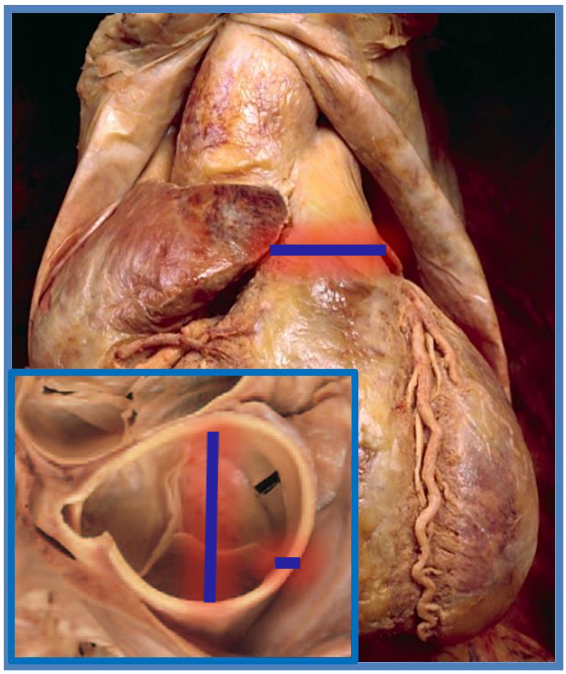


Figure 3.1: Ascending aorta proximal to fibrous pericardium (cadaver)

Figure 3.2: Brachial artery before bifurcation (cadaver)

3.7.2 CT study

Due to the difficulties visualising the arterial wall on imaging diagnostic scans, only the outer diameter was measured at each applicable arterial site (as seen in Table 3.5).

A DICOM viewer was used to analyse the diagnostic images included in this study. Using the on-screen measuring function, calibrated for each image, the outer diameters at the applicable sites were recorded.

The images below indicate the sites of measurement for the abdominal aorta before terminal bifurcation (AB), the left (LCI) and right common iliac (RCI) arteries at origin (Figure 3.3) and the ascending aorta (AA) proximal to fibrous pericardium (Figure 3.4) on a CT.

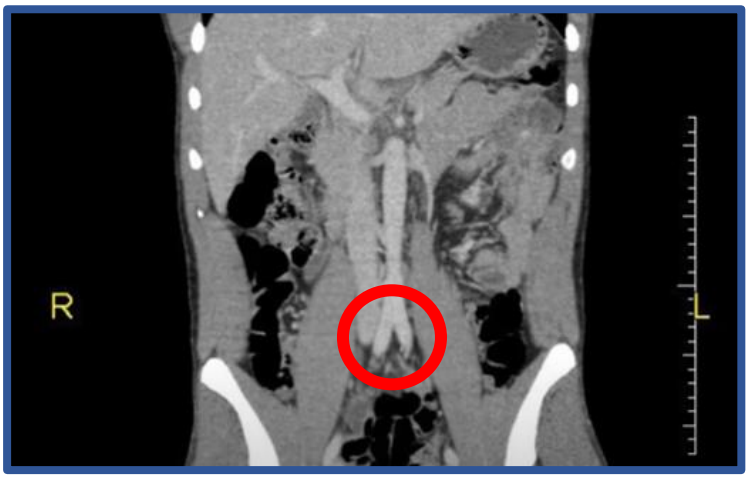
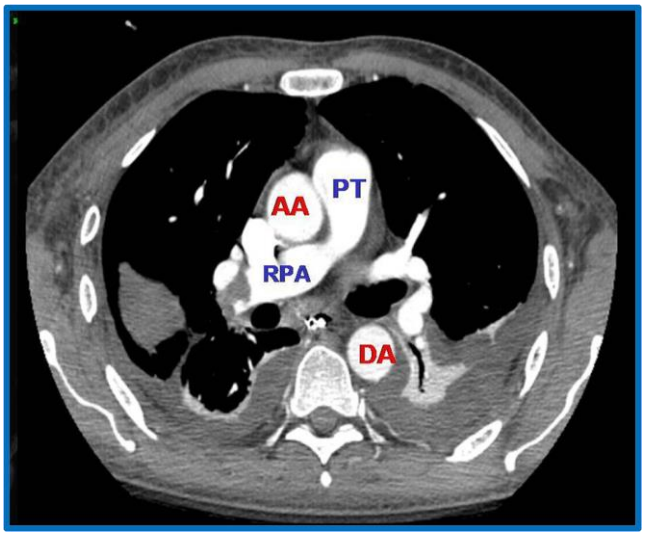


Figure 3.3: Abdominal aorta before terminal bifurcation and the left and right common iliac arteries at origin (CT)



AA	Ascending aorta
PT	Pulmonary trunk
RPA	right pulmonary artery
DA	descending aorta

Figure 3.4: Ascending aorta proximal to fibrous pericardium (CT)

3.7.3 Ultrasound study

Due to the difficulties visualising the arterial wall on imaging diagnostic scans, only the outer diameter was measured at each applicable arterial site (see Table 3.5).

A qualified anaesthesiologist observed the applicable arterial sites via his personal portable EdgeTM ultrasound machine (ref: P15000-11, SN-03P55Z) with a 6 – 13 MHz linear array probe (footprint size of 2.5 cm). Screen-photos were taken, and the outer diameters were measured in retrospect using the on-screen measuring function.

Figure 3.5 and Figure 3.6 illustrates the on-screen measuring of the femoral and brachial arteries respectively.

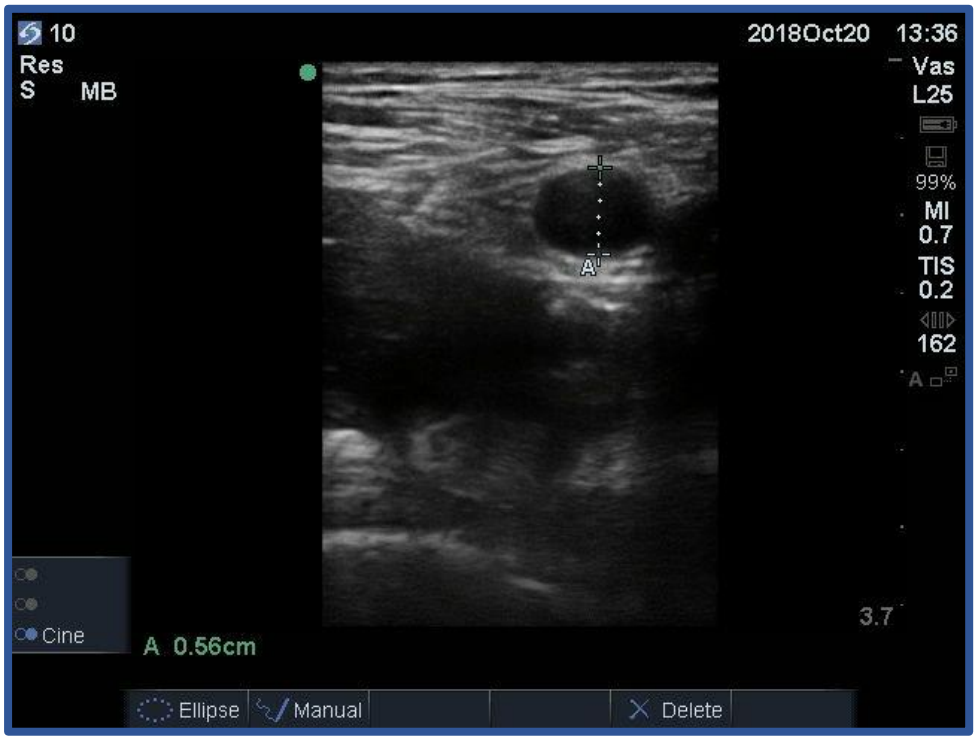


Figure 3.5: Right femoral artery inferior to inguinal ligament (ultrasound)

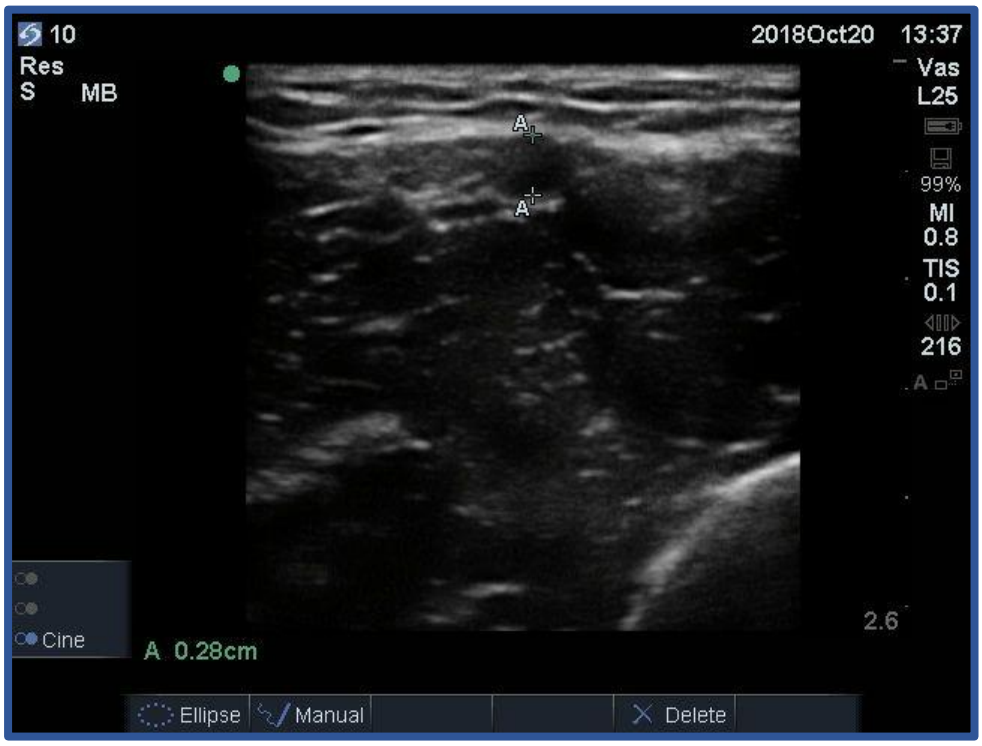


Figure 3.6: Left brachial artery before bifurcation (ultrasound)

3.8 Statistical analysis

Descriptive statistics were used to describe the data obtained; this included the mean, median, standard deviation (SD), minimum and maximum of all the dependent and independent variables. A range with a confidence interval of 95% was also calculated. The dependent variables were the relevant arterial dimensions (Table 3.5) at the applicable arterial sites (Table 3.6), while the independent variables were the demographic parameters (Table 3.4).

For each of the three studies, statistical analysis was done to determine the relationship between the measured arterial dimensions (Table 3.5) and the applicable demographic parameters (Table 3.4) for each of the relevant arterial sites (Table 3.6). Comparisons between population groupings in relation to demographic parameters (e.g. male *vs.* female or older *vs.* adult) were made using two-sample *t*-tests, while the strength of the correlations between arterial dimensions and demographic parameters were analysed using Pearson's correlation tests.

A paired *t*-test was done to compare arteries that can be found on the left and right side of the body for example internal carotid arteries (cadaver study) the brachial arteries (ultrasound

study) and subclavian arteries (CT study). For the ultrasound study, two-sample *t*-tests were done to compare measurements of left and right-handed individuals.

The results of the three studies were compared in order to conclude whether the arterial dimensions found in the three studies were comparable. Comparison between the three modalities measuring the older population group was done via one-way ANOVA (analysis of variance), with a Bonferroni Correction. Comparison between the two modalities measuring the adult population group was done via *t*-tests.

All statistical analyses were done with the assistance of a biostatistician using the STATA statistical software (Version 14). [51,52,102]

3.8.1 Reliability

Reliability refers to the consistency of the results. Different types of reliability can be estimated through statistical methods. [103-105] For the purpose of this research, intrarater reliability and interrater reliability were evaluated via Bland-Altman plots for each of the three studies.

Intrarater reliability is a measure of how consistent the primary investigator is at measuring a constant phenomenon (the arterial dimensions) and interrater reliability refers to how consistent an external observer is at measuring the same phenomenon, without any influence from the primary investigator. [103-105] Intrarater and interrater reliability evaluations thus analyse the repeatability of the measurement.

Bland and Altman introduced the Bland-Altman method to describe agreement between two quantitative measurements by constructing limits of agreement. These statistical limits are calculated by using the mean and the standard deviation of the differences between two measurements. To examine the assumptions of normality of differences and other characteristics, they used a graphical approach. [103-105] (see 4. Results)

3.8.2 Validity

Validity refers to the accuracy of a measurement. If results correspond to variations reported by other researchers, research validity is high. High reliability is one indicator that a measurement is valid. However, reliability on its own is not enough to ensure validity. Validity can be estimated by comparing the results to other relevant data.

Construct validity is the adherence of a measure to existing theory and knowledge. Content validity is the extent to which the measurement covers all aspects of the concept being measured. Criterion validity is the extent to which the result of a measure corresponds to other valid measures of the concept. Validity will therefore be further discussed with the analyses of the results.

3.9 Ethical considerations

The protocol received internal departmental endorsement, approval from the PhD Committee of the Faculty of Health Sciences and clearance from the Faculty of Health Sciences Research Ethics Committee with protocol number 346/2017 (Appendix B).

The acquisition and dissection of cadavers used for this research were in accordance with the rules and regulations set out in the South African National Health Act 61 of 2003. The cadaveric specimens used formed part of the cadaver collection of the Department of Anatomy, University of Pretoria. All cadavers were obtained through donation by the family members, or due to the deceased being unclaimed by family members. The cadaveric material was always handled with respect and care. No information which could possibly reveal the identities of the cadavers was obtained.

CT images contained in the database of the Department of Radiology, Steve Biko Academic Hospital were analysed retrospectively and was done with assistance and approval from the Head of the Department of Radiology and the Chief Executive Officer (CEO) of Steve Biko Academic Hospital. No living volunteers were used in this part of the study.

The ultrasound component of the study included the participation of student volunteers from the Department of Anatomy, University of Pretoria. Written informed consent from each volunteer was obtained prior to participation in this study. All demographic information regarding the volunteers were kept confidential and anonymous. Volunteers had to consent to each individual arterial site relevant to the ultrasound study (Table 3.6). Arterial sites not consented to were not measured. Permission to make use of the student volunteers was obtained from the Chairperson of the School of Medicine.

4. RESULTS

4.1 The Bland-Altman method

The analysis of intrarater reliability for AAM1 taken on cadavers will be used as an example.

Table 4.1: Intrarater reliability analysis for AAM1 in cadaver study

Variable	Measurements		Mean	Difference
	First take	Second take		
AAM1	37.73	37.71	37.72	0.02
	33.49	33.49	33.49	0
	26	26.01	26.01	-0.01
	43.6	43.65	43.63	-0.05
	31.95	32	31.98	-0.05
	35.32	35.32	35.32	0
	32.41	32.41	32.41	0
	28.86	28.86	28.86	0
	34.76	34.78	34.77	-0.02
	25.06	25.02	25.04	0.04
	23.51	23.5	23.51	0.01
	36.22	36.25	36.24	-0.03
	32.47	32.45	32.46	0.02
	38.02	38.02	38.02	0
	32.05	32.05	32.05	0
				Mean ± SD: -0.005 ± 0.024

Table 4.1 shows the mean of the differences as −0.005 mm. The data thus suggest that on average the second take measures 0.005 mm less than the first take. The SD of the differences is 0.024 mm. From the data in Table 4.1, a scatter plot was constructed.

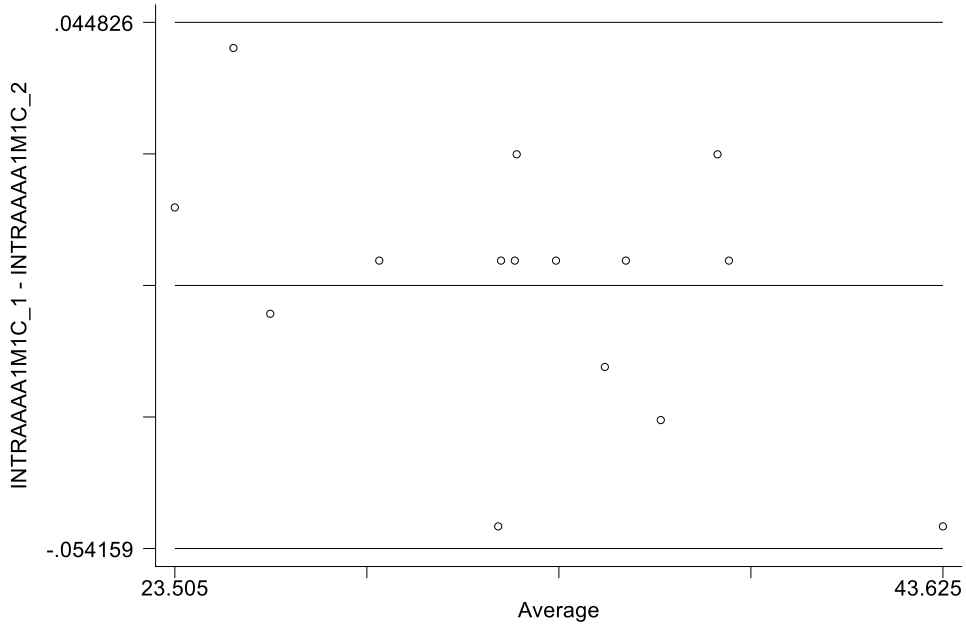


Figure 4.1: Bland-Altman plot

The three lines in Figure 4.1 represent the mean of differences (called bias) in the middle, the upper limit of agreement (mean +1.96 SD) at the top and the lower limit of agreement (mean -1.96 SD) at the bottom. The horizontal axis indicates the mean/average of the two measurements, and the vertical axis indicates the difference between the two values. [103-105]

Bland and Altman recommended that 95% of the data points should lie within 1.96 SD of the mean difference. [103-105] In the example, all data points (100%) lie inside the limits of agreement which indicates that there is agreement between “First take” and “Second take”.

From Bland-Altman plots constructed for the purpose of this research the following was found:

27/27 (100%) of Bland-Altman plot constructed to measure intrarater reliability for the cadaver study showed >95% of data points within the limits of agreement.
15/15 (100%) of Bland-Altman plot constructed to measure intrarater reliability for the CT study showed >95% of data points within the limits of agreement.
8/8 (100%) of Bland-Altman plot constructed to measure intrarater reliability for the CT study showed >95% of data points within the limits of agreement.
27/27 (100%) of Bland-Altman plot constructed to measure interrater reliability for the cadaver study showed >95% of data points within the limits of agreement.
15/15 (100%) of Bland-Altman plot constructed to measure interrater reliability for the CT study showed >95% of data points within the limits of agreement.

6/6 (100%) of Bland-Altman plot constructed to measure interrater reliability for the CT study showed >95% of data points within the limits of agreement.

This research thus demonstrated high intrarater reliability as well as high interrater reliability.

4.2 Cadaver study

Various two-sample *t*-tests were performed to establish whether there is a statistically significant difference between the arterial dimensions of a South Africa cadaver sample with reference to specific demographic parameters. Comparisons were drawn between large groupings (e.g. older individuals *vs.* adult individuals or black individuals *vs.* white individuals), as well as between more defined groupings (e.g. older males *vs.* adult males or black older males *vs.* white older males) of the various population groups.

Table 4.2 shows the probability values or *P*-values when comparing the older cadaver population (75.93 ± 9.20 years of age) with the adult cadaver population (43.94 ± 11.98 years of age) irrespective of sex and ancestry. The older sample consisted of 164 cadavers and the adult sample consisted of 157 cadavers.

It must be noted that throughout the results presented, in some instances not all relevant arterial sites could be measured on each individual cadaver – therefore the mentioned sample size could be slightly less for a specific arterial site.

Throughout the results presented for the cadaver study, a *P*-value smaller than 0.05 (shaded in red), indicates a statistically significant difference between the arterial dimensions of the two groupings. [104] For each variable, the means and standard deviations are also indicated.

In each of the tables in Section 4, please refer to Table 3.5 and Table 3.6 for definitions of the abbreviations used.

Table 4.2: Older cadaver population *vs.* adult cadaver population

Variable	Older population Mean±SD (mm)	Adult population Mean±SD (mm)	*P*-value
AAM1	33.51 ± 6.17	27.08 ± 4.9	0.000
AAM2	30.57 ± 7.13	24.46 ± 4.87	0.000
AAM3	1.47 ± 0.91	1.31 ± 0.38	0.105
ACM1	19.29 ± 4.13	16.14 ± 2.64	0.000
ACM2	17.17 ± 3.78	14.28 ± 2.75	0.000
ACM3	1.06 ± 0.66	0.93 ± 0.37	0.115
ABM1	18.83 ± 3.50	17.27 ± 3.29	0.004
ABM2	16.87 ± 3.69	15.59 ± 3.86	0.031
ABM3	0.98 ± 0.62	0.84 ± 0.57	0.135
LICM1	7.25 ± 1.68	6.19 ± 1.63	0.000
LICM2	6.25 ± 1.67	5.26 ± 1.58	0.000
LICM3	0.50 ± 0.25	0.47 ± 0.22	0.279
RICM1	6.85 ± 2.02	6.34 ± 1.55	0.047
RICM2	5.72 ± 1.96	5.41 ± 1.51	0.200
RICM3	0.56 ± 0.22	0.44 ± 0.26	0.001
LCCM1	8.42 ± 1.85	7.88 ± 1.65	0.029
LCCM2	6.93 ± 1.68	6.75 ± 1.62	0.420
LCCM3	0.74 ± 0.38	0.57 ± 0.19	0.000
RCCM1	8.36 ± 1.91	8.07 ± 1.67	0.244
RCCM2	5.93 ± 1.76	6.60 ± 2.03	0.221
RCCM3	0.72 ± 0.35	0.61 ± 0.24	0.014
LBAM1	5.60 ± 1.39	5.44 ± 1.19	0.365
LBAM2	4.77 ± 1.42	4.75 ± 1.24	0.944
LBAM3	0.42 ± 0.17	0.32 ± 0.14	0.000
RBAM1	6.12 ± 1.56	5.44 ± 1.24	0.001
RBAM2	5.34 ± 1.51	4.79 ± 1.22	0.004
RBAM3	0.39 ± 0.16	0.33 ± 0.14	0.002
LSCM1	8.38 ± 1.70	7.37 ± 1.77	0.000
LSCM2	7.02 ± 1.42	6.41 ± 1.61	0.005
LSCM3	0.68 ± 0.44	0.48 ± 0.20	0.000
RSCM1	9.10 ± 1.74	8.02 ± 1.54	0.000
RSCM2	7.78 ± 1.65	6.90 ± 1.44	0.000
RSCM3	0.66 ± 0.27	0.56 ± 0.33	0.017
LPAM1	7.84 ± 2.21	6.76 ± 1.90	0.001
LPAM2	6.61 ± 2.13	5.84 ± 1.91	0.018
LPAM3	0.62 ± 0.37	0.46 ± 0.20	0.001
RPAM1	7.52 ± 2.01	6.86 ± 1.56	0.024
RPAM2	6.27 ± 1.96	6.02 ± 1.59	0.387
RPAM3	0.63 ± 0.37	0.42 ± 0.27	0.000
LFAM1	8.90 ± 2.37	8.29 ± 1.57	0.049
LFAM2	7.54 ± 2.39	7.29 ± 1.60	0.427
LFAM3	0.68 ± 0.30	0.50 ± 0.21	0.000

Table 4.2: Older cadaver population *vs*. adult cadaver population (cont'd)

Variable	Older population Mean±SD (mm)	Adult population Mean±SD (mm)	P-value
RFAM1	8.80 ± 2.42	8.04 ± 1.88	0.023
RFAM2	7.26 ± 2.30	6.89 ± 1.76	0.234
RFAM3	0.77 ± 0.44	0.58 ± 0.24	0.001
LCIM1	11.70 ± 1.90	10.91 ± 1.66	0.004
LCIM2	9.68 ± 2.19	9.71 ± 1.65	0.936
LCIM3	1.01 ± 0.54	0.60 ± 0.22	0.000
RCIM1	11.95 ± 2.06	11.13 ± 2.13	0.010
RCIM2	10.30 ± 2.14	9.84 ± 2.01	0.147
RCIM3	0.83 ± 0.37	0.64 ± 0.31	0.001
LCM1	5.82 ± 2.17	4.67 ± 1.15	0.000
LCM2	4.77 ± 2.29	3.80 ± 1.22	0.001
LCM3	0.50 ± 0.29	0.41 ± 0.26	0.030
RCM1	4.26 ± 1.10	4.31 ± 1.35	0.804
RCM2	3.30 ± 1.24	3.53 ± 1.38	0.245
RCM3	0.48 ± 0.30	0.37 ± 0.21	0.004
IRM1	18.45 ± 0.80	17.43 ± 0.81	0.000
IRM2	16.46 ± 1.36	15.40 ± 1.22	0.000
IRM3	1.00 ± 0.63	1.01 ± 0.51	0.877

Table 4.3 shows the *P*-values when comparing black cadavers with white cadavers irrespective of sex and age. There were 105 black cadavers and 216 white cadavers.

Table 4.3: Black cadavers *vs*. white cadavers

Variable	Black individuals Mean±SD (mm)	White individuals Mean±SD (mm)	*P*-value
AAM1	27.13 ± 5.19	31.65 ± 6.44	0.000
AAM2	24.68 ± 5.16	28.72 ± 7.09	0.000
AAM3	1.22 ± 0.36	1.47 ± 0.79	0.019
ACM1	14. 90 ± 2.83	18.46 ± 3.7	0.000
ACM2	13.09 ± 2.94	16.42 ± 3.47	0.000
ACM3	0.90 ± 0.37	1.02 ± 0.58	0.264
ABM1	17.14 ± 2.36	18.37 ± 3.68	0.065
ABM2	15.77 ± 2.24	16.43 ± 4.11	0.380
ABM3	0.68 ± 0.36	0.97 ± 0.63	0.011
LICM1	6.47 ± 1.49	6.82 ± 1.83	0.177
LICM2	5.54 ± 1.35	5.84 ± 1.83	0.252
LICM3	0.46 ± 0.20	0.49 ± 0.25	0.399
RICM1	6.59 ± 1.27	6.57 ± 2.0	0.957
RICM2	5.56 ± 1.44	5.55 ± 1.86	0.970
RICM3	0.47 ± 0.24	0.51 ± 0.25	0.266
LCCM1	7.77 ± 1.59	8.32 ± 1.82	0.034
LCCM2	6.69 ± 1.59	6.91 ± 1.68	0.382
LCCM3	0.54 ± 0.17	0.71 ± 0.34	0.000

Table 4.3: Black cadavers *vs.* white cadavers (cont'd)

Variable	Black individuals Mean±SD (mm)	White individuals Mean±SD (mm)	P-value
RCCM1	7.96 ± 1.61	8.33 ± 1.87	0.155
RCCM2	6.44 ± 1.98	6.91 ± 1.87	0.086
RCCM3	0.62 ± 0.23	0.68 ± 0.33	0.140
LBAM1	5.30 ± 1.18	5.62 ± 1.33	0.093
LBAM2	4.69 ± 1.15	4.80 ± 1.40	0.585
LBAM3	0.31 ± 0.12	0.40 ± 0.17	0.000
RBAM1	5.43 ± 1.20	5.93 ± 1.51	0.016
RBAM2	4.83 ± 1.20	5.16 ±1.47	0.106
RBAM3	0.30 ± 0.11	0.39 ± 0.17	0.000
LSCM1	7.09 ± 1.75	8.21 ± 1.72	0.000
LSCM2	6.19 ± 1.62	6.94 ± 1.47	0.001
LSCM3	0.45 ± 0.14	0.64 ± 0.40	0.000
RSCM1	7.60 ± 1.49	8.98 ± 1.65	0.000
RSCM2	6.65 ± 1.38	7.64 ± 1.60	0.000
RSCM3	0.47 ± 0.15	0.67 ± 0.34	0.000
LPAM1	6.82 ± 2.01	7.43 ± 2.14	0.137
LPAM2	6.00 ± 2.00	6.29 ± 2.07	0.473
LPAM3	0.41 ± 0.19	0.57 ± 0.32	0.006
RPAM1	6.63 ± 1.66	7.36 ± 1.86	0.037
RPAM2	5.88 ± 1.74	6.22 ± 1.80	0.326
RPAM3	0.37 ± 0.16	0.57 ± 0.36	0.002
LFAM1	8.12 ± 1.55	8.73 ± 2.14	0.125
LFAM2	7.28 ± 1.77	7.46 ± 2.11	0.638
LFAM3	0.42 ± 0.19	0.63 ± 0.28	0.000
RFAM1	8.00 ± 1.69	8.55 ± 2.31	0.188
RFAM2	6.97 ± 1.54	7.11 ± 2.18	0.720
RFAM3	0.51 ± 0.20	0.72 ± 0.39	0.003
LCIM1	10.59 ± 1.87	11.53 ± 1.77	0.005
LCIM2	9.31 ± 1.91	9.80 ± 1.96	0.183
LCIM3	0.64 ± 0.32	0.87 ± 0.49	0.009
RCIM1	11.01 ± 1.83	11.74 ± 2.18	0.059
RCIM2	9.73 ± 1.77	10.19 ± 2.17	0.227
RCIM3	0.64 ± 0.28	0.77 ± 0.37	0.036
LCM1	4.46 ± 0.92	5.62 ± 2.03	0.000
LCM2	3.61 ± 1.10	4.60 ± 2.11	0.001
LCM3	0.39 ± 0.27	0.49 ± 0.27	0.023
RCM1	4.12 ± 0.99	4.37 ± 1.33	0.211
RCM2	3.37 ± 1.07	3.43 ± 1.42	0.778
RCM3	0.34 ± 0.24	0.47 ± 0.26	0.003
IRM1	17.72 ± 0.95	18.04 ± 0.94	0.048
IRM2	15.65 ± 1.40	16.07 ± 1.37	0.078
IRM3	1.04 ± 0.59	0.99 ± 0.57	0.621

Table 4.4 shows the *P*-values when comparing older male cadavers (73.81 ± 7.86 years of age) with adult male cadavers (46.97 ± 9.64 years of age) irrespective of race. The older male sample consisted of 106 cadavers and the adult male sample consisted of 98 cadavers.

Table 4.4: Older male cadavers *vs*. adult male cadavers

Variable	Older males Mean±SD (mm)	Adult males Mean±SD (mm)	P-value
AAM1	33.49 ± 6.52	27.65 ± 5.78	0.000
AAM2	30.35 ± 7.60	25.13 ± 5.77	0.000
AAM3	1.57 ± 0.99	1.26 ± 0.38	0.037
ACM1	19.15 ± 4.03	16.61 ± 2.76	0.001
ACM2	16.95 ± 3.73	14.64 ± 2.93	0.001
ACM3	1.10 ± 0.71	0.98 ± 0.50	0.379
ABM1	19.90 ± 3.53	19.05 ± 2.39	0.190
ABM2	18.12 ± 3.80	17.42 ± 2.21	0.299
ABM3	0.89 ± 0.44	0.82 ± 0.33	0.359
LICM1	7.60 ± 1.88	6.92 ± 1.62	0.045
LICM2	6.55 ± 1.80	5.89 ± 1.64	0.047
LICM3	0.52 ± 0.25	0.53 ± 0.24	0.834
RICM1	7.47 ± 1.86	6.88 ± 1.80	0.097
RICM2	6.28 ± 1.88	5.81 ± 1.78	0.188
RICM3	0.60 ± 0.24	0.48 ± 0.31	0.026
LCCM1	8.49 ± 1.61	8.01 ± 1.62	0.123
LCCM2	7.05 ± 1.63	6.83 ± 1.52	0.447
LCCM3	0.72 ± 0.33	0.59 ± 0.23	0.027
RCCM1	8.51 ± 1.71	8.58 ± 1.89	0.858
RCCM2	7.19 ± 1.75	6.75 ± 2.61	0.290
RCCM3	0.66 ± 0.24	0.66 ± 0.29	0.905
LBAM1	5.66 ± 1.44	5.83 ± 1.30	0.522
LBAM2	4.78 ± 1.46	5.07 ± 1.44	0.279
LBAM3	0.44 ± 0.17	0.34 ± 0.15	0.000
RBAM1	6.26 ± 1.32	5.86 ± 1.36	0.106
RBAM2	5.48 ± 1.35	4.25 ± 1.32	0.341
RBAM3	0.39 ± 0.15	0.31 ± 0.14	0.003
LSCM1	8.50 ± 1.55	7.96 ± 1.73	0.074
LSCM2	7.3 ± 1.44	6.99 ± 1.57	0.263
LSCM3	0.60 ± 0.28	0.48 ± 0.23	0.017
RSCM1	9.81 ± 1.50	8.39 ± 1.68	0.000
RSCM2	8.39 ±1.45	7.31 ± 1.59	0.000
RSCM3	0.71 ± 0.29	0.54 ± 0.29	0.002
LPAM1	8.37 ±2.49	7.19 ± 1.84	0.014
LPAM2	7.16 ± 2.32	6.29 ± 1.78	0.056
LPAM3	0.61 ± 0.38	0.45 ± 0.19	0.013
RPAM1	8.03 ± 2.22	6.64 ± 1.67	0.001
RPAM2	6.69 ± 2.13	5.77 ± 1.63	0.026
RPAM3	0.67 ± 0.43	0.44 ± 0.34	0.005

Table 4.4: Older male cadavers *vs*. adult male cadavers (cont'd)

Variable	Older males Mean±SD (mm)	Adult males Mean±SD (mm)	P-value
LFAM1	9.4 ± 2.69	8.57 ± 1.62	0.084
LFAM2	8.06 ± 2.64	7.51 ± 1.65	0.246
LFAM3	0.67 ± 0.32	0.53 ± 0.25	0.024
RFAM1	9.77 ± 2.18	8.31 ± 2.20	0.002
RFAM2	8.13 ± 2.06	7.31 ± 2.02	0.055
RFAM3	0.82 ± 0.44	0.50 ± 0.26	0.000
LCIM1	12.11 ± 2.03	11.58 ± 1.87	0.181
LCIM2	10.12 ± 2.36	10.37 ± 1.81	0.567
LCIM3	1.00 ± 0.53	0.61 ± 0.26	0.000
RCIM1	12.55 ± 2.08	12.17 ± 2.32	0.402
RCIM2	11.02 ± 2.21	10.87 ± 2.04	0.736
RCIM3	0.77 ± 0.33	0.65 ± 0.38	0.111
LCM1	5.89 ± 2.63	5.01 ± 0.96	0.040
LCM2	4.89 ± 2.66	4.14 ± 1.06	0.087
LCM3	0.50 ± 0.28	0.43 ± 0.31	0.260
RCM1	4.34 ± 1.13	4.74 ± 1.23	0.109
RCM2	3.28 ± 1.25	3.85 ± 1.42	0.042
RCM3	0.53 ± 0.33	0.40 ± 0.23	0.031
IRM1	18.70 ± 0.74	17.64 ± 0.71	0.000
IRM2	16.67 ± 1.32	15.80 ± 1.09	0.002
IRM3	1.01 ± 0.62	0.92 ± 0.44	0.453

Table 4.5 shows the *P*-values when comparing older female cadavers (79.79 ± 10.25 years of age) with adult female cadavers (38.92 ± 13.77 years of age) irrespective of ancestry. The older female sample consisted of 58 cadavers and the adult female sample consisted of 59 cadavers.

Table 4.5: Older female cadavers *vs*. adult female cadavers

Variable	Older females Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
AAM1	33.53 ± 5.70	26.52 ± 3.9	0.000
AAM2	30.87 ± 6.49	23.79 ± 3.72	0.000
AAM3	1.33 ± 0.77	1.36 ± 0.38	0.768
ACM1	19.50 ± 4.32	15.67 ± 2.46	0.000
ACM2	17.49 ± 3.88	13.91 ± 2.54	0.000
ACM3	1.01 ± 0.59	0.88 ± 0.15	0.179
ABM1	17.26 ± 2.83	15.23 ± 3.00	0.004
ABM2	15.05 ± 2.66	13.50 ± 4.28	0.068
ABM3	1.10 ± 0.81	0.86 ± 0.76	0.198
LICM1	6.67 ± 1.07	5.48 ± 1.30	0.000
LICM2	5.74 ± 1.30	4.64 ± 1.25	0.000
LICM3	0.47 ± 0.27	0.42 ± 0.17	0.327

Table 4.5: Older female cadavers *vs*. adult female cadavers (cont'd)

Variable	Older females Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
RICM1	5.82 ± 1.86	5.84 ± 1.08	0.937
RICM2	4.81 ± 1.76	5.02 ±1.08	0.470
RICM3	0.50 ± 0.16	0.41 ± 0.19	0.014
LCCM1	8.30 ± 2.22	7.76 ± 1.68	0.188
LCCM2	6.73 ± 1.78	6.67 ± 1.72	0.884
LCCM3	0.79 ± 0.44	0.54 ± 0.13	0.000
RCCM1	8.13 ± 2.19	7.61 ± 1.29	0.146
RCCM2	6.52 ± 1.72	6.45 ± 1.22	0.824
RCCM3	0.80 ± 0.47	0.58 ± 0.18	0.001
LBAM1	5.50 ± 1.33	5.04 ± 0.93	0.054
LBAM2	4.75 ± 1.37	4.43 ± 0.89	0.174
LBAM3	0.38 ± 0.16	0.31 ± 0.12	0.026
RBAM1	5.87 ± 1.90	5.02 ± 0.93	0.005
RBAM2	5.08 ± 1.75	4.33 ± 0.92	0.008
RBAM3	0.40 ± 0.19	0.34 ± 0.14	0.137
LSCM1	8.13 ± 1.96	6.80 ± 1.63	0.001
LSCM2	6.47 ± 1.24	5.83 ± 1.45	0.039
LSCM3	0.83 ± 0.62	0.48 ± 0.17	0.000
RSCM1	7.94 ± 1.46	7.68 ± 1.31	0.374
RSCM2	6.77 ± 1.47	6.52 ± 1.16	0.365
RSCM3	0.58 ± 0.19	0.58 ± 0.37	0.936
LPAM1	7.10 ± 1.47	6.28 ± 1.87	0.045
LPAM2	5.85 ± 1.57	5.33 ± 1.95	0.224
LPAM3	0.63 ± 0.37	0.47 ± 0.22	0.038
RPAM1	6.70 ± 1.29	7.12 ± 1.41	0.215
RPAM2	5.59 ± 1.45	6.31 ± 1.50	0.053
RPAM3	0.56 ± 0.23	0.41 ± 0.17	0.004
LFAM1	8.23 ± 1.68	7.99 ± 1.48	0.489
LFAM2	6.86 ± 1.80	7.07 ± 1.54	0.573
LFAM3	0.69 ± 0.60	0.46 ± 0.13	0.000
RFAM1	7.49 ± 2.10	7.75 ± 1.43	0.529
RFAM2	6.10 ± 2.10	6.44 ± 1.30	0.392
RFAM3	0.70 ± 0.44	0.65 ± 0.20	0.593
LCIM1	11.07 ± 1.50	10.20 ± 1.00	0.003
LCIM2	9.02 ± 1.74	9.00 ± 8.65	0.947
LCIM3	1.02 ± 0.57	0.60 ± 0.17	0.000
RCIM1	11.14 ± 1.75	10.06 ± 1.22	0.002
RCIM2	9.32 ± 1.62	8.79 ± 1.33	0.120
RCIM3	0.91 ± 0.41	0.64 ± 0.24	0.000
LCM1	5.71 ± 1.33	4.35 ± 1.23	0.000
LCM2	4.60 ± 1.72	3.49 ± 1.28	0.001
LCM3	0.49 ± 0.30	0.39 ± 0.20	0.055

Table 4.5: Older female cadavers *vs*. adult female cadavers (cont'd)

Variable	Older females Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
RCM1	4.17 ± 1.05	3.92 ± 1.35	0.359
RCM2	3.33 ± 1.23	3.23 ± 1.30	0.737
RCM3	0.42 ± 0.25	0.34 ± 0.18	0.108
IRM1	18.22 ± 0.79	17.22 ± 0.85	0.000
IRM2	16.25 ± 1.38	15.01 ± 1.22	0.000
IRM3	0.98 ± 0.65	1.10 ± 0.56	0.385

Table 4.6 shows the *P*-values when comparing older male cadavers (73.81 ± 7.86 years of age) with older female cadavers (79.80 ± 10.25 years of age) irrespective of ancestry. The older male sample consisted of 106 cadavers and the older female sample consisted of 58 cadavers.

Table 4.6: Older male cadavers *vs*. older female cadavers

Variable	Older males Mean±SD (mm)	Older females Mean±SD (mm)	P-value
AAM1	33.49 ± 6.52	33.53 ± 5.70	0.976
AAM2	30.35 ± 7.60	30.87 ± 6.49	0.726
AAM3	1.57 ± 0.99	1.33 ± 0.77	0.202
ACM1	19.15 ± 4.03	19.50 ± 4.32	0.693
ACM2	16.95 ± 3.73	17.49 ± 3.88	0.514
ACM3	1.10 ± 0.71	1.01 ± 0.59	0.531
ABM1	19.90 ± 3.53	17.26 ± 2.83	0.000
ABM2	18.12 ± 3.80	15.05 ± 2.66	0.000
ABM3	0.89 ± 0.44	1.10 ± 0.81	0.110
LICM1	7.60 ± 1.88	6.67 ± 1.07	0.007
LICM2	6.55 ± 1.80	5.74 ± 1.30	0.019
LICM3	0.53 ± 0.24	0.47 ± 0.28	0.259
RICM1	7.47 ± 1.86	5.82 ± 1.86	0.000
RICM2	6.28 ± 1.88	4.81 ± 1.76	0.000
RICM3	0.60 ± 0.24	0.50 ± 0.16	0.046
LCCM1	8.49 ± 1.61	8.30 ± 2.22	0.634
LCCM2	7.05 ± 1.63	6.73 ± 1.78	0.352
LCCM3	0.72 ± 0.33	0.79 ± 0.44	0.361
RCCM1	8.51 ± 2.71	8.13 ± 3.19	0.336
RCCM2	7.19 ± 1.75	6.52 ± 1.72	0.067
RCCM3	0.66 ± 0.24	0.80 ± 0.47	0.052
LBAM1	5.66 ± 1.44	5.50 ± 1.33	0.574
LBAM2	4.78 ± 1.46	4.75 ± 1.37	0.921
LBAM3	0.44 ± 0.17	0.38 ± 0.16	0.055
RBAM1	6.26 ± 1.32	5.87 ± 1.90	0.228
RBAM2	5.48 ± 1.35	5.08 ± 1.75	0.201
RBAM3	0.39 ± 0.15	0.40 ±1.87	0.877

Table 4.6: Older male cadavers *vs*. older female cadavers (cont'd)

Variable	Older males Mean±SD (mm)	Older females Mean±SD (mm)	P-value
LSCM1	8.50 ± 1.55	8.13 ± 1.96	0.308
LSCM2	7.30 ± 1.44	6.47 ± 1.24	0.006
LSCM3	0.60 ± 0.28	0.83 ± 0.62	0.014
RSCM1	9.81 ± 1.50	7.94 ± 1.46	0.000
RSCM2	8.39 ± 1.45	6.77 ± 1.47	0.000
RSCM3	0.71 ± 0.29	0.58 ± 0.19	0.023
LPAM1	8.37 ± 2.49	7.10 ±1.47	0.011
LPAM2	7.16 ± 2.32	5.85 ± 1.57	0.007
LPAM3	0.61 ± 0.38	0.63 ± 0.37	0.841
RPAM1	8.03 ± 2.22	6.7 ± 1.3	0.003
RPAM2	6.69 ± 2.13	5.59 ± 1.45	0.013
RPAM3	0.67 ± 0.43	0.56 ± 0.23	0.187
LFAM1	9.4 ± 2.69	8.23 ± 1.68	0.021
LFAM2	8.06 ± 2.64	6.86 ± 1.80	0.018
LFAM3	0.67 ± 0.32	0.69 ± 0.28	0.790
RFAM1	9.77 ± 2.18	7.49 ± 2.10	0.000
RFAM2	8.13 ± 2.06	6.10 ± 2.10	0.000
RFAM3	0.82 ± 0.44	0.70 ± 0.44	0.180
LCIM1	12.11 ± 2.03	11.07 ± 1.50	0.008
LCIM2	10.12 ± 2.36	9.02 ± 1.74	0.016
LCIM3	1.00 ± 0.53	1.02 ± 0.57	0.811
RCIM1	12.55 ± 2.08	11.14 ± 1.75	0.001
RCIM2	11.01 ± 2.21	9.32 ± 1.62	0.000
RCIM3	0.77 ± 0.33	0.91 ± 0.41	0.052
LCM1	5.89 ± 2.63	5.71 ± 1.33	0.689
LCM2	4.89 ± 2.66	4.60 ± 1.72	0.556
LCM3	0.50 ± 0.28	0.49 ± 0.30	0.883
RCM1	4.34 ± 1.13	4.17 ± 1.05	0.456
RCM2	3.28 ± 1.25	3.33 ± 1.23	0.847
RCM3	0.53 ± 0.33	0.42 ± 0.25	0.075
IRM1	18.70 ± 0.74	18.22 ± 0.79	0.006
IRM2	16.67 ± 1.32	16.25 ± 1.38	0.159
IRM3	1.01 ± 0.62	0.98 ± 0.65	0.852

Table 4.7 shows the *P*-values when comparing adult male cadavers (46.97 ± 9.63 years of age) with adult female cadavers (38.92 ± 13.77 years of age) irrespective of ancestry. The adult male sample consisted of 98 cadavers and the adult female sample consisted of 59 cadavers.

Table 4.7: Adult male cadavers *vs*. adult female cadavers

Variable	Adult males Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
AAM1	27.65 ± 5.78	26.53 ± 3.9	0.245
AAM2	25.13 ± 5.77	23.79 ± 3.72	0.161
AAM3	1.26 ± 0.38	1.36 ± 0.38	0.162
ACM1	16.61 ± 2.76	15.67 ± 2.46	0.104
ACM2	14.64 ± 2.93	13.91 ± 2.54	0.227
ACM3	0.98 ± 0.50	0.88 ± 0.15	0.195
ABM1	19.05 ± 2.39	15.23 ± 3.00	0.000
ABM2	17.42 ± 2.21	13.50 ±4.29	0.000
ABM3	0.82 ± 0.33	0.86 ± 0.76	0.714
LICM1	6.92 ± 1.62	5.48 ± 1.3	0.000
LICM2	5.89 ± 1.64	4.64 ± 1.25	0.000
LICM3	0.52 ± 0.25	0.42 ±0.17	0.025
RICM1	6.88 ± 1.80	5.84 ± 1.08	0.000
RICM2	5.81 ± 1.78	5.02 ± 1.08	0.006
RICM3	0.48 ± 0.31	0.41 ± 0.19	0.172
LCCM1	8.01 ± 1.62	7.76 ± 1.68	0.439
LCCM2	6.83 ± 1.52	6.67 ± 1.72	0.631
LCCM3	0.59 ± 0.23	0.54 ± 0.13	0.179
RCCM1	8.58 ± 1.89	7.61 ± 1.29	0.002
RCCM2	6.75 ± 2.61	6.45 ± 1.22	0.433
RCCM3	0.66 ± 0.29	0.58 ± 0.18	0.085
LBAM1	5.83 ± 1.30	5.04 ± 0.93	0.000
LBAM2	5.07 ± 1.44	4.43 ± 0.89	0.006
LBAM3	0.34 ± 0.15	0.31 ± 0.12	0.310
RBAM1	5.86 ± 1.36	5.02 ± 0.93	0.000
RBAM2	5.25 ± 1.32	4.33 ± 0.92	0.000
RBAM3	0.31 ± 0.14	0.34 ± 0.14	0.167
LSCM1	7.96 ± 1.73	6.80 ± 1.63	0.001
LSCM2	6.99 ± 1.57	5.83 ± 1.45	0.000
LSCM3	0.48 ± 0.23	0.48 ± 0.17	0.988
RSCM1	8.39 ± 1.68	7.68 ± 1.31	0.017
RSCM2	7.31 ± 1.59	6.52 ± 1.16	0.004
RSCM3	0.54 ± 0.29	0.58 ± 0.37	0.519
LPAM1	7.19 ± 1.84	6.28 ± 1.87	0.033
LPAM2	6.29 ± 1.78	5.33 ± 1.95	0.024
LPAM3	0.45 ± 0.19	0.47 ± 0.22	0.545
RPAM1	6.64 ± 1.67	7.12 ± 1.41	0.184
RPAM2	5.77 ± 1.63	6.31 ± 1.50	0.146
RPAM3	0.44 ± 0.34	0.41 ± 0.17	0.676
LFAM1	8.57 ± 1.48	7.99 ± 1.48	0.090
LFAM2	7.51 ± 1.65	7.07 ± 1.54	0.215
LFAM3	0.53 ± 0.25	0.46 ± 0.13	0.104

Table 4.7: Adult male cadavers *vs*. adult female cadavers (cont'd)

Variable	Adult males Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
RFAM1	8.31 ± 2.20	7.75 ± 1.43	0.178
RFAM2	7.31 ± 2.02	6.44 ± 1.30	0.024
RFAM3	0.58 ± 0.26	0.65 ± 0.20	0.004
LCIM1	11.58 ± 1.87	10.20 ± 1.00	0.000
LCIM2	10.37 ± 1.81	9.00 ± 1.08	0.000
LCIM3	0.61 ± 0.26	0.60 ± 0.17	0.866
RCIM1	12.17 ± 2.32	10.06 ± 1.23	0.000
RCIM2	10.87 ± 2.04	8.79 ± 1.33	0.000
RCIM3	0.65 ± 0.38	0.64 ± 0.24	0.837
LCM1	5.01 ± 0.96	4.35 ± 1.23	0.006
LCM2	4.14 ± 1.06	3.49 ± 1.28	0.010
LCM3	0.43 ± 0.31	0.39 ± 0.20	0.412
RCM1	4.74 ± 1.23	3.92 ± 1.35	0.004
RCM2	3.85 ± 1.42	3.23 ± 1.30	0.036
RCM3	0.40 ± 0.23	0.34 ± 0.18	0.190
IRM1	17.64 ± 0.71	17.22 ± 0.85	0.017
IRM2	15.80 ± 1.09	15.01 ± 1.22	0.003
IRM3	0.92 ± 0.44	1.10 ± 0.59	0.110

Table 4.8 shows the *P*-values when comparing black male cadavers with black female cadavers irrespective of age. There were 76 cadavers in the black male sample and 29 cadavers in the black female sample.

Table 4.8: Black male cadavers *vs*. black female cadavers

Variable	Black males Mean±SD (mm)	Black females Mean±SD (mm)	P-value
AAM1	27.81 ± 6.24	26.2 ± 3.14	0.216
AAM2	25.41 ± 6.25	23.68 ± 2.98	0.179
AAM3	1.20 ± 0.36	1.26 ± 0.36	0.488
ACM1	15.49 ± 2.67	14.05 ± 2.95	0.147
ACM2	13.60 ± 2.74	12.36 ± 3.16	0.232
ACM3	0.94 ± 0.46	0.84 ± 0.19	0.438
ABM1	18.10 ± 2.14	15.77 ± 2.02	0.003
ABM2	16.50 ± 2.11	14.73 ±2.06	0.021
ABM3	0.80 ± 0.40	0.52 ± 0.21	0.024
LICM1	7.10 ± 1.58	5.56 ± 0.68	0.000
LICM2	6.02 ± 1.51	4.85 ± 0.63	0.000
LICM3	0.54 ± 0.22	0.35 ± 0.08	0.000
RICM1	6.78 ± 1.54	6.34 ± 0.74	0.176
RICM2	5.60 ± 1.73	5.51 ± 0.92	0.803
RICM3	0.51 ± 0.25	0.41 ± 0.23	0.120
LCCM1	7.61 ± 1.43	7.99 ± 1.78	0.332
LCCM2	6.48 ± 1.36	6.99 ± 1.84	0.200

Table 4.8: Black male cadavers *vs*. black female cadavers (cont'd)

Variable	Black males Mean±SD (mm)	Black females Mean±SD (mm)	P-value
LCCM3	0.56 ± 0.20	0.50 ± 0.13	0.156
RCCM1	8.30 ± 1.69	7.46 ± 1.37	0.033
RCCM2	6.54 ± 2.34	6.27 ± 1.26	0.582
RCCM3	0.64 ± 0.28	0.59 ± 0.13	0.466
LBAM1	5.48 ± 1.16	5.01 ± 1.16	0.113
LBAM2	4.81 ± 1.16	4.49 ± 1.14	0.274
LBAM3	0.34 ± 0.13	0.26 ± 0.08	0.012
RBAM1	5.78 ± 1.25	4.84 ± 0.85	0.001
RBAM2	5.18 ± 1.25	4.25 ± 0.85	0.001
RBAM3	0.30 ± 0.10	0.30 ± 0.12	0.841
LSCM1	7.86 ± 1.68	5.99 ± 1.17	0.000
LSCM2	6.92 ± 1.53	5.15 ± 1.08	0.000
LSCM3	0.47 ± 0.16	0.42 ± 0.11	0.138
RSCM1	8.04 ± 1.60	7.01 ± 1.12	0.005
RSCM2	7.08 ± 1.47	6.08 ± 1.03	0.003
RSCM3	0.48 ± 0.15	0.47 ± 0.14	0.774
LPAM1	6.86 ± 1.68	6.76 ± 2.55	0.900
LPAM2	5.96 ± 1.61	6.06 ± 2.58	0.889
LPAM3	0.45 ± 0.19	0.35 ± 0.19	0.164
RPAM1	6.27 ± 1.35	7.20 ± 1.97	0.110
RPAM2	5.46 ± 1.32	6.55 ± 2.16	0.076
RPAM3	0.40 ± 1.76	0.33 ± 0.12	0.182
LFAM1	8.05 ± 1.49	8.24 ± 1.68	0.732
LFAM2	7.11 ± 1.75	7.51 ± 1.83	0.528
LFAM3	0.47 ± 0.23	0.36 ± 0.11	0.126
RFAM1	8.39 ± 1.78	7.39 ± 1.39	0.084
RFAM2	7.30 ± 1.74	6.47 ± 1.04	0.119
RFAM3	0.55 ± 0.20	0.46 ± 0.18	0.198
LCIM1	11.08 ± 2.18	9.88 ± 0.97	0.054
LCIM2	9.63 ± 2.30	8.85 ± 1.03	0.230
LCIM3	0.73 ± 0.36	0.51 ± 0.21	0.046
RCIM1	11.41 ± 2.13	10.38 ± 0.98	0.087
RCIM2	10.06 ± 2.03	9.21 ± 1.10	0.151
RCIM3	0.68 ± 0.30	0.58 ± 0.25	0.310
LCM1	4.61 ± 1.00	4.24 ± 0.76	0.136
LCM2	3.83 ± 1.07	3.30 ± 1.10	0.071
LCM3	0.39 ± 0.29	0.39 ± 0.25	0.960
RCM1	4.24 ± 0.97	4.0 ± 1.02	0.307
RCM2	3.36 ± 1.17	3.39 ± 0.94	0.903
RCM3	0.39 ± 0.30	0.29 ± 0.14	0.118
IRM1	17.99 ± 0.89	17.29 ± 0.91	0.008
IRM2	16.22 ± 1.09	14.73 ± 1.38	0.000
IRM3	0.89 ± 0.40	1.28 ± 0.77	0.017

Table 4.9 shows the *P*-values when comparing white male cadavers (128 in the sample) with white female cadavers (88 in the sample), irrespective of age.

Table 4.9: White male cadavers *vs*. white female cadavers

Variable	White males Mean±SD (mm)	White females Mean±SD (mm)	P-value
AAM1	32.27 ± 6.63	30.97 ± 6.21	0.242
AAM2	29.19 ± 7.44	28.20 ± 6.69	0.417
AAM3	1.54 ± 0.90	1.39 ± 0.65	0.262
ACM1	18.70 ± 3.70	18.18 ± 3.73	0.404
ACM2	16.56 ± 3.53	16.26 ± 3.41	0.617
ACM3	1.07 ± 0.66	0.96 ± 0.45	0.239
ABM1	19.93 ± 3.23	16.39 ± 3.27	0.000
ABM2	18.18 ± 3.39	14.19 ± 3.89	0.000
ABM3	0.88 ± 0.40	1.10 ± 0.83	0.044
LICM1	7.39 ± 1.89	6.15 ±1.50	0.000
LICM2	6.37 ± 1.86	5.20 ± 1.59	0.000
LICM3	0.51 ± 0.25	0.47 ± 0.25	0.419
RICM1	7.40 ± 1.96	5.61 ± 1.59	0.000
RICM2	6.29 ± 1.86	4.70 ± 1.47	0.000
RICM3	0.56 ± 0.30	0.46 ± 0.16	0.023
LCCM1	8.62 ± 1.62	7.97 ± 1.99	0.037
LCCM2	7.20 ± 1.64	6.57 ± 1.68	0.027
LCCM3	0.71 ± 0.33	0.70 ± 0.36	0.883
RCCM1	8.68 ± 1.84	7.96 ± 1.84	0.024
RCCM2	7.23 ± 2.11	6.57 ± 1.50	0.035
RCCM3	0.67 ± 0.26	0.70 ± 0.40	0.648
LBAM1	5.89 ± 1.46	5.31 ± 1.10	0.009
LBAM2	5.98 ± 1.60	4.58 ± 1.11	0.091
LBAM3	0.42 ± 0.18	0.37 ± 0.15	0.042
RBAM1	6.24 ± 1.38	5.57 ± 1.59	0.007
RBAM2	5.48 ± 1.38	4.78 ± 1.50	0.004
RBAM3	0.38 ± 0.17	0.39 ± 0.17	0.684
LSCM1	8.45 ± 1.62	7.91 ± 1.82	0.065
LSCM2	7.28 ± 1.48	6.50 ± 1.33	0.002
LSCM3	0.58 ± 0.30	0.70 ± 0.50	0.084
RSCM1	9.72 ± 1.52	8.11 ± 1.35	0.000
RSCM2	8.31 ± 1.51	6.85 ±1.33	0.000
RSCM3	0.71 ± 0.33	0.63 ± 0.35	0.195
LPAM1	8.10 ± 2.36	6.64 ± 1.52	0.000
LPAM2	6.99 ± 2.20	5.47 ± 1.56	0.000
LPAM3	0.56 ± 0.34	0.59 ± 0.31	0.582
RPAM1	7.75 ± 2.17	6.86 ± 1.18	0.008
RPAM2	6.52 ± 2.06	5.83 ± 1.29	0.034
RPAM3	0.61 ± 0.44	0.52 ± 0.22	0.147
LFAM1	9.29 ± 2.41	8.08 ± 1.56	0.001
LFAM2	8.00 ± 2.35	6.84 ± 1.62	0.001

Table 4.9: White male cadavers *vs*. white female cadavers (cont'd)

Variable	White males Mean±SD (mm)	White females Mean±SD (mm)	P-value
LFAM3	0.65 ± 0.30	0.62 ± 0.24	0.510
RFAM1	9.32 ± 2.40	7.68 ± 1.86	0.000
RFAM2	7.89 ± 2.15	6.24 ± 1.86	0.000
RFAM3	0.71 ± 0.43	0.72 ± 0.35	0.936
LCIM1	12.11 ±1.86	10.80 ± 1.35	0.000
LCIM2	10.39 ± 2.07	9.05 ± 1.52	0.000
LCIM3	0.86 ± 0.50	0.88 ± 0.48	0.850
RCIM1	12.71 ± 2.12	10.67 ± 1.72	0.000
RCIM2	11.25 ± 2.09	9.02 ± 1.59	0.000
RCIM3	0.73 ± 0.37	0.82 ± 0.37	0.151
LCM1	6.01 ± 2.38	5.23 ± 1.54	0.032
LCM2	4.97 ± 2.45	4.26 ± 1.67	0.057
LCM3	0.52 ± 0.29	0.46 ± 0.25	0.192
RCM1	4.68 ± 1.28	4.06 ± 1.30	0.009
RCM2	3.64 ± 1.45	3.23 ± 1.37	0.110
RCM3	0.52 ± 0.28	0.42 ± 0.23	0.029
IRM1	18.29 ± 0.88	17.85 ± 0.94	0.014
IRM2	16.25 ± 1.41	15.92 ±1.34	0.212
IRM3	1.02 ± 0.62	0.97 ± 0.53	0.624

Table 4.10 shows the *P*-values when comparing older black male cadavers (71.73 ± 6.67 years of age) with older white male cadavers (74.36 ± 8.09 years of age). There were 22 older black male cadavers and 84 older white male cadavers.

Table 4.10: Older black male cadavers *vs*. older white male cadavers

Variable	Older black males Mean±SD (mm)	Older white males Mean±SD (mm)	P-value
AAM1	31. 81 ± 7.9	33.80 ± 6.28	0.405
AAM2	29.56 ± 8.10	30.50 ± 7.58	0.738
AAM3	1.12 ± 0.43	1.65 ± 1.04	0.144
ACM1	16.26 ± 3.54	19.51 ± 3.97	0.062
ACM2	14.56 ± 3.15	17.25 ± 3.71	0.096
ACM3	0.85 ± 0.31	1.13 ± 0.74	0.375
ABM1	18.16 ± 2.11	20.16 ± 3.65	0.165
ABM2	16.25 ± 2.38	18.40 ± 3.91	0.165
ABM3	0.96 ± 0.50	0.88 ± 0.43	0.676
LICM1	7.92 ± 1.76	7.54 ± 1.91	0.559
LICM2	6.80 ± 1.63	6.50 ± 1.84	0.642
LICM3	0.56 ± 0.20	0.52 ± 0.24	0.582
RICM1	7.15 ± 1.28	7.53 ± 1.95	0.586
RICM2	5.87 ± 1.19	6.35 ± 0.28	0.482
RICM3	0.64 ± 0.22	0.59 ± 0.24	0.516
LCCM1	7.26 ± 1.63	8.75 ± 1.50	0.005
LCCM2	6.07 ± 1.67	7.26 ± 1.56	0.026

Table 4.10: Older black male cadavers *vs*. older white male cadavers (cont'd)

Variable	Older black males Mean±SD (mm)	Older white males Mean±SD (mm)	P-value
LCCM3	0.59 ± 0.19	0.74 ± 0.35	0.185
RCCM1	8.48 ± 2.19	8.52 ± 1.61	0.942
RCCM2	7.26 ± 1.97	7.18 ± 1.72	0.889
RCCM3	0.61 ± 0.25	0.67 ± 0.24	0.438
LBAM1	5.63 ± 1.60	5.67 ± 1.42	0.927
LBAM2	4.81 ± 1.55	4.77 ± 1.46	0.934
LBAM3	0.41 ± 0.14	0.45 ± 0.17	0.454
RBAM1	6.57 ± 1.30	6.20 ± 1.33	0.393
RBAM2	5.90 ± 1.42	5.40 ± 1.33	0.264
RBAM3	0.34 ± 0.12	0.40 ± 0.16	0.220
LSCM1	8.14 ± 1.84	8.58 ± 1.49	0.397
LSCM2	7.09 ± 1.56	7.35 ± 1.42	0.589
LSCM3	0.53 ± 0.21	0.62 ± 0.29	0.343
RSCM1	8.50 ± 1.57	10.09 ± 1.34	0.001
RSCM2	7.52 ± 1.29	8.58 ± 1.42	0.026
RSCM3	0.49 ± 0.20	0.76 ± 0.29	0.005
LPAM1	7.08 ± 1.83	8.57 ± 2.54	0.176
LPAM2	6.22 ± 1.65	7.30 ± 2.39	0.296
LPAM3	0.43 ± 0.27	0.64 ± 0.39	0.214
RPAM1	6.68 ± 1.36	8.25 ± 2.26	0.083
RPAM2	5.89 ± 1.27	6.82 ± 2.22	0.286
RPAM3	0.40 ± 0.23	0.72 ± 0.58	0.068
LFAM1	7.91 ± 1.60	9.60 ± 2.75	0.150
LFAM2	6.85 ± 2.09	8.22 ±2.69	0.236
LFAM3	0.53 ± 0.28	0.69 ± 0.32	0.255
RFAM1	7.61 ± 1.49	10.12 ± 2.08	0.004
RFAM2	6.38 ± 1.49	8.41 ± 2.01	0.014
RFAM3	0.61 ± 0.22	0.86 ± 0.45	0.177
LCIM1	10.23 ± 1.21	12.37 ± 1.99	0.008
LCIM2	8.70 ± 2.02	10.31 ± 2.35	0.090
LCIM3	0.77 ± 0.23	1.03 ± 0.42	0.224
RCIM1	11.57 ± 1.48	12.69 ± 2.13	0.188
RCIM2	10.41 ± 1.82	11.10 ± 2.26	0.442
RCIM3	0.58 ± 0.20	0.79 ± 0.33	0.110
LCM1	4.50 ± 1.06	6.22 ± 2.78	0.063
LCM2	3.73 ± 0.92	5.16 ± 2.86	0.127
LCM3	0.39 ± 0.19	0.53 ± 0.30	0.154
RCM1	4.13 ± 1.07	4.40 ± 1.15	0.506
RCM2	3.21 ± 1.18	3.29 ± 1.28	0.853
RCM3	0.46 ± 0.42	0.55 ± 0.30	0.425
IRM1	18.92 ± 0.53	18.61 ± 0.80	0.251
IRM2	16.79 ± 1.30	16.63 ± 1.35	0.728
IRM3	1.06 ± 0.50	0.99 ± 0.76	0.758

Table 4.11 shows the *P*-values when comparing adult black male cadavers (44.67 ± 10.48 years of age) with adult white male cadavers (49.80 ± 7.70 years of age). The adult black male sample consisted of 54 cadavers and the adult white male sample consisted of 44 cadavers.

Table 4.11: Adult black male cadavers *vs*. adult white male cadavers

Variable	Adult black males Mean±SD (mm)	Adult white males Mean±SD (mm)	P-value
AAM1	26.57 ± 5.19	29.01 ± 6.31	0.131
AAM2	24.13 ± 5.06	26.40 ± 6.46	0.161
AAM3	1.22 ± 0.35	1.31 ±0.43	0.419
ACM1	15.16 ± 2.28	17.33 ± 2.73	0.014
ACM2	13.19 ± 2.56	15.37 ±2.88	0.021
ACM3	0.99 ± 0.51	0.98 ± 0.50	0.974
ABM1	18.06 ± 2.24	19.52 ± 2.35	0.069
ABM2	16.64 ± 2.04	17.79 ±2.23	0.125
ABM3	0.71 ± 0.32	0.87 ±0.33	0.161
LICM1	6.80 ± 1.42	7.06 ± 1.85	0.583
LICM2	5.73 ± 1.38	6.07 ±1.91	0.473
LICM3	0.53 ± 0.22	0.49 ± 0.28	0.567
RICM1	6.65 ± 1.61	7.14 ± 1.98	0.336
RICM2	5.51 ± 1.89	6.16 ±1.61	0.194
RICM3	0.47 ± 0.24	0.49 ± 0.38	0.787
LCCM1	7.75 ± 1.36	8.34 ± 1.88	0.197
LCCM2	6.64 ± 1.22	7.05 ± 1.84	0.348
LCCM3	0.55 ± 0.20	0.64 ± 0.25	0.151
RCCM1	8.23 ± 1.50	8.99 ± 2.25	0.151
RCCM2	6.29 ± 2.44	7.34 ± 2.75	0.134
RCCM3	0.64 ± 0.29	0.67 ± 0.30	0.758
LBAM1	5.43 ± 1.00	6.34 ± 1.47	0.008
LBAM2	4.81 ± 1.02	5.39 ± 1.80	0.127
LBAM3	0.31 ± 0.12	0.37 ± 0.18	0.170
RBAM1	5.51 ± 1.13	6.35 ± 1.52	0.023
RBAM2	4.93 ± 1.10	5.68 ± 1.50	0.037
RBAM3	0.29 ± 0.09	0.33 ± 0.19	0.244
LSCM1	7.76 ± 1.64	8.19 ± 1.85	0.370
LSCM2	6.86 ± 1.55	7.15 ± 1.62	0.508
LSCM3	0.45 ± 0.14	0.52 ± 0.31	0.273
RSCM1	7.84 ± 1.61	8.95 ± 1.60	0.017
RSCM2	6.90 ± 1.52	7.74 ± 1.57	0.056
RSCM3	0.47 ± 0.14	0.60 ± 0.38	0.110
LPAM1	6.77 ± 1.67	7.42 ± 1.92	0.276
LPAM2	5.86 ± 1.64	6.54 ± 1.84	0.243
LPAM3	0.45 ± 0.17	0.44 ± 0.20	0.859
RPAM1	6.06 ± 1.35	6.95 ± 1.76	0.108
RPAM2	5.25 ± 1.33	6.04 ± 1.73	0.142
RPAM3	0.41 ± 0.15	0.45 ± 0.40	0.684

Table 4.11: Adult black male cadavers *vs*. adult white male cadavers (cont'd)

Variable	Adult black males Mean±SD (mm)	Adult white males Mean±SD (mm)	P-value
LFAM1	8.11 ± 1.50	8.81 ± 1.65	0.190
LFAM2	7.23 ± 1.66	7.65 ± 1.65	0.438
LFAM3	0.44 ± 0.21	0.58 ± 0.27	0.097
RFAM1	8.76 ± 1.83	8.07 ± 2.37	0.337
RFAM2	7.72 ± 1.73	7.08 ± 2.16	0.330
RFAM3	0.52 ± 0.19	0.49 ± 0.29	0.779
LCIM1	11.48 ± 2.45	11.63 ± 1.52	0.800
LCIM2	10.06 ± 2.36	10.53 ± 1.46	0.427
LCIM3	0.71 ± 0.23	0.55 ± 0.26	0.058
RCIM1	11.34 ± 2.39	12.76 ± 2.13	0.053
RCIM2	9.91 ± 2.15	11.55 ± 1.70	0.010
RCIM3	0.72 ± 0.33	0.61 ± 0.41	0.370
LCM1	4.65 ± 1.00	5.52 ± 0.66	0.003
LCM2	3.87 ± 1.14	4.53 ± 0.82	0.043
LCM3	0.39 ± 0.33	0.50 ± 0.28	0.280
RCM1	4.29 ± 0.94	5.29 ± 1.34	0.007
RCM2	3.42 ± 1.18	4.38 ± 1.54	0.025
RCM3	0.36 ± 0.23	0.45 ± 0.21	0.173
IRM1	17.53 ± 0.64	17.78 ± 0.77	0.269
IRM2	15.93 ± 0.86	15.65 ± 1.32	0.432
IRM3	0.80 ± 0.32	1.07 ± 0.54	0.061

Table 4.12 shows the *P*-values when comparing adult black female cadavers (36.14 ± 11.13 years of age) with adult white female cadavers (41.42 ± 15.53 years of age). A similar comparison could not be done for older black female cadavers and older white female cadavers since the older black female grouping was too small. The adult black female sample consisted of 28 cadavers and the adult white female sample consisted of 31 cadavers.

Table 4.12: Adult black female cadavers *vs*. adult white female cadavers

Variable	Adult black females Mean±SD (mm)	Adult white females Mean±SD (mm)	P-value
AAM1	26.20 ± 3.14	26.89 ± 4.65	0.528
AAM2	23.68 ± 2.98	23.92 ± 4.46	0.814
AAM3	1.26 ± 0.36	1.48 ± 0.38	0.034
ACM1	14.05 ± 2.95	16.48 ± 1.72	0.002
ACM2	12.36 ± 3.16	14.69 ± 1.76	0.004
ACM3	0.84 ± 0.19	0.89 ± 0.12	0.301
ABM1	15.77 ± 2.02	14.87 ± 3.51	0.390
ABM2	14.73 ± 2.06	12.68 ± 5.17	0.169
ABM3	0.52 ± 0.21	1.09 ± 0.90	0.026
LICM1	5.56 ± 0.68	5.40 ± 1.73	0.671
LICM2	4.85 ± 0.63	4.42 ± 1.66	0.225
LICM3	0.35 ± 0.08	0.49 ± 0.21	0.003
RICM1	6.34 ± 0.74	5.36 ± 1.14	0.001
RICM2	5.51 ± 0.92	4.56 ±1.03	0.001
RICM3	0.41 ± 0.23	0.40 ± 0.14	0.821
LCCM1	7.99 ± 1.78	7.53 ± 1.57	0.307
LCCM2	6.99 ± 1.84	6.35 ± 1.55	0.172
LCCM3	0.50 ± 0.13	0.59 ± 0.12	0.013
RCCM1	7.46 ± 1.37	7.74 ± 1.23	0.414
RCCM2	6.27 ± 1.26	6.63 ± 1.19	0.280
RCCM3	0.59 ± 0.13	0.56 ± 0.22	0.471
LBAM1	5.01 ± 1.16	5.07 ± 0.67	0.831
LBAM2	4.49 ± 1.14	4.37 ± 0.60	0.603
LBAM3	0.26 ± 0.08	0.35 ± 0.14	0.005
RBAM1	4.84 ± 0.85	5.17 ± 0.98	0.182
RBAM2	4.25 ± 0.85	4.40 ± 0.99	0.544
RBAM3	0.30 ± 0.12	0.39 ± 0.15	0.013
LSCM1	5.99 ± 1.17	7.63 ± 1.64	0.000
LSCM2	5.15 ± 0.11	6.55 ± 0.20	0.000
LSCM3	0.42 ± 0.11	0.55 ± 0.20	0.003
RSCM1	7.01 ± 1.12	8.36 ± 1.15	0.000
RSCM2	6.08 ± 1.03	6.97 ± 1.14	0.004
RSCM3	0.47 ± 0.14	0.70 ± 0.49	0.023
LPAM1	6.76 ± 2.55	6.01 ± 1.37	0.248
LPAM2	6.06 ± 2.58	4.93 ± 1.41	0.091
LPAM3	0.35 ± 0.19	0.54 ± 0.21	0.011
RPAM1	7.20 ± 1.97	7.08 ± 1.00	0.800
RPAM2	6.55 ± 2.16	6.16 ± 0.97	0.465
RPAM3	0.33 ± 0.12	0.46 ± 0.18	0.024
LFAM1	8.24 ± 1.68	7.85 ± 1.37	0.438
LFAM2	7.51 ± 1.83	6.83 ± 1.34	0.188
LFAM3	0.36 ± 0.11	0.51 ± 0.11	0.000

Table 4.12: Adult black female cadavers *vs*. adult white female cadavers (cont'd)

Variable	Adult black females Mean±SD (mm)	Adult white females Mean±SD (mm)	P-value
RFAM1	7.39 ± 1.39	7.94 ± 1.44	0.250
RFAM2	6.47 ± 1.04	6.43 ± 1.44	0.927
RFAM3	0.46 ± 0.18	0.76 ± 0.12	0.000
LCIM1	9.88 ± 0.97	10.39 ± 0.98	0.118
LCIM2	8.85 ± 1.03	9.09 ± 1.13	0.506
LCIM3	0.51 ± 0.21	0.65 ± 0.13	0.014
RCIM1	10.38 ± 0.98	9.87 ± 1.34	0.211
RCIM2	9.21 ± 1.10	8.53 ± 1.42	0.118
RCIM3	0.58 ± 0.25	0.67 ± 0.23	0.253
LCM1	4.24 ± 0.76	4.46 ± 1.57	0.540
LCM2	3.30 ± 1.10	3.68 ± 1.44	0.317
LCM3	0.39 ± 0.25	0.39 ± 0.14	0.906
RCM1	3.97 ± 1.02	3.87 ± 1.68	0.819
RCM2	3.39 ± 0.94	3.05 ± 1.62	0.379
RCM3	0.29 ± 0.14	0.41 ± 0.21	0.020
IRM1	17.19 ± 0.81	17.24 ± 0.90	0.849
IRM2	14.77 ± 1.40	15.22 ± 1.02	0.241
IRM3	1.21 ± 0.71	1.01 ± 0.38	0.258

A paired *t*-test was done to compare arterial dimensions of arterial sites found on the left and right side of a cadaver body. Table 4.13 shows the *P*-values when comparing the respective arterial sets.

Table 4.13: Left *vs*. right sided arterial sites

Arterial sets	Left side Mean±SD (mm)	Right side Mean±SD (mm)	P-value
LICM1 *vs*. RICM1	6.71 ± 1.75	6.61 ± 1.81	0.432
LCCM1 *vs*. RCCM1	8.11 ± 1.77	8.22 ± 1.81	0.418
LBAM1 *vs*. RBAM1	5.53 ± 1.30	5.77 ± 1.45	0.005
LSCM1 *vs*. RSCM1	7.85 ± 1.80	8.59 ± 1.71	0.000
LPAM1 *vs*. RPAM1	7.33 ± 2.15	7.22 ± 1.83	0.523
LFAM1 *vs*. RFAM1	8.72 ± 1.98	8.44 ± 2.23	0.046
LCIM1 *vs*. RCIM1	11.33 ± 1.81	11.54 ± 2.11	0.086
LCM1 *vs*. RCM1	5.26 ± 1.83	4.32 ± 1.23	0.000

The strength of the correlation between the arterial dimensions and demographic parameters of a South African cadaver sample were analysed using Pearson's correlation tests. A Pearson's correlation attempts to draw a line of best fit through the data of two variables, and the Pearson correlation coefficient, *r*, indicates how far away all these data points are from this line of best fit. An *r*-value can range from -1 for a perfect negative linear relationship to +1

for a perfect positive linear relationship. A value of 0 (zero) indicates no relationship between two variables. [105]

Table 4.14 depicts the *r*-values for the correlation between the dependent variable (arterial dimensions) and the various independent variables (demographic parameters) for the cadaver study.

Researchers have suggested the following for the absolute value of r[105]:
0.001-0.199: very weak correlation
0.200-0.399: weak correlation
0.400-0.599: moderate correlation
0.600-0.799: strong correlation
0.800-1.000: very strong correlation

In Table 4.14, positive relationships are indicated in white. Moderate positive relationships (0.400-0.599) * are shaded in green, weak positive relationships (0.200-0.399) * are shaded in blue and very weak positive relationships (0.001-0.199) * are shaded in red.

Negative relationships are indicated in black, weak negative relationships (0.200-0.399) * are shaded in blue and very weak (0.001-0.199) * negative relationships are shaded in red.

* Absolute values

Table 4.14: Correlation between dependent and independent variables of cadaver study

Dependent variable	Independent variables			
	Age	Weight	Height	BMI
AAM1	0.532	0.218	-0.007	0.229
AAM2	0.479	0.186	-0.021	0.205
AAM3	0.115	0.083	0.067	0.044
ACM1	0.465	0.252	-0.016	0.318
ACM2	0.453	0.267	-0.033	0.342
ACM3	0.126	0.005	0.051	-0.013
ABM1	0.223	0.316	0.332	0.184
ABM2	0.128	0.312	0.374	0.164
ABM3	0.241	-0.074	-0.223	0.014
LICM1	0.346	0.166	0.090	0.211
LICM2	0.349	0.125	0.075	0.174
LICM3	0.015	0.156	0.061	0.146
RICM1	0.118	0.178	0.259	0.087
RICM2	0.072	0.141	0.228	0.059
RICM3	0.249	0.159	0.104	0.128
LCCM1	0.170	0.358	0.056	0.311
LCCM2	0.076	0.352	0.097	0.291
LCCM3	0.286	0.090	-0.095	0.116
RCCM1	0.091	0.277	0.092	0.272
RCCM2	0.073	0.300	0.120	0.293
RCCM3	0.185	0.156	-0.040	0.148
LBAM1	0.082	0.251	0.139	0.211
LBAM2	0.030	0.158	0.081	0.149
LBAM3	0.311	0.309	0.060	0.244
RBAM1	0.260	0.275	0.173	0.234
RBAM2	0.211	0.241	0.176	0.210
RBAM3	0.256	0.194	0.019	0.148
LSCM1	0.381	0.064	0.022	0.064
LSCM2	0.300	0.078	0.071	0.056
LSCM3	0.320	-0.005	-0.092	0.039
RSCM1	0.309	0.220	0.240	0.137
RSCM2	0.273	0.178	0.236	0.099
RSCM3	0.156	0.145	0.054	0.120
LPAM1	0.279	0.192	0.098	0.187
LPAM2	0.187	0.215	0.131	0.197
LPAM3	0.338	-0.054	-0.099	-0.013

Table 4.14: Correlation between dependent and independent variables of cadaver study (cont'd)

Dependent variable	Independent variables			
	Age	Weight	Height	BMI
RPAM1	0.130	0.142	0.110	0.113
RPAM2	0.012	0.110	0.091	0.084
RPAM3	0.318	0.095	0.056	0.084
LFAM1	0.179	0.234	0.121	0.212
LFAM2	0.084	0.246	0.148	0.213
LFAM3	0.355	-0.048	-0.099	-0.003
RFAM1	0.171	0.170	0.174	0.087
RFAM2	0.086	0.136	0.207	0.039
RFAM3	0.270	0.128	-0.057	0.152
LCIM1	0.275	0.184	0.183	0.141
LCIM2	0.050	0.153	0.210	0.090
LCIM3	0.432	0.041	-0.081	0.088
RCIM1	0.249	0.247	0.288	0.157
RCIM2	0.171	0.268	0.337	0.166
RCIM3	0.242	-0.049	-0.128	-0.017
LCM1	0.300	0.194	0.025	0.196
LCM2	0.240	0.142	0.049	0.123
LCM3	0.214	0.142	-0.035	0.193
RCM1	0.043	0.183	0.202	0.104
RCM2	-0.039	0.103	0.142	0.043
RCM3	0.207	0.171	0.122	0.137
IRM1	0.447	0.138	0.092	0.161
IRM2	0.286	0.046	0.067	0.077
IRM3	0.024	0.060	-0.004	0.041

4.3 CT study

Various two-sample *t*-tests were performed to establish whether there is a statistically significant difference between the arterial dimensions of a South Africa CT sample with reference to specific demographic parameters. Comparisons were drawn between large groupings (e.g. older individuals *vs.* adult individuals or black individuals *vs.* white individuals), as well as between more defined groupings (e.g. older males *vs.* adult males or black older males *vs.* white older males) of the various population groups.

Table 4.15 shows the probability values or *P*-values when comparing the older CT population (79.14 ± 11.32 years of age) with the adult CT population (37.70 ± 12.12 years of age)

irrespective of sex and ancestry. The older CT sample consisted of 80 individuals and the adult CT sample consisted of 133 individuals.

It must be noted that throughout the results presented, in some instances not all relevant arterial sites could be measured on each individual – therefore the mentioned sample size could be slightly less for a specific arterial site.

Throughout the results presented for the CT study, a *P*-value smaller than 0.05 (shaded in blue), indicates a statistically significant difference between the arterial dimensions of the two groupings. [104] For each variable, the means and standard deviations are also indicated.

Table 4.15: Older CT population *vs*. adult CT population

Variable	Older population Mean±SD (mm)	Adult population Mean±SD (mm)	P-value
AAM1	29.87 ± 5.91	25.43 ± 4.65	0.000
ACM1	18.28 ± 3.97	17.26 ± 3.23	0.100
ABM1	16.72 ± 3.01	16.85 ± 2.88	0.809
LICM1	6.17 ± 1.46	6.4 ± 1.57	0.370
RICM1	5.93 ± 1.50	6.55 ± 1.40	0.012
LCCM1	8.10 ± 1.98	8.66 ± 2.15	0.106
RCCM1	7.93 ± 1.80	8.42 ± 1.72	0.088
LSCM1	7.54 ± 1.89	8.80 ± 2.61	0.001
RSCM1	7.96 ± 1.49	9.05 ± 2.44	0.001
LPAM1	6.86 ± 1.58	6.92 ± 1.75	0.846
RPAM1	6.94 ± 1.34	7.75 ± 1.55	0.004
LFAM1	8.26 ± 1.71	8.54 ± 1.82	0.367
RFAM1	7.76 ± 1.87	8.46 ± 1.77	0.031
LCIM1	10.79 ± 1.45	10.74 ± 1.89	0.868
RCIM1	10.85 ± 1.64	10.98 ± 1.90	0.688

Table 4.16 shows the *P*-values when comparing black CT individuals with white CT individuals irrespective of sex and age. The black CT sample consisted of 114 individuals and the white CT sample consisted of 99 individuals.

Table 4.16: Black CT individuals *vs.* white CT individuals

Variable	Black individuals Mean±SD (mm)	White individuals Mean±SD (mm)	P-value
AAM1	25.08 ± 4.20	30.22 ± 5.98	0.000
ACM1	17.22 ± 3.45	18.12 ± 3.68	0.148
ABM1	16.92 ± 2.80	16.69 ± 3.05	0.664
LICM1	6.57 ± 1.45	6.11 ± 1.50	0.069
RICM1	6.75 ± 1.24	5.81 ± 1.55	0.000
LCCM1	8.81 ± 2.16	8.09 ± 1.96	0.041
RCCM1	8.43 ± 1.78	8.02 ± 1.76	0.177
LSCM1	8.46 ± 2.66	8.01 ± 2.10	0.271
RSCM1	8.83 ± 2.41	8.30 ± 1.76	0.133
LPAM1	7.10 ± 1.78	6.71 ± 1.56	0.194
RPAM1	7.73 ± 1.56	7.15 ± 1.44	0.038
LFAM1	8.53 ± 1.89	8.32 ± 1.67	0.521
RFAM1	8.52 ± 1.86	7.84 ± 1.77	0.031
LCIM1	10.59 ± 1.87	10.92 ± 1.54	0.269
RCIM1	10.96 ± 1.82	10.89 ± 1.77	0.817

Table 4.17 shows the *P*-values when comparing older male CT individuals (79.40 ± 12.24 years of age) with adult male CT individuals (37.27 ± 11.84 years of age) irrespective of ancestry. The older male CT sample consisted of 41 individuals and the adult male CT sample consisted of 54 individuals.

Table 4.17: Older male CT individuals *vs.* adult male CT individuals

Variable	Older males Mean±SD (mm)	Adult males Mean±SD (mm)	P-value
AAM1	27.18 ± 4.58	24.91 ± 4.02	0.021
ACM1	16.43 ± 2.46	18.08 ± 3.24	0.033
ABM1	16.03 ± 3.21	17.67 ± 2.39	0.031
LICM1	5.58 ± 1.50	7.01 ± 1.52	0.000
RICM1	5.9 ± 1.12	7.22 ± 1.19	0.000
LCCM1	7.87 ± 1.66	9.59 ± 2.24	0.001
RCCM1	7.71 ± 1.36	9.10 ± 1.70	0.000
LSCM1	6.97 ± 1.69	10.34 ± 2.35	0.000
RSCM1	7.85 ± 1.40	10.39 ± 2.37	0.000
LPAM1	6.65 ± 1.73	7.51 ± 1.57	0.062
RPAM1	7.11 ± 1.42	8.21 ± 1.67	0.019
LFAM1	8.21 ± 1.82	8.81 ± 1.90	0.231
RFAM1	7.95 ± 1.45	8.73 ± 1.80	0.083
LCIM1	10.47 ± 1.44	10.97 ± 2.16	0.317
RCIM1	10.38 ± 1.20	11.60 ± 1.98	0.009

Table 4.18 shows the *P*-values when comparing older female CT individuals (78.87 ± 10.44 years of age) with adult female CT individuals (38.00 ± 12.38 years of age) irrespective of

ancestry. The older female CT sample consisted of 39 individuals and the adult female CT sample consisted of 79 individuals.

Table 4.18: Older female CT individuals *vs*. adult female CT individuals

Variable	Older females Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
AAM1	32.56 ± 5.92	25.96 ± 5.22	0.000
ACM1	19.74 ± 4.34	16.50 ± 3.07	0.000
ABM1	17.16 ± 2.85	15.98 ± 3.13	0.108
LICM1	6.76 ± 1.16	5.81 ± 1.39	0.003
RICM1	5.96 ± 1.87	5.91 ± 1.29	0.892
LCCM1	8.35 ± 2.29	7.85 ± 1.71	0.289
RCCM1	8.17 ± 2.19	7.84 ± 1.51	0.445
LSCM1	8.2 ± 1.92	7.25 ± 1.84	0.041
RSCM1	8.07 ± 1.59	7.71 ± 1.64	0.340
LPAM1	7.02 ± 1.47	6.37 ± 1.76	0.117
RPAM1	6.82 ± 1.30	7.31 ± 1.31	0.147
LFAM1	8.29 ± 1.66	8.26 ± 1.71	0.947
RFAM1	7.64 ± 2.11	8.19 ± 1.73	0.228
LCIM1	11.01 ± 1.43	10.47 ± 1.53	0.134
RCIM1	11.14 ± 1.82	10.28 ± 1.56	0.033

Table 4.19 shows the *P*-values when comparing older male CT individuals (79.40 ± 12.24 years of age) with older female CT individuals (78.87 ± 10.44 years of age) irrespective of ancestry. The older male CT sample consisted of 41 individuals and the older female CT sample consisted of 39 individuals.

Table 4.19: Older male CT individuals *vs*. older female CT individuals

Variable	Older males Mean±SD (mm)	Older females Mean±SD (mm)	P-value
AAM1	27.18 ± 4.58	32.56 ± 5.92	0.000
ACM1	16.43 ± 2.46	19.74 ± 4.34	0.001
ABM1	16.03 ± 3.21	17.16 ± 2.85	0.181
LICM1	5.58 ± 1.50	6.76 ± 1.16	0.001
RICM1	5.9 ± 1.12	5.96 ± 1.87	0.862
LCCM1	7.87 ± 1.67	8.35 ± 2.29	0.320
RCCM1	7.71 ± 1.36	8.17 ± 2.19	0.283
LSCM1	6.97 ± 1.69	8.2 ± 1.92	0.007
RSCM1	7.85 ± 1.40	8.07 ± 1.59	0.535
LPAM1	6.65 ± 1.73	7.02 ± 1.47	0.417
RPAM1	7.11 ± 1.42	6.82 ± 1.30	0.474
LFAM1	8.21 ± 1.82	8.29 ± 1.66	0.873
RFAM1	7.95 ± 1.45	7.64 ± 2.11	0.548
LCIM1	10.47 ± 1.44	11.01 ± 1.43	0.168
RCIM1	10.38 ± 1.20	11.14 ± 1.82	0.082

Table 4.20 shows the *P*-values when comparing adult male CT individuals (37.27 ± 11.84 years of age) with adult female CT individuals (38.00 ± 12.38 years of age) irrespective of ancestry. The adult male CT sample consisted of 54 individuals and the adult female CT sample consisted of 79 individuals.

Table 4.20: Adult male CT individuals *vs*. adult female CT individuals

Variable	Adult males Mean±SD (mm)	Adult females Mean±SD (mm)	P-value
AAM1	24.91 ± 4.02	25.96 ± 5.22	0.295
ACM1	18.08 ± 3.24	16.50 ± 3.07	0.032
ABM1	17.67 ± 2.39	15.98 ± 3.13	0.012
LICM1	7.01 ± 1.52	5.81 ± 1.39	0.001
RICM1	7.22 ± 1.19	5.91 ± 1.29	0.000
LCCM1	9.59 ± 2.24	7.85 ± 1.71	0.000
RCCM1	9.10 ± 1.70	7.84 ± 1.51	0.001
LSCM1	10.34 ± 2.35	7.25 ± 1.84	0.000
RSCM1	10.39 ± 2.37	7.71 ± 1.64	0.000
LPAM1	7.51 ± 1.57	6.37 ± 1.76	0.005
RPAM1	8.21 ± 1.67	7.31 ± 1.31	0.013
LFAM1	8.81 ± 1.90	8.26 ± 1.71	0.196
RFAM1	8.73 ± 1.8	8.19 ± 1.73	0.189
LCIM1	10.97 ± 2.16	10.47 ± 1.53	0.247
RCIM1	11.60 ± 1.98	10.28 ± 1.56	0.002

Table 4.21 shows the *P*-values when comparing black male CT individuals with black female CT individuals irrespective of age. The black male CT sample consisted of 62 individuals and the black female CT sample consisted of 52 individuals.

Table 4.21: Black male CT individuals *vs*. black female CT individuals

Variable	Black males Mean±SD (mm)	Black females Mean±SD (mm)	P-value
AAM1	25.25 ± 3.97	24.80 ± 4.59	0.637
ACM1	17.36 ± 3.42	17.06 ± 3.55	0.732
ABM1	17.62 ± 2.48	15.95 ± 2.98	0.022
LICM1	6.65 ± 1.50	6.40 ± 1.36	0.513
RICM1	6.93 ± 1.18	6.37 ± 1.32	0.090
LCCM1	8.98 ± 2.34	8.45 ± 1.72	0.347
RCCM1	8.51 ± 1.81	8.25 ± 1.75	0.576
LSCM1	8.84 ± 2.79	7.62 ± 2.17	0.075
RSCM1	9.13 ± 2.54	8.17 ± 2.01	0.123
LPAM1	7.54 ± 1.76	6.55 ± 1.67	0.032
RPAM1	8.11 ± 1.76	7.21 ± 1.25	0.031
LFAM1	8.84 ± 2.01	8.12 ± 1.66	0.143
RFAM1	8.57 ± 1.93	8.47 ± 1.81	0.831
LCIM1	10.77 ± 2.17	10.33 ± 1.34	0.347
RCIM1	11.31 ± 2.07	10.46 ± 1.25	0.063

Table 4.22 shows the *P*-values when comparing white male CT individuals (33 in the sample) with white female CT individuals (66 in the sample) irrespective of age.

Table 4.22: White male CT individuals *vs*. white female CT individuals

Variable	White males Mean±SD (mm)	White females Mean±SD (mm)	P-value
AAM1	27.27 ± 4.95	31.95 ± 5.90	0.001
ACM1	17.43 ± 2.57	18.57 ± 4.23	0.201
ABM1	16.30 ± 3.10	16.9 ± 3.05	0.448
LICM1	5.82 ± 1.83	6.26 ± 1.28	0.232
RICM1	5.96 ± 1.36	5.72 ± 1.66	0.531
LCCM1	8.25 ± 1.67	8.00 ± 2.11	0.610
RCCM1	8.15 ± 1.93	8.15 ± 1.45	0.631
LSCM1	8.45 ± 2.42	7.75 ± 1.87	0.184
RSCM1	9.20 ± 1.94	7.81 ± 1.45	0.001
LPAM1	6.67 ± 1.40	6.73 ± 1.67	0.885
RPAM1	7.38 ± 1.58	7.03 ± 1.36	0.373
LFAM1	8.25 ± 1.66	8.37 ± 1.69	0.777
RFAM1	8.25 ± 1.38	7.59 ± 1.94	0.134
LCIM1	10.82 ± 1.54	10.98 ± 1.55	0.672
RCIM1	10.92 ± 1.36	10.87 ± 1.96	0.900

Table 4.23 shows the *P*-values when comparing older black male CT individuals (80.00 ± 10.00 years of age) with older white male CT individuals (78.96 ± 13.87 years of age). The older black male CT sample consisted of 18 individuals and the older white male CT sample consisted of 23 individuals.

Table 4.23: Older black male CT individuals *vs.* older white male CT individuals

Variable	Older black males Mean±SD (mm)	Older white males Mean±SD (mm)	*P*-value
AAM1	26.03 ± 3.97	28.2 ± 4.95	0.159
ACM1	15.76 ± 3.50	16.59 ± 2.23	0.511
ABM1	16.72 ± 1.32	15.81 ± 3.61	0.594
LICM1	5.66 ± 0.85	5.5 ± 1.93	0.769
RICM1	6.28 ± 0.86	5.60 ± 1.22	0.067
LCCM1	7.82 ± 1.64	7.91 ± 1.72	0.885
RCCM1	7.43 ± 1.37	7.93 ± 1.34	0.262
LSCM1	6.32 ± 1.20	7.56 ± 1.87	0.026
RSCM1	7.15 ± 1.15	8.48 ± 1.32	0.003
LPAM1	7.85 ± 2.59	6.36 ± 1.43	0.125
RPAM1	8.00 ± 2.20	6.87 ± 1.13	0.166
LFAM1	8.63 ± 1.73	8.13 ± 1.87	0.629
RFAM1	7.45 ± 1.70	8.05 ± 1.43	0.464
LCIM1	9.94 ± 1.11	10.61 ± 1.52	0.369
RCIM1	9.94 ± 1.11	10.51 ± 1.22	0.363

Table 4.24 shows the *P*-values when comparing adult black male CT individuals (37.33 ± 12.09 years of age) with adult white male CT individuals (37.00 ± 11.23 years of age). The adult black male CT sample consisted of 44 individuals and the adult white male CT sample consisted of 10 individuals.

Table 4.24: Adult black male CT individuals *vs*. adult white male CT individuals

Variable	Black adult males Mean±SD (mm)	White adult males Mean±SD (mm)	P-value
AAM1	24.88 ± 3.97	25.05 ± 4.50	0.913
ACM1	17.64 ± 3.39	19.66 ± 2.12	0.119
ABM1	17.78 ± 2.61	17.29 ± 1.36	0.613
LICM1	7.14 ± 1.52	6.49 ± 1.49	0.285
RICM1	7.27 ± 1.19	6.99 ± 1.26	0.578
LCCM1	9.69 ± 2.44	9.19 ± 1.18	0.605
RCCM1	9.17 ± 1.74	8.81 ± 1.67	0.631
LSCM1	10.22 ± 2.42	10.86 ± 2.13	0.527
RSCM1	10.22 ± 2.43	11.17 ± 2.06	0.343
LPAM1	7.50 ± 1.68	7.53 ± 0.96	0.963
RPAM1	8.12 ± 1.64	8.63 ± 1.93	0.505
LFAM1	8.87 ± 2.07	8.59 ± 0.92	0.730
RFAM1	8.72 ± 1.93	8.79 ± 1.18	0.932
LCIM1	10.90 ± 2.27	11.34 ± 1.59	0.625
RCIM1	11.52 ± 2.12	12.00 ± 1.15	0.565

Table 4.25 shows the *P*-values when comparing adult black female CT individuals (37.53 ± 10.79 years of age) with adult white female CT individuals (40.45 ± 14.15 years of age). The adult black female CT sample consisted of 50 individuals and the adult white female CT sample consisted of 29 individuals.

Table 4.25: Adult black female CT individuals *vs*. adult white female CT individuals

Variable	Adult black females Mean±SD (mm)	Adult white females Mean±SD (mm)	P-value
AAM1	24.86 ± 4.72	28.80 ± 5.55	0.024
ACM1	16.63 ± 3.29	16.23 ± 2.66	0.703
ABM1	15.83 ± 2.97	16.31 ± 3.58	0.678
LICM1	6.25 ± 1.21	5.46 ± 1.30	0.068
RICM1	6.30 ± 1.31	5.38 ± 1.18	0.036
LCCM1	8.40 ± 1.75	7.39 ± 1.53	0.073
RCCM1	8.28 ± 1.79	7.48 ± 0.98	0.120
LSCM1	7.30 ± 1.99	7.24 ± 1.89	0.929
RSCM1	7.85 ± 1.77	7.66 ± 1.65	0.749
LPAM1	6.52 ± 1.72	6.11 ± 1.86	0.507
RPAM1	7.17 ± 1.26	7.55 ± 1.41	0.399
LFAM1	8.15 ± 1.67	8.48 ± 1.83	0.588
RFAM1	8.42 ± 1.84	7.70 ± 1.40	0.239
LCIM1	10.22 ± 1.33	11.04 ± 1.86	0.142
RCIM1	10.39 ± 1.26	10.03 ± 2.13	0.525

Table 4.26 shows the *P*-values when comparing older black female CT individuals (65.00 ± 00.00 years of age) with older white female CT individuals (79.62 ± 10.18 years of age). The comparison could not be done for all measurements since the older black female grouping was too small for certain measurements (shaded in black). The older black female CT sample consisted of 2 individuals and the older white female CT sample consisted of 37 individuals.

Table 4.26: Older black female CT individuals *vs*. older white female CT individuals

Variable	Older black females Mean±SD (mm)	Older white females Mean±SD (mm)	*P*-value
AAM1	23.95 ± 1.77	33.07 ± 5.68	0.032
ACM1	22.80 ± 0.71	19.55 ± 4.41	0.312
ABM1		17.10 ± 2.87	
LICM1		6.68 ± 1.07	
RICM1		5.9 ± 1.86	
LCCM1		8.31 ± 2.31	
RCCM1		8.18 ± 2.22	
LSCM1	10.85 ± 0.35	8.02 ± 1.84	0.041
RSCM1	11.35 ± 1.77	7.87 ± 1.36	0.002
LPAM1	6.90 ± 1.13	7.03 ± 1.51	0.908
RPAM1		6.76 ± 1.29	
LFAM1	7.70 ± 2.12	8.33 ± 1.67	0.614
RFAM1	9.10 ± 1.56	7.55 ± 2.13	0.322
LCIM1	11.70 ± 0.28	10.96 ± 1.46	0.487
RCIM1	11.35 ± 0.64	11.13 ± 1.87	0.868

A paired *t*-test was done to compare arterial dimensions of arterial sites found on the left and right side. Table 4.27 shows the *P*-values when comparing the respective arterial sets in the CT study. A *P*-value smaller than 0.05 (shaded in blue), indicates a statistically significant difference between the left and right sided arterial sites. [104] For each arterial dimension, the mean and standard deviation are also indicated.

Table 4.27: Left *vs.* right sided arterial sets

Arterial set	Left side Mean±SD (mm)	Right side Mean±SD (mm)	*P*-value
LICM1 *vs*. RICM1	6.28 ± 1.53	6.32 ± 1.48	0.748
LCCM1 *vs*. RCCM1	8.39 ± 2.08	8.18 ± 1.79	0.192
LSCM1 *vs*. RSCM1	8.21 ± 2.38	8.58 ± 2.10	0.008
LPAM1 *vs*. RPAM1	6.90 ± 1.69	7.44 ± 1.53	0.002
LFAM1 *vs*. RFAM1	8.43 ± 1.78	8.16 ± 1.85	0.071
LCOM1 *vs*. RCIM1	10.74 ± 1.70	10.84 ± 1.72	0.343

The strength of the correlation between the arterial dimensions and demographic parameters of a South African CT sample were analysed using Pearson's correlation tests. A Pearson's correlation attempts to draw a line of best fit through the data of two variables, and the Pearson correlation coefficient, *r*, indicates how far away all these data points are from this line of best fit. An *r*-value can range from -1 for a perfect negative linear relationship to +1 for a perfect positive linear relationship. A value of 0 (zero) indicates no relationship between two variables.[105]

Table 4.28 depicts the *r*-values for the correlation between the dependent variable (arterial dimensions) and the independent variable (age) for the CT study.

In Table 4.28, moderate positive relationships (0.400-0.599) * are indicated in white, shaded in green, weak positive relationships (0.200-0.399) * are shaded in blue and very weak positive relationships (0.001-0.199) * are shaded in red.

Weak negative relationships (0.200-0.399) * are indicated in black, shaded in blue and very weak (0.001-0.199) * negative relationships are shaded in red.

Table 4.28: Correlation between dependent and independent variables of CT study

Dependent variable	Independent variable
	Age
AAM1	0.516
ACM1	0.100
ABM1	-0.019
LICM1	0.019
RICM1	-0.194
LCCM1	-0.122
RCCM1	-0.145
LSCM1	-0.268
RSCM1	-0.271
LPAM1	-0.047
RPAM1	-0.318
LFAM1	-0.107
RFAM1	-0.213
LCIM1	0.078
RCIM1	0.000

4.4 Ultrasound study

Various two-sample *t*-tests were performed to establish whether there is a statistically significant difference between the arterial dimensions of a South Africa ultrasound sample with

reference to specific demographic parameters. Comparisons were drawn between large groupings (e.g. black individuals *vs.* white individuals), as well as between more defined groupings (e.g. black adult males *vs.* white adult males) of the various population groups. The older population was not included in this study.

Table 4.29 shows the *P*-values when comparing black ultrasound individuals with white ultrasound individuals irrespective of sex and age. The black ultrasound sample consisted of 32 individuals and the white ultrasound sample consisted of 49 individuals.

It must be noted that throughout the results presented, in some instances not all relevant arterial sites could be measured on each individual – therefore the mentioned sample size could be slightly less for a specific arterial site.

Throughout the results presented for the ultrasound study, a *P*-value smaller than 0.05 (shaded in green), indicates a statistically significant difference between the arterial dimensions of the two groupings. [104] For each variable, the means and standard deviations are also indicated.

Table 4.29: Black ultrasound individuals *vs*. white ultrasound individuals

Variable	Black individuals Mean±SD (mm)	White individuals Mean±SD (mm)	*P*-value
LBAM1	5.80 ± 1.55	5.77 ± 2.03	0.937
RBAM1	5.98 ± 2.07	5.68 ± 1.68	0.536
LSCM1	6.55 ± 1.36	7.32 ± 1.76	0.078
RSCM1	7.33 ± 2.38	7.72 ± 1.95	0.479
LPAM1	6.38 ± 1.64	6.62 ± 2.11	0.639
RPAM1	6.90 ± 1.73	6.75 ± 1.51	0.718
LFAM1	7.22 ± 1.91	7.86 ± 1.73	0.176
RFAM1	7.26 ± 1.83	7.71 ± 2.16	0.407

Table 4.30 shows the *P*-values when comparing adult male ultrasound individuals (22.30 ± 3.74 years of age) with adult female ultrasound individuals (21.59 ± 3.32 years of age) irrespective of ancestry. The adult male ultrasound sample consisted of 40 individuals and the adult female ultrasound sample consisted of 41 individuals.

Table 4.30: Adult male ultrasound individuals *vs*. adult female ultrasound individuals

Variable	Adult males Mean±SD (mm)	Adult females Mean±SD (mm)	*P*-value
LBAM1	6.08 ± 2.13	5.41 ± 1.38	0.100
RBAM1	6.03 ± 1.86	5.42 ± 1.52	0.109
LSCM1	7.70 ± 1.66	6.28 ± 1.22	0.000
RSCM1	8.29 ± 1.89	6.53 ± 1.90	0.000
LPAM1	7.33 ± 2.06	5.88 ± 1.53	0.001
RPAM1	6.79 ± 1.74	6.78 ± 1.27	0.977
LFAM1	8.35 ± 1.68	7.29 ± 1.77	0.007
RFAM1	8.25 ± 2.16	7.05 ± 1.67	0.007

Table 4.31 shows the *P*-values when comparing black male ultrasound individuals with black female ultrasound individuals irrespective of age. The black male ultrasound sample consisted of 13 individuals and the black female ultrasound sample consisted of 19 individuals.

Table 4.31: Black male ultrasound individuals *vs*. black female ultrasound individuals

Variable	Black males Mean±SD (mm)	Black females Mean±SD (mm)	*P*-value
LBAM1	6.48 ± 1.63	5.39 ± 1.41	0.123
RBAM1	6.79 ± 2.57	5.48 ± 1.60	0.163
LSCM1	7.49 ± 1.47	5.97 ± 0.94	0.009
RSCM1	8.78 ± 1.94	6.45 ± 2.24	0.025
LPAM1	6.49 ± 1.24	6.31 ± 1.89	0.814
RPAM1	7.50 ± 1.75	6.52 ± 1.67	0.216
LFAM1	7.64 ± 1.48	6.96 ± 2.15	0.445
RFAM1	7.31 ± 1.95	7.22 ± 1.84	0.917

Table 4.32 shows the *P*-values when comparing white male ultrasound individuals with white female ultrasound individuals irrespective of age. The white male ultrasound sample consisted of 27 individuals and the white female ultrasound sample consisted of 22 individuals.

Table 4.32: White male ultrasound individuals *vs*. white female ultrasound individuals

Variable	White males Mean±SD (mm)	White females Mean±SD (mm)	*P*-value
LBAM1	6.00 ± 2.40	5.48 ± 1.43	0.374
RBAM1	5.89 ± 1.77	5.43 ± 1.57	0.340
LSCM1	7.93 ± 1.81	6.58 ± 1.41	0.006
RSCM1	8.39 ± 1.88	6.90 ± 1.73	0.006
LPAM1	7.52 ± 2.26	5.51 ± 1.25	0.001
RPAM1	6.66 ± 1.80	6.86 ± 1.06	0.643
LFAM1	8.33 ± 1.74	7.25 ± 1.56	0.031
RFAM1	8.52 ± 2.24	6.66 ± 1.53	0.002

Table 4.33 shows the *P*-values when comparing adult black male ultrasound individuals (21.38 ± 4.47 years of age) with adult white male ultrasound individuals (22.74 ± 3.72 years of age). The black male ultrasound sample consisted of 13 individuals and the white male ultrasound sample consisted of 27 individuals.

Table 4.33: Adult black male ultrasound individuals *vs*. adult white male ultrasound individuals

Variable	Adult black males Mean±SD (mm)	Adult white males Mean±SD (mm)	*P*-value
LBAM1	6.48 ± 1.63	6.00 ± 2.40	0.605
RBAM1	6.79 ± 2.57	5.89 ± 1.77	0.265
LSCM1	7.49 ± 1.47	7.93 ± 1.81	0.537
RSCM1	8.78 ± 1.94	8.39 ± 1.88	0.619
LPAM1	6.49 ± 1.24	7.52 ± 2.26	0.227
RPAM1	7.50 ± 1.75	6.66 ± 1.80	0.249
LFAM1	7.64 ± 1.48	8.33 ± 1.74	0.315
RFAM1	7.31 ± 1.95	8.52 ± 2.24	0.178

Table 4.34 shows the *P*-values when comparing adult black female ultrasound individuals (20.31 ± 2.69 years of age) with adult white female ultrasound individuals (22.05 ± 3.64 years of age). The black female ultrasound sample consisted of 19 individuals and the white female ultrasound sample consisted of 22 individuals.

Table 4.34: Adult black female ultrasound individuals *vs*. adult white female ultrasound individuals

Variable	Adult black females Mean±SD (mm)	Adult white females Mean±SD (mm)	*P*-value
LBAM1	5.39 ± 1.41	4.48 ± 1.43	0.866
RBAM1	5.48 ± 1.60	5.43 ± 1.57	0.929
LSCM1	5.97 ± 0.94	6.58 ± 1.41	0.177
RSCM1	6.45 ± 2.24	6.90 ± 1.73	0.511
LPAM1	6.31 ± 1.89	5.51 ± 1.25	0.142
RPAM1	6.52 ± 1.67	6.86 ± 1.06	0.472
LFAM1	6.96 ± 2.15	7.25 ± 1.56	0.651
RFAM1	7.22 ± 1.84	6.66 ± 1.53	0.343

A paired *t*-test was done to compare arterial dimensions of arterial sites found on the left and right side. Table 4.35 shows the *P*-values when comparing the respective arterial sets in the ultrasound study.

Table 4.35: Left *vs*. right sided arterial sets

Arterial set	Left side Mean±SD (mm)	Right side Mean±SD (mm)	*P*-value
LBAM1 *vs*. RBAM1	5.74 ± 1.81	5.72 ± 1.72	0.894
LSCM1 *vs*. RSCM1	6.98 ± 1.61	7.40 ± 2.08	0.068
LPAM1 *vs*. RPAM1	6.60 ± 1.96	6.78 ± 1.51	0.489
LFAM1 *vs*. RFAM1	7.82 ± 1.79	7.65 ± 2.01	0.404

A two-sample *t*-tests were done to compare measurements of left and right-handed individuals in the ultrasound study. Table 4.36 indicates the *P*-values when comparing these measurements. There were 5 left-handed individuals and 35 right-handed individuals.

Table 4.36: Left *vs*. right-handed individuals

Variable	Left-handed individuals Mean±SD (mm)	Right-handed individuals Mean±SD (mm)	*P*-value
LBAM1	5.17 ± 1.77	5.82 ± 1.81	0.291
RBAM1	5.35 ± 1.49	5.77 ± 1.75	0.470
LSCM1	7.68 ± 2.22	6.88 ± 1.50	0.144
RSCM1	6.92 ± 1.52	7.46 ± 2.15	0.443
LPAM1	6.07 ± 1.33	6.67 ± 2.01	0.366
RPAM1	7.24 ± 1.39	6.71 ± 1.53	0.307
LFAM1	7.33 ± 1.56	7.89 ± 1.82	0.356
RFAM1	7.37 ± 2.37	7.69 ± 1.97	0.640

The strength of the correlation between the arterial dimensions and demographic parameters of a South African ultrasound sample were analysed using Pearson's correlation tests. A Pearson's correlation attempts to draw a line of best fit through the data of two variables, and the Pearson correlation coefficient, *r*, indicates how far away all these data points are to this line of best fit. An *r*-value can range from -1 for a perfect negative linear relationship to +1 for a perfect positive linear relationship. A value of 0 (zero) indicates no relationship between two variables. [105]

Table 4.37 depicts the *r*-values for the correlation between the dependent variable (arterial dimensions) and the various independent variables (demographic parameters) for the ultrasound study.

In Table 4.37, positive relationships are indicated in white, moderate positive relationships (0.400-0.599) * are shaded in green, weak positive relationships (0.200-0.399) * are shaded in blue and very weak positive relationships (0.001-0.199) * are shaded in red.

Negative relationships are indicated in black, weak negative relationships (0.200-0.399) * are shaded in blue and very weak (0.001-0.199) * negative relationships are shaded in red.

Table 4.37: Correlation between dependent and independent variables of ultrasound study

Dependent variable	Independent variables			
	Age	Weight	Height	BMI
LBAM1	-0.188	0.070	0.122	0.038
RBAM1	-0.202	0.069	0.220	-0.011
LSCM1	0.240	0.188	0.277	0.085
RSCM1	0.156	0.268	0.361	0.145
LPAM1	0.026	0.272	0.325	0.138
RPAM1	0.049	0.174	0.059	0.178
LFAM1	0.291	0.233	0.116	0.212
RFAM1	0.105	0.267	0.136	0.249

4.5 Inter-study comparisons

The one-way analysis of variance (ANOVA) is used to determine whether there are any statistically significant differences between the means of two or more independent (unrelated) groups - although statisticians tend to only use it when there are a minimum of three, rather than two groups. [103-105]

One-way ANOVA is an omnibus test statistic and cannot tell you which specific groups were statistically significantly different from each other; it only informs that at least two groups were different. Determining which of these groups differ from each other can be done using a post hoc test such as the Bonferroni Correction. [103-105]

Throughout the results presented for inter-study comparisons, a *P*-value smaller than 0.05 (shaded in orange) indicates a statistically significant difference between at least two studies.[104] A Bonferroni corrected *P*-value indicates where the statistically significant difference lies – a Bonferroni corrected *P*-value smaller than 0.05 (shaded in yellow), indicates a statistically significant difference between the two indicated studies.

Table 4.38 indicates the combined results of the one-way ANOVA and Bonferroni Correction for the adult female population.

Table 4.38: Comparison between modalities measuring adult females

Variable	Cadaver Mean±SD (mm)	CT Mean±SD (mm)	Ultrasound Mean±SD (mm)	*P*-value	Bonferroni corrected *P*-value		
					Cadaver - CT	Cadaver – US*	CT –US
LSCM1	6.80 ± 1.63	7.25 ± 1.84	6.28 ±1.22	0.027	0.523	0.351	0.022
RSCM1	7.68 ± 1.31	7.71 ±1.64	6.53 ± 1.90	0.001	1.000	0.002	0.004
LPAM1	6.28 ± 1.87	6.37 ± 1.76	5.88 ±1.53	0.397	1.000	0.916	0.613
RPAM1	7.12 ± 1.41	7.31 ± 1.31	6.78 ± 1.27	0.211	1.000	0.775	0.254
LFAM1	7.99 ± 1.48	8.26 ± 1.71	7.29 ± 1.77	0.033	1.000	0.191	0.036
RFAM1	7.75 ± 1.43	8.19 ± 1.73	7.05 ± 1.76	0.009	0.686	0.166	0.007

*US – ultrasound

Table 4.39 indicates the combined results of the one-way ANOVA and Bonferroni Correction for the adult male population.

Table 4.39: Comparison between modalities measuring adult males

Variable	Cadaver Mean±SD (mm)	CT Mean±SD (mm)	Ultrasound Mean±SD (mm)	*P*-value	Bonferroni corrected *P*-value		
					Cadaver – CT	Cadaver – US*	CT –US
LSCM1	7.96 ± 1.73	10.34 ± 2.35	7.7 ± 1.66	0.000	0.000	1.000	0.000
RSCM1	8.39 ± 1.68	10.39 ± 2.37	8.29 ± 1.89	0.000	0.000	1.000	0.000
LPAM1	7.19 ± 1.84	7.51 ± 1.57	7.33 ± 2.06	0.752	1.000	1.000	1.000
RPAM1	6.64 ± 1.67	8.21 ± 1.67	6.79 ± 1.74	0.000	0.000	1.000	0.001
LFAM1	8.57 ± 1.62	8.81 ± 1.9	8.35 ± 1.68	0.507	1.000	1.000	0.735
RFAM1	8.31 ± 2.20	8.73 ± 1.8	8.25 ± 2.16	0.539	1.000	1.000	0.919

*US – ultrasound

A similar comparison was done for the older population – only studied in cadaver and CT. Table 4.40 indicates the results of the *t*-tests for the older female population.

Table 4.40: Comparison between modalities measuring older females

Variable	Cadaver Mean±SD (mm)	CT Mean±SD (mm)	*P*-value
AAM1	33.53 ± 5.70	32.56 ± 5.92	0.470
ACM1	19.50 ± 4.32	19.74 ± 4.34	0.816
ABM1	17.26 ± 2.83	17.16 ± 2.85	0.886
LICM1	6.67 ± 1.07	6.76 ± 1.16	0.723
RICM1	5.82 ± 1.86	6.0 ± 1.87	0.748
LCCM1	8.30 ± 2.22	8.35 ± 2.29	0.937
RCCM1	8.13 ± 2.19	8.17 ± 2.19	0.943
LSCM1	8.13 ± 1.96	8.2 ±1.92	0.887
RSCM1	7.94 ± 1.46	8.07 ± 1.59	0.704
LPAM1	7.10 ± 1.47	7.02 ± 1.47	0.823
RPAM1	6.70 ± 1.29	6.82 ± 1.30	0.740
LFAM1	8.23 ± 1.68	8.29 ± 1.66	0.891
RFAM1	7.49 ± 2.10	7.64 ± 2.11	0.769
LCIM1	11.07 ± 1.50	11.01 ± 1.43	0.850
RCIM1	11.14 ± 1.75	11.14 ± 1.82	0.987

Table 4.41 indicates the results of the two-sample *t*-tests for the older male population.

Table 4.41: Comparison between modalities measuring older males

Variable	Cadaver Mean±SD (mm)	CT Mean±SD (mm)	*P*-value
AAM1	33.49 ± 5.52	27.18 ± 4.58	0.000
ACM1	19.15 ± 4.03	16.43 ± 2.46	0.002
ABM1	19.90 ± 3.53	16.03 ± 3.2	0.000
LICM1	7.60 ± 1.88	5.58 ± 1.50	0.000
RICM1	7.47 ± 1.86	5.9 ± 1.12	0.000
LCCM1	8.49 ± 1.61	7.87 ± 1.66	0.072
RCCM1	8.51 ± 1.71	7.70 ± 1.36	0.016
LSCM1	8.50 ± 1.55	6.97 ±1.69	0.000
RSCM1	9.81 ± 1.50	7.85 ± 1.40	0.000
LPAM1	8.37 ± 2.49	6.65 ± 1.73	0.006
RPAM1	8.03 ± 2.22	7.11 ± 1.42	0.099
LFAM1	9.4 ± 2.69	8.21 ± 1.82	0.058
RFAM1	9.77 ± 2.18	7.95 ± 1.45	0.001
LCIM1	12.11 ± 2.03	10.47 ± 1.44	0.001
RCIM1	10.55 ± 2.08	10.38 ± 1.20	0.000

5. DISCUSSION

Arterial change is a key contributor to cardiovascular pathology and mortality. Statistics on normal arterial dimensions for a South African population is scarce, but crucial when assessing whether a dilatation or stenosis are pathological or normal.

Arterial dimensions are useful parameters for the vascular ageing process as several researchers have described an age-related increase in the arterial lumen and an increase in wall thickness. [37-56,93-100]

The primary purpose of this research was to compare arterial measurements taken using cadaveric material with arterial measurements taken with CT and ultrasound. The aim was to establish whether there is a statistically significant difference between measurements taken on the different approaches. The study also aimed to examine the effects of various demographic parameters such as age, sex, weight, height and BMI on the arterial diameters of a South African population.

For the purpose of flow in the discussion, the three different studies (cadaver, CT and ultrasound) will first be analysed separately, considering the effects of the various demographic parameters, before discussing the inter-study comparisons and comparability of the different approaches.

5.1 Limitations of the study

5.1.1 Cadaver study

Limitations of the cadaver study included the possibility that the use of cadaveric tissue to measure the arterial diameter could yield measurements that do not accurately reflect a living population. However, shrinkage and distortion have been shown to be minimal, making cadaveric research possible and valid. [51,52] Arteries contain a high percentage of elastic tissue and smooth muscle in the tunica media, therefore arteries are not prone to collapse and should accurately reflect their true diameter. The non-collapsing nature of arteries was validated by the pilot study that found no statistically significant difference between the cadaver and CT measurements with the exception of the left subclavian artery and left common carotid artery.[51-53]

Another limitation is that if not specifically indicated in the cadaver records in the Department of Anatomy, it was impossible to determine whether the cadavers used in the study suffered from conditions such as hypertension, atherosclerosis, diabetes mellitus or hypercholesterolaemia. It was also not clear whether they were smokers or suffered from other risk factors that could have accelerated age-related changes in the structure and function of their arterial anatomy. Even though cadavers with known/visible aortic aneurysms, aortic dissections or those who have evidently undergone previous cardiovascular surgery were excluded from the study, it cannot be stated as absolute fact that all cadavers that suffered from cardiovascular disease were excluded. However, the use of a large cadaver sample over the course of the postgraduate study should have minimised the influence these limiting factors could have had on the study.

Finally, the demographic distribution of the different population groups studied (older males, adult males, older females, adult females) was not always equal. It was decided to include all cadavers that satisfied the inclusion criteria to add as many South African individuals as possible to the database of measurements – as long as the minimum sample size for each population group as calculated in consultation with the bio-statistician were upheld. In addition, the ancestry of the cadaver was noted during data collection, but only further explored during data analyses. There is thus also not an equal distribution of ancestries among the population groups as all cadavers that satisfied the inclusion criteria were included. The picture of representation is directly related to the availability of cadavers in the Department of Anatomy.

5.1.2 CT study

Due to the fact that CT images are frequently used for diagnostic purposes, there are a vast amount of CT images available from the Steve Biko Academic Hospital database that could have been used for the current research. The use of CT images however posed some limitations to the research process.

The arterial wall cannot be clearly visualised on a CT image and therefore only the outer diameter could be measured for the CT study. The inner diameter and wall thickness measurements taken on the cadaver sample could thus not be compared to the CT sample. Comparisons of outer diameter measurements will however be made for all three studies (cadaver, CT and ultrasound).

Full body CT images are scarce and expensive and thus it was impossible to measure all 20 arterial sites on a single individual. The 40 measurements in each population group (adult

male, adult female, older male, older female) of each of the 20 arterial sites were thus measured using the imaging records of 213 patients. All available demographic data for each of the 213 patients were recorded.

Similar to the limitation described for the cadaver study, the demographic distribution of the different population groups (older males, adult males, older females, adult females) were not always equal. It was decided to include all CT images that satisfied the inclusion criteria to add as many South African individuals as possible to the database of measurements – as long as the minimum sample size for each population group as calculated in consultation with the bio-statistician were upheld. In addition, the ancestry of the patient was noted during data collection, but only further explored during data analyses. There is thus also not an equal distribution of ancestries among the population groups as all images that satisfied the inclusion criteria were included. The picture of representation is directly related to the range of patients seen by the Radiology Department and the population served by the Steve Biko Academic Hospital.

Not all arteries measured in the cadaver study could be included in the CT study. In contrast to the aorta and its branches that can be visualised on a chest and/or abdominal CT with the pictured pathology being unrelated (e.g. an ovarian cyst), a CT of the arm will almost certainly involve or affect the brachial artery (e.g. a broken arm or soft tissue damage). CT images of a healthy, unaffected brachial arteries are thus difficult to find and therefore the brachial artery was excluded from the CT study. Similarly, the left and right coronary arteries are not easily visualisable on a normal CT scan and were thus also excluded from the CT study. In addition, the infrarenal aorta was added to the study at a later stage and was thus only added to the cadaver study. It could be used for comparative studies in future research.

5.1.3 Ultrasound study

Similar to the limitation described for the CT study, the arterial wall cannot be seen on ultrasound images and therefore only the outer diameter could be measured for the ultrasound study. The inner diameter and wall thickness measurements taken on the cadaver sample could thus not be compared to the ultrasound sample (or the CT sample). Comparisons of outer diameter measurements will however be made for all three studies.

In addition, ultrasound investigations are not suitable for all arteries due to difficulty in visualisation. Several arteries were for this reason excluded from the ultrasound study

including aortic measurements, internal carotid – and common carotid arteries as well as the common iliac arteries.

The ultrasound study included the students in the Department of Anatomy at the University of Pretoria as living volunteers. The visualisation of their arteries via portable ultrasound was also used a teaching and learning opportunity. However, due to the age of students in the Department of Anatomy, the older sample group was not studied via ultrasound. The ultrasound sample (male and female adults) are thus used as a control group – measured against the corresponding groups (male- and female adults) in the CT and cadaver study. In addition, the average age of the ultrasound adult group is low. It is thus not representative of all South Africa adults (18 to 60 years of age). This group could be extended to be more representative during future research.

It is possible that the lack of significant differences between the black and white ultrasound populations are due to less pronounced differences in background (socio-economic or socio-demographic factors) when compared to the other populations studied. This limitation will be eliminated when the ultrasound group is extended to include volunteers from all walks of life in future research.

5.2 Arterial dimensions affected by demographics in a South African population

5.2.1 Cadaver study

Older cadaver populations *vs*. adult cadaver population

As indicated in Table 4.2, statistically significant differences were seen between the arterial dimensions of the older cadaver population and the adult cadaver population, irrespective of sex and ancestry. These significant differences were found in 70% of the comparisons between these two populations.

All wall thickness measurements were larger in the older population except for the infrarenal aorta. Due to the fact that the infrarenal aorta was added to the arterial sites of interest at a later stage, the sample size relevant to this arterial site is much smaller since it was not included in the pilot study. The significantly smaller sample size can possibly explain why larger dimensions were found in the adult population.

For the older cadaver- and adult cadaver populations, statistically significant differences were found in 75% of the wall thickness measurements - the exceptions included the aorta at all four sites measured and the left internal carotid artery. For this populational comparison, the wall thickness of the aorta and left internal carotid artery were thus not significantly affected by age.

According to McVeigh *et al*., the effects of ageing on the vascular tree are heterogeneous and the mechanical properties of the arteries vary depending on the arterial site studied - thus the difference between elastic and muscular arteries. [106] With ageing, the larger elastic arteries demonstrate an increase in collagen content, covalent cross linking of the collagen, elastin fracture, and calcification and reduction in their elastin content. There are also changes in endothelial function, wall thickness to lumen ratio, and arterial stiffness with ageing. [107] This notion by Jani and Rajkumar, could possibly explain that even though the wall thickness of the four aortic sites were not significantly different when comparing the older cadaver population and the adult cadaver population, a statistically significant difference was found for all four aortic sites in relation to the outer – and inner diameter. [107] The elastic aorta is thus expanding with age, affecting the wall thickness to lumen ratio even with an effect on wall thickness.

Research by Janzen *et al,* described a transitional zone in the tunica media structure at the carotid bifurcation. In their study, they confirmed the existence of such a transitional zone in the carotid artery tripod – defined as an arterial segment transitioning from elastic to muscular. The length of this transitional zone was found to be variable. [108] In a carotid symmetry study by Smith and Larsen, bilateral carotid angiograms of the neck in 100 adult patients show the bifurcation of the left common carotid artery to be located cranial to the right in 50% of the cases, while the right bifurcation was higher in 22%. The origin of the internal carotid artery was at the dorsal or dorsolateral aspect of the common carotid artery in 82% on the right side and in 94% on the left, while a dorsomedial or medial origin was found in 18% on the right side and in 6% on the left. [109]

The existence of a transition zone as well as the asymmetry in bifurcation between the left and right could thus explain the phenomenon that the wall thickness of the left internal carotid artery was not significantly influenced by age in the South African cadaver population studied.

Virmani *et al.* reported that with ageing, post-mortem studies show arterial wall thickening that consists of an increase in the tunica intima thickness even in populations with a low incidence of atherosclerosis. They found that the tunica intima thickness in the carotid arteries

increased threefold between 20 years and 90 years of age. Excess thickness of the tunica intima at a given age predicted silent coronary artery disease and this was accelerated in the presence of known cardiovascular risk factors.[96]

According to the results of the current research, age is thus an important non-modifiable cardiovascular risk factor as seen in the significant increase in wall thickness in the older cadaver population with the exception of the aortic sites and the left internal carotid artery.[96,106,107]

For the comparison between the older cadaver population and the adult cadaver population, only 15% of the outer diameter measurements were not significantly different. This included the right common carotid artery, left brachial artery and right coronary artery.

For inner diameter, 50% of the measurements were not significantly different. This included the right internal carotid artery, left and right common carotid arteries, left brachial artery, right popliteal artery, left and right femoral arteries, left and right common iliac arteries and right coronary artery.

From the results is it seen that the left brachial artery, right common carotid artery and right coronary artery do not show a statistically significant difference in either the outer or inner diameter but show a significant difference in relation to wall thickness.

Also interesting is that the inner diameter and outer diameter of the right coronary artery are larger in the adult population (although not significantly) but the wall thickness is significantly larger in the older population – possibly indicating that this artery is especially susceptible to thickening of the arterial wall in old age due to possible atherosclerotic deposits or other diseases. The larger outer and inner diameter found in the adult population could be related to higher levels of cardiovascular activity when compared to the more sedentary lifestyle of the older population. The blood demands of the muscular wall of the heart during high intensity cardiovascular activity will over time have a direct effect on the diameter of the coronary arteries supplying the wall.

As reported by Janzen *et al.,* the common carotid arteries and internal carotid arteries have variable elastic and muscular properties that could influence the effect age would have on the arterial diameter. [108] The rest of the arteries that did not show any significant difference with regard to inner diameter or outer diameter when comparing the older cadaver and adult cadaver population, are all also classified as muscular.

The stiffening of large arteries with ageing is the leading cause of increased pulse pressure, a marker of cardiovascular risk in the general population and a predictor of severe cardiovascular events. [110,111] Some studies have demonstrated that arterial stiffness only increases progressively with age in the elastic arteries, but not in muscular arteries. [112-115] This interesting discrepancy have been mainly attributed to the observation that age-associated geometrical changes are not homogenous along the arterial tree and that elastin fragmentation occurs predominantly in the elastic arteries, where the stretch amplitude is high. [110,116] The relationship between this notion and the observations made during the current research should be further studied to determine the relationship these age-related homogenous changes have on hypertension and other cardiovascular events in a South African population.

Black cadaver populations *vs.* white cadaver population

As indicated in Table 4.3, statistically significant differences in arterial dimensions were seen between the black cadaver population and the white cadaver population, irrespective of age and sex. These differences were found in 50% of the arterial measurements – 20% less than when comparing the same population only with regard to age (irrespective of sex and ancestry).

Arterial dimensions were found to be larger in the white cadaver population except for the outer and inner diameter of the right internal carotid artery and the infrarenal aortic wall thickness.

Statistically significant differences were found between 75% of the wall thickness measurements - the exceptions being the abdominal aorta at the level of the coeliac trunk, infrarenal aorta, the left and right internal carotid arteries and right common carotid artery. Of these arteries the two aortic measurements and the left internal carotid artery were also not significantly different with regard to wall thickness when comparing the older population with the adult population (Table 4.2) and would possibly be related to the transitional zone as described by Janzen *et al*. [108]

Ancestry (irrespective of age and sex) thus plays a significant role on the wall thickness of the measured arteries with significant differences in 75% of measurements– indicative of the effect pathology could have on the arterial wall in groups with different ancestries and vital in understanding the higher prevalence of different cardiovascular events and pathology in

certain ancestral groups. However, in retrospective studies, one would not be able to isolate the reason for any differences in ancestry, as the differences could possibly be accounted for by other socio-economic and socio-demographic factors – demographic information that were not available in the cadaver records and one that the researcher could not assume. [52]

Vascular changes related to hypertension include thickening of the walls of large elastic and muscular arteries, remodelling of small muscular arteries resulting in increased wall to lumen ratio, reduced number of vessels in the microcirculation and lengthening of small arteries.[117]

Of the inner diameter measurements, 75% were not significantly different. The few that were significantly different included the ascending aorta, abdominal aorta at the level of the coeliac trunk, left and right subclavian arteries and left coronary artery.

Statistically significant differences were seen in 50% of the outer diameter measurements. Those that were not significantly different included the abdominal aorta at bifurcation, left and right internal carotid arteries, right common carotid artery, left brachial artery, left popliteal artery, left and right femoral arteries, right common iliac artery and right coronary artery. Of these arteries the right internal carotid artery, right common carotid artery, left brachial artery, left and right femoral arteries, right common iliac artery and right coronary artery were also not significantly different when comparing the older population with the adult population (Table 4.2).

The difference in arterial dimensions with regard to ancestry is thus mostly limited to wall thickness with the white cadaver population having a thicker arterial wall.

Older male cadaver population *vs*. adult male cadaver population

Statistically significant differences in arterial dimensions were seen between the older male cadaver population and the adult male cadaver population (Table 4.4). These differences were found in 48% of the arterial measurements. When the sex variable is added to the age variable for the sake of comparison, statistically significant differences decrease from 70% to 48% - diminishing the role of sex in relation to differences in arterial dimensions.

For wall thickness, statistically significant differences were found in 65% of the measurements - the exceptions included the abdominal aorta at the level of the coeliac trunk, abdominal aorta before bifurcation, infrarenal aorta, the left internal carotid artery, right common carotid artery, right common iliac artery and left coronary artery. Once again, the wall thickness of

the aortic sites and the internal carotid artery were found to be not significantly different – as was the case when comparing the older cadavers with the adult cadavers and the black cadavers with the white cadavers.

Of the inner diameter measurements, 65% were not significantly different. The few that were significant included the ascending aorta, abdominal aorta at the level of the coeliac trunk, infrarenal aorta, left internal carotid artery, right subclavian artery, right popliteal artery and right coronary artery.

For the outer diameter, 55% of the difference in measurements were not statistically significant. The exceptions included the ascending aorta, aorta at the level of the coeliac trunk, infrarenal aorta, left internal carotid, right subclavian, left and right popliteal, right femoral and left coronary.

Once again, the results indicate that the most significant morphological difference lies in the wall thickness of arterial dimensions. The arterial dimensions were found to be larger in the older male cadaver population with exception of the wall thickness of the left internal carotid artery, the outer diameters of the right common carotid artery, left brachial artery and right coronary arteries and the inner diameters of the left brachial artery, left common iliac artery and right coronary artery. None of these exceptions was statistically significant.

An interesting reoccurring phenomenon is that no statistically significant difference was found with regard to wall thickness for aortic measurements, but that statistically significant differences were found for these sites for the inner and outer diameter measurements even in cases where little other statistically significant differences were found in relation to inner and/or outer diameter measurements. For the South African cadaver population studied, the elastic aorta thus seems to expand with age with no significant effect on the wall thickness.

Older female cadaver population *vs.* adult female cadaver population

As indicated in Table 4.5, statistically significant differences in arterial dimensions were seen between the older female cadaver population and the adult female cadaver population. Similar to the older male *vs.* adult male cadaver population (48%), these differences were found in only 47% of the arterial measurements.

Only 50% wall thickness measurements indicated statistically significant differences excluding the ascending aorta, abdominal aorta at the level of the coeliac trunk, abdominal

aorta before bifurcation, infrarenal aorta, the left internal carotid artery, right brachial artery, right subclavian artery, right femoral artery, left and right coronary arteries.

Of the inner diameter measurements, 65% of the differences were not statistically significant. The few that were significantly different included the ascending aorta, abdominal aorta at the level of the coeliac trunk, infrarenal aorta, left internal carotid artery, right brachial artery, left subclavian artery and left coronary artery.

For the outer diameter, 55% of the differences in measurements were statistically significant. This included the ascending aorta, aorta at the level of the coeliac trunk, abdominal aorta before bifurcation, infrarenal aorta, left internal carotid artery, right brachial artery, left subclavian artery, left popliteal artery, left and right common iliac arteries and left coronary artery.

Arterial dimensions were found to be larger in the older adult female population with the exception of the wall thickness of the ascending aorta and infrarenal aorta, the outer diameter of the right internal carotid artery, right popliteal and right femoral arteries and the inner diameter of the right internal carotid artery, right popliteal artery, left femoral and right femoral arteries. None of these exceptions was statistically significant. For the female cadaver population comparisons, most morphological differences were seen in the outer diameter whereas for the male cadaver population comparisons (Table 4.4), most morphological differences were seen in the wall thickness measurements.

Older female cadaver population *vs.* older male cadaver population

As indicated in Table 4.6, statistically significant differences in arterial dimensions were seen between the older female cadaver population and the older male cadaver population. These differences were found in 43% of the arterial measurements.

Only 20% of the differences in wall thickness were statistically significant including the right internal carotid artery, left and right subclavian arteries, and left common iliac artery.

Of the inner diameter measurements, 55% of the differences were statistically significant. This included abdominal aorta before bifurcation, left and right internal carotid arteries, left and right subclavian arteries, left and right popliteal arteries, left and right femoral arteries and left and right common iliac arteries. For all these significant differences, the larger dimensions were found in the older male population. Inner diameter dimensions were found

to be larger in the older female population for the ascending aorta, aorta at the level of the coeliac trunk and the right coronary artery.

For the outer diameter, 55% of the difference in measurements were statistically significant. This included the abdominal aorta before bifurcation, infrarenal aorta, left and right internal carotid arteries, right subclavian artery, left and right popliteal arteries, left and right femoral arteries and left and right common iliac arteries. For all these statistically significant measurements, the larger dimensions were found in the older male cadaver population. Outer diameter dimensions were found to be larger in the older female population for the ascending aorta and aorta at the level of the coeliac trunk.

Although most of the arterial dimensions were found to be larger in the older male cadaver population, there were a lot of exceptions especially with regard to wall thickness. In 45% of wall thickness measurements, the dimensions were larger in the older female cadaver population. Two of these were significant (there were only four significant differences in total) including the left subclavian artery and the left common iliac artery.

A possible explanation, as previously mentioned, is that age plays a more significant role than sex when it comes to changes in arterial dimensions – the older female cadaver population had an average age of 79.79 years and the average age of the older male cadaver population was 73.81 years.

Adult female cadaver population *vs.* adult male cadaver population

Statistically significant differences in arterial dimensions were seen between the adult female cadaver population and the adult male cadaver population as indicated in Table 4.7. These differences were found in 50% of the arterial measurements – mostly for the inner and outer diameters.

Only 10% of wall thickness measurements were significantly different including the right internal carotid and right femoral arteries. This observation adds weight to the possibility that ageing contributes largely to the changes seen in arterial dimensions, especially with regard to wall thickness, and that sex does not play such a significant role.

Of the inner diameter measurements, 70% were significantly different. The few that were not significantly different included the ascending aorta, abdominal aorta at the level of the coeliac trunk, left and right common carotid arteries, right popliteal and left femoral.

For the outer diameter, 70% of the differences in measurements were statistically significant. The few that were not significantly different included the ascending aorta, aorta at the level of the coeliac trunk, left common carotid, right popliteal, left and right femoral.

This phenomenon highlights the role that sex plays in relation to morphological differences in arterial dimensions. Sex had a significant effect on the inner and outer diameter but a smaller effect on wall thickness.

Measurements were mostly found to be larger in adult male cadavers than in adult female cadavers, with some exceptions. Most of the exceptions were found in the wall thickness measurements including ascending aorta, abdominal aorta before bifurcation, right brachial artery, right subclavian artery, left popliteal artery, right femoral artery (statistically significant), infrarenal aorta. Other exceptions were the larger inner and outer diameter found in the adult female population for the right popliteal artery (not statistically significant).

Black female cadaver population *vs.* black male cadaver population

As indicated in Table 4.8, only a few statistically significant differences (30%) in arterial dimensions were seen between the black female cadaver population and the black male cadaver population.

Only 25% of wall thickness measurements were significantly different including the abdominal aorta before bifurcation, infrarenal aorta, left internal carotid artery, left brachial artery and left common iliac artery.

Of the inner diameter measurements, 30% were significantly different including the abdominal aorta before bifurcation, infrarenal aorta, left internal carotid artery, right brachial artery and left and right subclavian arteries.

For the outer diameter, 35% of the measurements were significantly different including the abdominal aorta before bifurcation, infrarenal aorta, left internal carotid artery, right common carotid artery, right brachial artery and left and right subclavian arteries.

The black male cadavers were found to have larger arterial dimensions with some exceptions including the wall thickness of the ascending aorta and infrarenal aorta (statistically significant), the inner diameter of the left common carotid artery, left popliteal artery, right

popliteal artery, left femoral artery and right coronary artery and the outer diameter of the right popliteal artery and left femoral artery.

For a black South African cadaver population, there is thus not an overall significant amount of sexual dimorphism when comparing the arterial dimensions of male and female cadavers without considering age. Interestingly the arterial sites that did show sexual dimorphism included the abdominal aorta before bifurcation, infrarenal aorta and left internal carotid artery for all three measurements. The right brachial artery and left and right subclavian arteries showed sexual dimorphism in relation to their outer and inner diameters. In all these cases the dimensions were larger in the black male cadavers except for the wall thickness of the infrarenal aorta.

White female cadaver population *vs*. white male cadaver population

As indicated in Table 4.9, statistically significant differences in arterial dimensions were seen between the white female cadaver population and the white male cadaver population. These differences were found in 57% of the arterial measurements. The white cadaver population thus shows more sexual dimorphism when compared to the black cadaver population (30%).

The differences were to a lesser extent found in the wall thickness and more in the outer and inner diameter measurements.

Only 20% of the wall thickness measurements were statistically significant including the abdominal aorta before bifurcation, right internal carotid artery, left brachial, right coronary. The wall thickness measurement was found to be larger in white female cadavers in 40% of the arteries including the abdominal aorta before bifurcation, right common carotid, right brachial, left subclavian, left popliteal, right femoral, left common iliac and right common iliac arteries.

The only other measurement where female dimensions were larger was the inner diameter of the right popliteal artery. Of the inner diameter measurements, 70% were significantly different, the few that were not statistically significantly different included the ascending aorta, aorta at the level of the coeliac trunk, infrarenal aorta, left brachial artery and left and right coronary arteries.

For the outer diameter, statistically significant differences were seen in 80% of the measurements, the few that were not statistically significantly different included the ascending aorta, aorta at the level of the coeliac trunk, left brachial, left subclavian.

The inner and outer diameters of the white cadaver population thus show significant numbers of sexual dimorphism.

Older black male cadaver population *vs.* older white male cadaver population

As indicated in Table 4.10, very few (12%) statistically significant differences in arterial dimensions were seen between the older black male cadaver population and the older white male cadaver population.

The only statistically significant differences were found in the inner and outer diameters of the left common carotid artery, inner and outer diameter as well as wall thickness of the right subclavian artery and the inner and outer diameter of the right femoral artery.

Dimensions were found to be larger in older white male cadavers with the exception of the wall thickness of the abdominal aorta before bifurcation, left internal carotid, right internal carotid and infrarenal aorta, outer diameter of left internal carotid, right brachial artery and infrarenal aorta and inner diameter of right common carotid artery, left internal carotid artery, right brachial artery and infrarenal aorta. None of these exceptions was statistically significant.

When comparing an older male cadaver population with regard to ancestry there is thus little statistically significant difference.

Adult black male cadaver population *vs.* adult white male cadaver population

Similarly, when comparing an adult male cadaver population with regard to ancestry, statistically significant differences were only found in 18% of the arterial measurements (Table 4.11).

The only measurements that were significantly different were the outer and inner diameter of the aorta at the level of the coeliac trunk, outer diameter of left brachial artery, outer and inner diameter of the right brachial artery, outer diameter of the right subclavian artery, inner diameter of the right common iliac artery, inner and outer diameter of the left common iliac

artery, outer and inner diameter of the right coronary artery. None of the differences in the wall thickness measurements was statistically significant.

Dimensions were found to be larger in the adult white male cadaver population with some exceptions – most notably 35% of wall thickness measurements including the aorta at the level of the coeliac trunk, left internal carotid artery, right internal carotid artery, left popliteal artery, and also the outer diameter of the right femoral artery and the inner diameter of the right femoral and infrarenal arteries.

Adult black female cadaver population *vs.* adult white female cadaver population

When looking at females in a similar fashion, more statistically significant differences are noted when compared to the male cadaver population.

As indicated in Table 4.12, statistically significant differences in arterial dimensions were seen between the adult black female cadaver population and the adult white female cadaver population. These differences were found in 37% of the arterial measurements (compared to 18% in the male cadaver population).

Most of these differences were found in the wall thickness – 70% of these measurements were significantly different, the exceptions being aorta at the level of the coeliac trunk, infrarenal aorta, right internal and common carotid arteries, right common iliac artery and left coronary artery. For the wall thickness measurements, larger dimensions were found in the adult white female population with the exception of the right internal carotid artery and the infrarenal aorta.

Of the inner diameter measurements, only 20% were significantly different, including the aorta at the level of the coeliac trunk, right internal carotid artery, left and subclavian artery. Larger dimensions were found in the adult white female population with the exception of the abdominal aorta before bifurcation, left and right internal carotid arteries, left common carotid artery, left brachial artery, left and right popliteal arteries, left and right femoral arteries, right common iliac artery and right coronary artery.

For the outer diameter, 20% of the measurements were statistically significant different, including the aorta at the level of the coeliac trunk, right internal carotid artery and left and right subclavian arteries. Larger dimensions were found in the adult white female population with the exception of the abdominal aorta before bifurcation, left and right internal carotid

arteries, left common carotid artery, left and right popliteal arteries, right common iliac artery and right coronary artery.

Left *vs.* right-sided arteries in a cadaver population

As indicated in Table 4.13, a statistically significant difference was found between the left and right brachial arteries, the left and right subclavian arteries, left and right femoral arteries and left and right coronary arteries. The brachial arteries and subclavian arteries were larger on the right and the femoral arteries and coronary arteries were larger on the left.

Lorbeer *et al.* also found the left femoral artery to be larger than the right femoral artery. They report that differences between left and right leg arterial diameters could be relevant in association with leg dominance. It can be assumed that in most participants the right leg is the dominant one resulting in more muscle mass which can lead to a compression of the vessels to a certain degree. [118] However, little is known about the prevalence of the dominant leg in the general South African population, and in the current study such data were not available to further explain this finding. Similarly, the significant difference between the left and right brachial arteries could possibly be explained by handedness. In the South African cadaver population, the right brachial artery was significantly larger. When considering the possible explanation by Lorbeer *et al*. that the femoral artery in the dominant leg could be more compressed (in the femoral triangle) due to muscle mass, it is important to consider that this might not be the case in the dominant arm due to less muscle mass and possible constrictions.

For the larger subclavian artery found on the right in the South African cadaver population studied, the reason could possibly be related to the difference in origin between the two arteries. On the left side of the body, the subclavian comes directly off the aortic arch, while on the right side it arises from the relatively short brachiocephalic artery when it bifurcates into the subclavian and the right common carotid artery.

A larger left coronary artery is probably related to its supply to the left side of the heart. The left side of the heart is larger and more muscular because it pumps blood to the rest of the body.

No significant difference was found between left and right internal carotid arteries, left and right common carotid arteries, left and right popliteal arteries or left and right common iliac arteries.

Correlation strength of arterial dimensions *vs.* demographic parameters

Table 4.14 indicated the strength of the correlation between the arterial dimensions and demographic parameters. Moderately strong positive relationships were found between age and 10% of the measurements including inner and outer diameter of the ascending aorta, inner and outer diameter of the aorta at the level of the coeliac trunk, outer diameter of the infrarenal aorta and wall thickness of left common iliac. This observation confirms notions made prior in the discussion that age has a significant influence on the inner and outer diameters of the elastic aorta.

The rest of the measurements correlated positively but weak or positively but very weak with age except for the inner diameter of the right coronary artery that showed a very weak negative correlation with age.

All measurements had a weak positive or very weak positive correlation with weight except for the wall thickness of the abdominal aorta before bifurcation, the wall thickness of left subclavian, popliteal and femoral and wall thickness of right common iliac arteries that showed very weak negative correlations.

Height correlated negatively with 23% of the measurements including the inner and outer diameter of the ascending aorta, the inner and outer diameter of the aorta at the level of the coeliac trunk, wall thickness of the infrarenal aorta, wall thickness of the left and right common carotid, and the wall thickness of the left subclavian, left femoral, left popliteal, left and right common iliac and left coronary, which all had very weak negative correlations and the wall thickness of the abdominal aorta before bifurcation with a weak correlation.

BMI demonstrated weak or very weak positive relationships with all measurements except for the wall thickness of the aorta at the level of the coeliac trunk, the wall thickness of the left femoral artery and left popliteal artery and the wall thickness of the right common iliac arteries who had very weak negative relationships. Similar to the observations made when the arterial dimensions are correlated with weight, an increased BMI thus caused a thinning of the arterial wall in arteries prone to aneurysms.

As also seen in the populational comparisons made, age is thus the demographic parameter with the strongest influence on arterial dimensions.

5.2.2 CT study

Older CT population *vs*. adult CT population

As indicated in Table 4.15, statistically significant differences in outer diameter measurements were seen between the older CT population and the adult CT population. These differences were found in 40% of the measurements, including the ascending aorta, the right internal carotid artery, the left subclavian and right subclavian arteries, the right popliteal artery and the right femoral artery. Compared to the outer diameter comparison for the South African cadaver population (85%), there are less statistically significant differences – possibly related to the significant smaller sample size in the CT population.

Interestingly the outer diameter was larger in the adult CT population in 80% of the measurements including all but one (ascending aorta) of the measurements that were significantly different. This is a strange phenomenon as age was determined to be the strongest indication of an increase in outer diameter in die South African cadaver population studied. The vast difference in sample size could possibly have had an influence - the adult cadaver population consisted of 157 cadavers, the older cadaver population consisted of 164 cadavers, the adult CT population consisted of 133 individuals and the older CT population consisted of a mere 80 individuals. However, as mentioned during the discussion of materials and methods, even though the CT sample consisted of 213 individuals in total, more or less 40 images of each arterial site was measured. The CT sample is thus considerably less for each artery compared to the cadaver population.

Black CT population *vs.* white CT population

As indicated in Table 4.16, statistically significant differences in arterial dimensions were seen between the black CT population and the white CT population. These differences were found in 33% of the outer diameter measurements including that of the ascending aorta, the right internal carotid artery, the left common carotid artery, right popliteal artery and right femoral artery.

The outer diameter dimensions were found to be larger in the black CT population. The only significant difference where the dimensions were larger in the white CT population was the ascending aorta. The same comparison for a South African cadaver population demonstrated larger arterial dimensions in the white population. Again, the possibility exists that a larger and/or more equal sample size could yield different results.

Older male CT population *vs.* adult male CT population

In Table 4.17 statistically significant differences in arterial dimensions can be seen between the older male CT population and the adult male CT population. These differences were found in 73% of the arterial measurements, with the exceptions of the left popliteal artery, the left femoral artery, the right femoral artery and the left common iliac artery.

The outer diameter was found to be larger in the adult male CT population in 93% of the measurements, with the exception of the ascending aorta. Once more, the possibility exists that a larger and/or more equal sample size could yield different results.

Older female CT population *vs.* adult female CT population

The phenomenon seen above changes for the female population. As indicated in Table 4.18 statistically significant differences in arterial dimensions were seen between the older female CT population and the adult female CT population. These differences were found in 33% of the arterial measurements including the outer diameter of the ascending aorta, aorta at the level of the coeliac trunk, left internal carotid, left subclavian and right common iliac arteries.

Outer diameter dimensions were found to be larger in the older female CT population with only two exceptions – the right popliteal and right femoral artery. There were thus less significant differences, but the larger arterial dimensions were found in the older population as would be expected.

Older male CT population *vs.* older female CT population

As seen in Table 4.19, statistically significant differences in arterial dimensions were seen between the older male CT population and the older female CT population. These differences were found in 27% of the arterial measurements including the outer diameter of the ascending aorta, aorta at the level of the coeliac trunk, left internal carotid artery and left subclavian artery.

Unexpectedly, outer diameter dimensions were found to be larger in the older female CT population with the same exceptions as seen in Table 4.18 – the right popliteal and right femoral arteries.

Adult male CT population *vs.* adult female CT population

As indicated in Table 4.20, statistically significant differences in arterial dimensions were seen between the adult male CT population and the adult female CT population. These differences were found in 73% of the arterial measurements, with the exceptions of the ascending aorta, left and right femoral arteries, and left common iliac artery.

As expected, the dimensions were larger for the adult male CT population with the exception of the ascending aorta.

Black male CT population *vs*. black female CT population

As indicated in Table 4.21 statistically significant differences in arterial dimensions were seen between the black male CT population and the black female CT population. These differences were found in only 20% of the arterial measurements including the abdominal aorta before bifurcation and the left and right popliteal arteries. As expected, the black male CT population had larger outer diameters in all arteries measured.

White male CT population *vs.* white female CT population

As indicated in Table 4.22 statistically significant differences in arterial dimensions were seen between the white male CT population and the white female CT population. These differences were found in only two of the arterial measurements including the ascending aorta and the right subclavian artery.

Larger dimensions were found in the white male population in 47% of the measurements with the underwhelming majority of 53% in the white female population.

Older black male CT population *vs.* older white male CT population

As indicated in Table 4.23 statistically significant differences in arterial dimensions were seen between the older black male CT population and the older white male CT population. These differences were found in only two of the arterial measurements including the left and right subclavian artery.

For the two groups compared, 60% of the measurements were larger in the older white population including the left and right subclavian arteries. The older white population also had larger dimensions in the cadaver study.

The left and right internal carotid arteries, left and right popliteal arteries and left femoral artery were found to be larger in the older black CT population.

Adult black male CT population *vs.* adult white male CT population

As indicated in Table 4.24, no statistically significant differences in arterial dimensions were seen between the adult black male CT population and the adult white male CT population.

The outer diameter was found to be larger in the white adult CT population in 60% of measurements. Similarly to the older population, the left and right internal carotid arteries, as well as the left femoral artery were found to be larger in the black adult CT population. Other arteries found to be larger in the black adult CT population included the abdominal aorta before bifurcation and the left and right common carotid arteries.

Adult black female CT population *vs*. adult white female CT population

As indicated in Table 4.25 statistically significant differences in arterial dimensions were seen between the adult black female CT population and the adult white female CT population. These differences were found in only two of the arterial measurements including the ascending aorta and the right internal carotid artery.

In 67% of cases, the larger artery was found in the adult black female population. Arteries that were larger in the adult white population included the ascending aorta, abdominal aorta before bifurcation, right popliteal artery, left femoral artery and left common iliac artery.

Older black female CT population *vs.* older white female CT population

As indicated in Table 4.26 statistically significant differences in arterial dimensions were seen between the older black female CT population and the older white female CT population. These differences were found in only three of the arterial measurements including the ascending aorta and the left and right subclavian artery.

Only 60% of the arteries could be compared due to a small sample of older black females. Of these comparisons 67% of arteries were found to be larger in older black females, the exceptions being the ascending aorta, left popliteal artery and left femoral artery. These results should however be interpreted with care due to the restricted sample size.

Left *vs.* right-sided arteries in a CT population

As indicated in Table 4.27 statistically significant differences in arterial dimensions were seen between the left and right subclavian and left and right popliteal arteries. The subclavian arteries also showed a significant difference between left and right in the cadaver study. In both studies the larger artery was found in the right.

Correlation strength of arterial dimensions *vs.* demographic parameters

For the South African CT sample, the arterial dimensions were correlated with age (Table 4.28) and interestingly 67% of the correlations were negative and 33% were positive. The ascending aorta had a moderately strong positive correlation with age – confirming the clearly important influence age has on the dilatation of the elastic aorta even in a small sample. Very weak positive relationships with age were found in aorta at the level of the coeliac trunk, left internal carotid artery and left common iliac artery.

A weak negative correlation with age was found in left and right subclavian arteries, right popliteal artery and right femoral artery. A very weak negative correlation with age were found in abdominal aorta before bifurcation, right internal carotid artery, left and right common carotid artery, left popliteal artery and left femoral artery.

The strength and direction of these correlations could change with an increased, more representative sample size.

5.2.3 Ultrasound study

Black ultrasound population *vs.* white ultrasound population

Table 4.29 shows no statistically significant differences in arterial dimensions between the black ultrasound population and the white ultrasound population. In 63% of the measurements, the larger dimensions were found in the white ultrasound population, which included the left and right subclavian arteries, the left popliteal artery and the left and right femoral arteries.

This is consistent with findings made in the cadaver study. The differences might become significant when the sample size is increased.

Adult male ultrasound population *vs.* adult female ultrasound population

As indicated in Table 4.30, statistically significant differences in arterial dimensions were seen between the adult male ultrasound population and the adult female ultrasound population. These differences were found in 63% of the arterial measurements including the outer diameter of the left and right subclavian arteries, left popliteal artery and left and right femoral arteries. As expected, for all the measurements taken, larger arteries were found in the adult male ultrasound population.

Black male ultrasound populations *vs.* black female ultrasound population

As indicated in Table 4.31, statistically significant differences in arterial dimensions were seen between the black male ultrasound population and the black female ultrasound population. These differences were found in 25% of the arterial measurements including the outer diameter of the left and right subclavian arteries. For all the measurements taken, larger arteries were found in the black male ultrasound population.

White male ultrasound population *vs*. white female ultrasound population

As indicated in Table 4.32, statistically significant differences in arterial dimensions were seen between the white male ultrasound population and the white female ultrasound population. These differences were found in 63% of the arterial measurements including the outer diameter of the left and right subclavian arteries, left popliteal, left and right femoral arteries. For all measurements taken, larger arteries were found in the white male ultrasound population (as expected) with the exception of the right popliteal artery.

Adult black male ultrasound population *vs.* adult white male ultrasound population

As indicated in Table 4.33, no statistically significant differences in arterial dimensions were seen between the adult black male ultrasound population and the adult white male ultrasound population. Inconclusively, half of the measurements were larger in the adult black male ultrasound population including the left and right brachial arteries, right subclavian artery and right popliteal artery. The left subclavian, left popliteal, left femoral and right femoral arteries were larger in the adult white male population.

Adult black female ultrasound population *vs*. adult white female ultrasound population

As indicated in Table 4.34, no statistically significant differences in arterial dimensions were seen between the adult black female ultrasound population and the adult white female ultrasound population. A similar tendence were seen when comparing the male population. The left and right brachial arteries, left popliteal artery and right femoral artery were larger in adult black females and the left and right subclavian arteries, right popliteal artery and left femoral artery were larger in adult white females.

Left *vs.* right-sided arteries in an ultrasound population

For the ultrasound population studied, no statistically significant differences were found between arteries on the left and right side of the body as indicated in Table 4.35. The brachial artery and femoral artery were larger on the left and the subclavian and popliteal arteries were larger on the right.

Left *vs.* right-handed individuals

In addition, no statistically significant difference was found in the paired arteries of right and left-handed individuals as indicated in Table 4.36. A larger and more representative sample size could yield a different result.

Correlation strength of arterial dimensions *vs.* demographic parameters

As indicated in Table 4.37, the arterial measurements of the ultrasound population showed positive correlations with weight and height – 50% very weak and 50% weak correlations. For age, two relationships were negative – left brachial artery (very weak) and right brachial artery (weak). The rest of the correlations with age were positive but very weak or weak. For BMI, the right brachial artery had a very weak negative correlation. The rest of the correlations with BMI were positive.

5.2.4 Inter-study comparisons

As per Table 4.38, a statistically significant difference was found between the CT sample and the ultrasound sample for all measurements but the left and right popliteal arteries for the adult female population. There is thus poor comparability between the two diagnostic imaging methodologies with regard to arterial dimensions for the adult female population The

phenomenon continues for the adult male population (Table 4.39) where statistically significant differences were found for all measurements but the left popliteal artery and left and right femoral arteries.

The adult female population had an average age of 38 years (CT) and 21.59 years (ultrasound). The adult male population had an average age of 36.85 years (CT) and 22.3 years (ultrasound). These differences in age could account for the statistically significant differences seen.

There was no statistically significant difference between the cadaver measurements and the CT measurements for the adult female population (Table 3.38) – indicating good comparability between the two methodologies. The same cannot be said for the adult male population (Table 3.39) with statistically significant differences found for the left and right femoral arteries and the right popliteal artery.

Again, age could contribute significantly to these observations as the adult female population had an average age of 38 years (CT) and 38.92 years (cadaver) – very similar average ages. The adult male population had an average age of 36.85 years (CT) and 46.97 years (cadaver) – a difference of about a decade.

For the comparison between the cadaver and ultrasound measurements, the only statistically significant difference in the adult female population (Table 4.38) was found for the right subclavian artery. For the adult male population (Table 4.39) no statistically significant differences was found. There is thus good comparability between measurements taken on cadavers and ultrasound.

Unexpectedly, the average age of the two populations did not compare well – 21.59 years (ultrasound) and 38.92 years (cadaver). For the adult male population, the average age was 46.97 years (cadaver) and 22.3 years (ultrasound).

As per Table 4.40, there is no statistically significant difference between cadaver and CT measurements for the older female population. However, for the older male population (Table 4.41) the only arteries that showed no statistically significant difference is the left common carotid artery, right popliteal artery and left femoral artery. There is thus an inconsistency with regard to the comparability of cadaveric and CT measurements between the older female and older male populations.

The older female cadaver sample had an average age of 79.79 years and the older female CT sample had an average age of 78.87 years. The average age of each sample is thus very close together and could explain the good comparability found between these two samples. The older male cadaver sample however had an average age of 73.81 years and the older male CT sample had an average age of 78.93 years. This difference in average age could possibly be the reason that the two samples do not compare well.

5.3 Comparing the South African population to foreign populations

In a Brazilian population studied by Da Silva *et al*., the infra-renal aortic diameter was found to be greater in male cadavers than in female cadavers and in both sexes the infra-renal aortic diameter increased with age. [37] For the South African population studied, the infra-renal aorta was found to be 18.70 mm in the older male cadaver population, 18.22 mm in the older female cadaver population, 17.65 mm in the adult male cadaver population and 17.22 mm in the adult female cadaver population. Similarly to what Da Silva found for the Brazilian population, a statistically significant difference was found between the older cadaver population and the adult cadaver population in the current South African research with the infra-renal aorta being larger in the older cadaver population.

These South African measurements compared well to Korean measurements by Joh *et al.*, who found the infra-renal aorta to be 19.00 mm and 17.90 mm for male and females respectively. [57] Joh *et al.* found the infra-renal aortic diameter to be 17.50 mm for Koreans between 50 and 60 years of age, 18.10 mm for Koreans between 60 and 70 years of age and 19.40 mm for Koreans between 70 and 80 years of age. [57] Ouriel *et al*. found slightly larger dimensions in an American population - 23.00 mm in males and 19.00 mm in females. [58] Sariosmanoglu *et al.* reported slightly smaller dimensions for a Turkish population - 16.00 mm for males and 15.00 mm for females. [59] In the American population studied by Rogers *et al*., the infra-renal diameter was 19.30 mm for males, larger than in South African male cadavers and 16.70 mm for females, smaller than in South African female cadavers. [60]

Patel *et al*. found the inner diameter of the common iliac arteries and abdominal aorta, before bifurcation, to be larger in males. [38] For the South African cadaver population studied, the inner diameter of the left and right iliac arteries for older male cadavers were 10.12 mm and 11.02 mm respectively. For the older female population, the dimensions were 9.02 mm and 9.32 mm respectively. For the adult male population, 10.37 mm and 10.87 mm on the left and right respectively and for the adult female population 9.00 mm and 8.79 mm. Congruent with the findings by Patel, results for the South African cadaver population showed significantly larger

common iliac arteries in males. Joh *et al.* also discovered sexual dimorphism in the Korean population and reported slightly larger dimensions compared to the South African cadaver population. Joh *et al*. reported a right common iliac artery of 12.20 mm in males and 11.70 in females. They reported a left common iliac artery of 14.70 mm in males and 11.50 mm in females. [57]

For the South African cadaver population studied, the abdominal aorta before bifurcation was measured to be 18.12 mm and 15.05 mm in an older male and older female population respectively. It was 17.42 mm and 13.50 mm in an adult male and female population respectively. In accordance with Patel *et al*., the abdominal aortic dimensions were found to be significantly larger in males. [38]

Ilayperuma *et al*. highlighted sexual dimorphism in the diameters of the coronary arteries in a group of Sri Lankan adults. [39] The diameters were smaller in females in comparison with males. Sexual dimorphism was also seen in the South African cadaver population studied. For comparisons in the adult population, male cadavers had significantly larger outer and inner diameters for the right and left coronary arteries. For comparisons in the older population, males had larger dimensions even though none of the comparisons were statistically significant.

In an ultrasound study of a living Swedish population, Sandgren *et al.* reported that the inner diameter of the popliteal artery increased with age, initially during childhood growth, but also in adults. Demographic information was correlated with this measurement, and males were found to have larger arteries than females. [43] In the South African cadaver population, the measurements for the popliteal arteries are significantly larger in the older population with the exception of the inner diameter of the right popliteal artery which is larger in the older population but not significantly. The older population also demonstrated sexual dimorphism with significantly larger dimensions found in the outer and inner diameters of both left and right popliteal arteries. Less sexual dimorphism was found in the adult population with only the left popliteal artery demonstrating a significantly larger inner and outer diameter in male cadavers. The outer and inner diameter of the right popliteal artery were larger in female cadavers although not significantly. For the South African ultrasound population (adult) studied, significant sexual dimorphism was also found, especially in relation to the left popliteal artery.

The mean femoral arterial diameter of the same Swedish population was 9.80 mm in males and 8.20 mm in females. Sandgren *et al*. found no indication of sexual dimorphism for the femoral artery. Sandgren *et al.* found an increase in the diameter of the femoral artery during

growth, parallel to the increase in body size. At 18 years of age, at the end of childhood growth, male subjects had larger diameters than female subjects. [44] In the South African cadaver population, older subjects had larger dimensions that were statistically significant in the outer diameter and wall thickness of both the left and right femoral arteries. When comparisons are made within the older population, males had larger arteries with the differences in outer and inner diameter being statistically significant. For the adult population, males also had larger dimensions but the only measurements that were statistically significant were the inner diameter and wall thickness of the right femoral artery.

5.4 Future considerations and research

Future research should focus on expanding the CT and ultrasound studies to include more South Africans and extend the representation of the sample size. In addition, the older population should be included in the ultrasound study.

Contemplating the importance of age as a cardiovascular risk factor and contributor to arterial dilatation, future research should consider breaking up the study into smaller age groups e.g. 20-30 years, 30-40 years, 40-50 years.

The current study raises important questions about the comparability of measurements taken on ultrasound, CT and cadavers and should be investigated further. MRI could be added to future studies.

6. CONCLUSION

Vascular ageing contributes to the age dependent rise in hypertension and atherosclerotic disease. Ageing confers a greater risk for cardiovascular disease than the conventional risk factors like lipid levels, smoking, diabetes, and sedentary lifestyle. [107]

The most noticeable characteristic of vascular ageing is the change in the mechanical and structural properties of the vascular wall. Arteries have intrinsic and functional properties that are subject to lifelong stress and hormonal changes. These properties are changed in the presence of modifiable cardiovascular risk factors such as hypertension, obesity, smoking, and lifestyle, and non-modifiable risk factors such as age, genetics, and family history. [107]

Statistical comparisons of three populations groups confirmed that measurements conducted on cadaver samples compared favourably with similar measurements conducted on living samples using CT scans and ultrasound images. This has dramatic implications as it will allow future studies of the arterial dimensions to be compared with other similar studies as well as between different modalities/population groups. This could yield large data sets of arterial dimensions over different populations, ages, and other demographic profiles. There was however poor comparability between the CT population and the ultrasound population. This problem might be resolved with larger sample sizes and populations with more comparable average ages, however it could also shed light on a possible problem with regard to image diagnostic measurements. On average the CT measurements are slightly larger than the cadaver measurements and ultrasound measurements are slightly smaller than the cadaver measurements. The middle measurement (cadaver) is thus comparable to either side but the difference between the CT and ultrasound measurements is significant. If this phenomenon remains even after follow-up studies with increased sample sizes and an age representative population it could be an important finding.

In accordance with the abovementioned notions by Jani and Rajkumar [107], the current study also found that age is the most important demographic parameter when assessing change in arterial dimensions. Results indicate that age specifically affects the wall thickness of muscular arteries and the diameter of elastic arteries. Even though some sexual dimorphism is noted, sex had a significantly smaller effect on arterial dimensions compared to age. Weight, height and BMI correlated weakly with a change in arterial dimension.

Arterial pathology is a major contributor to cardiovascular disease and mortality. Data on normal arterial dimensions for a South African population is scarce, but essential when

evaluating whether a dilatation or stenosis are pathological. This study thus supports other research indicating an age-related increase in the dilatation of the arterial lumen. The arterial diameter is thus a useful indicator of the vascular ageing process.

The measurements collected could serve as the foundation of an extensive reference dataset for South African arterial dimensions. The three datasets (Appendix A) can be combined when the relevant datasets are expanded and found to be comparable.

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APPENDIX A: REFERENCE DATA SETS

South African cadaver population averages and range with CI95				
Arterial measurement	**Older male (mm)**	**Older female (mm)**	**Adult male (mm)**	**Adult female (mm)**
AAM1	33.49 (31.81-35.17)	33.53 (31.76-35.30)	27.65 (26.08-29.22)	26.52 (25.47-27.57)
AAM2	30.35 (28.40-32.31)	30.87 (28.86-32.88)	25.13 (23.56-26.70)	23.79 (22.79-24.80)
AAM3	1.57 (1.31-1.82)	1.33 (1.09-1.57)	1.26 (1.16-1.36)	1.36 (1.26-1.47)
ACM1	19.15 (18.07-20.22)	19.50 (18.09-20-91)	16.61 (15.77-17.44)	15.67 (14.92-16.41)
ACM2	16.95 (15.96-17.95)	17.49 (16.22-18.75)	14.64 (13.75-15.53)	13.91 (13.15-14.68)
ACM3	1.10 (0.91-1.29)	1.01 (0.81-1.20)	0.98 (0.83-1.13)	0.88 (0.83-0.92)
IRM1	18.70 (18.47-18.93)	18.22 (17.97-18.46)	17.65 (17.43-17.86)	17.22 (16.96-17.48)
IRM2	16.67 (16.26-17.08)	16.25 (15.82-16.67)	15.80 (15.47-16.14)	15.01 (14.64-15.39)
IRM3	1.01 (0.82-1.21)	0.98 (0.79-1.18)	0.92 (0.78-1.06)	1.10 (10.93-1.27)
ABM1	19.90 (18.96-20.84)	17.26 (16.35-18.17)	19.05 (18.31-19.79)	15.23 (14.24-16.23)
ABM2	18.12 (17.10-19.13)	15.05 (14.19-15.91)	17.42 (16.73-18.10)	13.50 (12.08-14.92)
ABM3	0.89 (0.77-1.01)	1.10 (0.84-1.36)	0.82 (0.71-0.92)	0.86 (0.61-1.11)
LICM1	7.60 (7.13-8.08)	6.67 (6.32-7.02)	6.92 (6.47-7.37)	5.48 (5.12-5.83)
LICM2	6.55 (6.10-7.01)	5.74 (5.31-6.16)	5.89 (5.43-6.34)	4.64 (4.30-4.99)
LICM3	0.53 (0.47-0.58)	0.47 (0.38-0.55)	0.52 (0.45-0.58)	0.42 (0.37-0.47)
RICM1	7.47 (6.99-7.95)	5.82 (5.20-6.43)	6.88 (6.39-7.37)	5.84 (5.56-6.13)
RICM2	6.28 (5.79-6.76)	4.81 (4.23-5.39)	5.81 (5.33-6.30)	5.02 (4.74-5.31)
RICM3	0.60 (0.53-0.66)	0.50 (0.45-0.56)	0.48 (0.39-0.56)	0.41 (0.36-0.46)
LCCM1	8.49 (8.09-8.88)	8.30 (7.59-9.02)	8.01 (7.57-8.46)	7.76 (7.32-8.21)
LCCM2	7.05 (6.65-7.46)	6.73 (6.16-7.30)	6.83 (6.83-6.41)	6.67 (6.22-7.13)
LCCM3	0.72 (0.63-0.80)	0.79 (0.65-0.93)	0.59 (0.43-0.66)	0.54 (0.51-0.58)
RCCM1	8.51 (8.08-8.95)	8.13 (7.43-8.83)	8.58 (8.07-9.08)	7.61 (7.27-7.94)
RCCM2	7.19 (6.74-7.64)	6.52 (5.98-7.07)	6.75 (6.08-6.43)	6.45 (6.14-6.77)
RCCM3	0.66 (0.61-0.72)	0.80 (0.65-0.96)	0.66 (0.58-0.73)	0.58 (0.53-0.62)
LBAM1	5.66 (5.31-6.02)	5.50 (5.07-5.93)	5.83 (5.49-6.16)	5.04 (4.80-5.29)
LBAM2	4.78 (4.41-5.14)	4.75 (4.31-5.19)	5.07 (4.70-5.44)	4.43 (4.19-4.66)
LBAM3	0.44 (0.40-0.49)	0.38 (0.32-0.43)	0.34 (0.30-0.38)	0.31 (0.28-0.34)
RBAM1	6.26 (5.94-6.58)	5.87 (5.26-6.48)	5.86 (5.50-6.22)	5.02 (4.77-5.26)
RBAM2	5.48 (5.15-5.81)	5.08 (4.52-5.65)	5.25 (4.90-5.60)	4.33 (4.08-4.57)
RBAM3	0.39 (0.35-0.43)	0.40 (0.34-0.46)	0.31 (0.27-0.34)	0.34 (0.31-0.38)
LSCM1	8.50 (8.12-8.89)	8.13 (7.46-8.80)	7.96 (7.49-8.42)	6.80 (6.37-7.23)
LSCM2	7.30 (6.95-7.66)	6.47 (6.04-6.89)	6.99 (6.57-7.41)	5.83 (5.45-6.21)
LSCM3	0.60 (0.53-0.67)	0.83 (0.62-1.04)	0.48 (0.42-0.55)	0.48 (0.44-0.53)
RSCM1	9.81 (9.44-10.18)	7.94 (7.47-8.40)	8.39 (7.92-8.85)	7.68 (7.33-8.02)
RSCM2	8.39 (8.03-8.75)	6.77 (6.30-7.23)	7.31 (6.88-7.75)	6.52 (6.21-6.82)
RSCM3	0.71 (0.64-0.78)	0.58 (0.52-0.65)	0.54 (0.46-0.62)	0.58 (0.48-0.68)
LPAM1	8.37 (7.65-9.09)	7.10 (6.60-7.61)	7.19 (6.63-7.74)	6.28 (5.67-6.88)
LPAM2	7.16 (6.49-7.82)	5.85 (5.32-6.39)	6.29 (5.76-6.83)	5.33 (4.70-5.96)
LPAM3	0.61 (0.50-0.72)	0.63 (0.50-0.75)	0.45 (0.39-0.50)	0.47 (0.40-0.54)
RPAM1	8.03 (7.41-8.64)	6.70 (6.25-7.16)	6.64 (6.13-7.15)	7.12 (6.66-7.59)
RPAM2	6.69 (6.10-7.28)	5.59 (5.08-6.10)	5.77 (5.27-6.27)	6.31 (5.81-6.80)
RPAM3	0.67 (0.5-0.79)	0.56 (0.48-0.64)	0.44 (0.33-0.54)	0.41 (0.35-0.47)
LFAM1	9.40 (8.66-10.14)	8.23 (7.70-8.77)	8.57 (8.08-9.06)	7.99 (7.53-8.44)

LFAM2	8.06 (7.33-8.78)	6.86 (6.28-7.43)	7.51 (7.01-8.01)	7.07 (6.59-7.55)
LFAM3	0.67 (0.58-0.76)	0.69 (0.60-0.78)	0.53 (0.46-0.61)	0.46 (0.42-0.50)
RFAM1	9.77 (9.17-10.37)	7.49 (6.83-8.16)	8.31 (7.65-8.97)	7.75 (7.31-8.19)
RFAM2	8.13 (7.56-8.69)	6.10 (5.43-6.77)	7.31 (6.70-7.91)	6.44 (6.04-6.85)
RFAM3	0.82 (0.70-0.94)	0.70 (0.55-0.84)	0.50 (0.43-0.58)	0.65 (0.59-0.72)
LCIM1	12.11 (11.59-12.63)	11.07 (10.60-11.55)	11.58 (11.02-12.14)	10.20 (9.89-10.51)
LCIM2	10.12 (9.51-10.72)	9.02 (8.47-9.58)	10.37 (9.82-10.91)	9.00 (8.67-9.34)
LCIM3	1.00 (0.86-1.13)	1.02 (0.84-1.20)	0.61 (0.53-0.68)	0.60 (0.54-0.65)
RCIM1	12.55 (12.01-13.09)	11.14 (10.61-11.67)	12.17 (11.46-12.88)	10.06 (9.68-10.44)
RCIM2	11.02 (10.44-11.59)	9.32 (8.83-9.81)	10.87 (10.24-11.49)	8.79 (8.37-9.20)
RCIM3	0.77 (0.68-0.85)	0.91 (0.79-1.04)	0.65 (0.54-0.77)	0.64 (0.56-0.71)
LCAM1	5.89 (5.19-6.60)	5.71 (5.29-6.13)	5.01 (4.72-5.30)	4.35 (4.03-4.70)
LCAM2	4.89 (4.17-5.60)	4.60 (4.07-5.13)	4.14 (3.82-4.46)	3.53 (3.19-3.87)
LCAM3	0.50 (0.43-0.58)	0.49 (0.40-0.59)	0.43 (0.34-0.53)	0.39 (0.33-0.45)
RCAM1	4.34 (4.03-4.66)	4.17 (3.84-4.49)	4.74 (4.37-5.11)	3.92 (3.54-4.31)
RCAM2	3.28 (2.93-3.62)	3.33 (2.94-3.71)	3.85 (3.42-4.27)	3.23 (2.86-3.61)
RCAM3	0.53 (0.44-0.62)	0.42 (0.34-0.50)	0.40 (0.33-0.47)	0.34 (0.29-0.40)

South African CT population averages and ranges with CI95				
Arterial measurement	**Older male (mm)**	**Older female (mm)**	**Adult male (mm)**	**Adult female (mm)**
AAM1	27.19 (25.73-28.64)	32.56 (30.63-34.49)	24.84 (23.64-26.05)	25.96 (26.08-27.52)
ACM1	16.19 (15.17-17.21)	19.74 (18.26-21.22)	18.30 (17.32-19.27)	16.50 (14.91-17.45)
ABM1	15.86 (14.52-17.21)	17.16 (16.19-18.13)	17.82 (17.08-18.55)	15.98 (13.99-17.01)
LICM1	5.57 (5.07-6.08)	6.76 (6.36-7.16)	7.05 (6.56-7.54)	5.81 (5.14-6.25)
RICM1	5.93 (5.57-6.29)	5.96 (5.31-6.62)	7.22 (6.82-7.61)	5.91 (5.43-6.32)
LCCM1	7.88 (7.35-8.40)	8.35 (7.57-9.13)	9.63 (8.87-10.39)	7.85 (7.05-8.38)
RCCM1	7.68 (7.25-8.10)	8.17 (7.43-8.90)	9.17 (8.61-9.73)	7.84 (6.94-8.30)
LSCM1	6.91 (6.37-7.46)	8.20 (7.53-8.87)	10.49 (9.79-11.20)	7.25 (6.37-8.30)
RSCM1	7.78 (7.32-8.25)	8.07 (7.55-8.60)	10.53 (9.81-11.25)	7.71 (7.07-8.23)
LPAM1	6.52 (5.77-7.27)	7.02 (6.48-7.56)	7.61 (7.13-8.10)	6.37 (5.46-6.94)
RPAM1	7.03 (6.40-7.66)	6.82 (6.33-7.31)	8.29 (7.74-8.84)	7.31 (6.58-7.73)
LFAM1	8.14 (7.42-8.87)	8.29 (7.73-8.85)	8.88 (8.26-9.49)	8.26 (7.34-8.82)
RFAM1	7.91 (7.33-8.48)	7.64 (6.93-8.35)	8.78 (8.19-9.37)	8.19 (7.20-8.74)
LCIM1	10.41 (9.84-10.99)	11.01 (10.53-11.49)	11.02 (10.35-11.69)	10.47 (9.65-10.97)
RCIM1	10.33 (9.85-10.81)	11.14 (10.56-11.71)	11.66 (11.05-12.28)	10.28 (.46-10.79)

South African ultrasound population averages and ranges with CI95		
Arterial measurement	**Adult male (mm)**	**Adult female (mm)**
LBAM1	6.08 (5.41-6.74)	5.41 (4.99-5.83)
RBAM1	6.03 (5.45-6.61)	5.41 (4.95-5.88)
LSCM1	7.70 (7.19-8.21)	6.28 (5.91-6.65)
RSCM1	8.29 (7.70-8.87)	6.53 (5.95-7.11)
LPAM1	7.33 (6.69-7.97)	5.88 (5.41-6.34)
RPAM1	6.79 (6.25-7.32)	6.78 (6.38-7.17)
LFAM1	8.35 (7.83-8.87)	7.29 (6.74-7.84)
RFAM1	8.25 (7.58-8.92)	7.05 (6.54-7.57)

APPENDIX B: ETHICS DOCUMENTATION

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences

Institution: The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 03/20/2022.
- IORG #: IORG0001762 OMB No. 0990-0279 Approved for use through February 28, 2022 and Expires: 03/04/2023.

18 September 2020

Approval Certificate
Annual Renewal

Ethics Reference No.: 346/2017
Title: A comparison of arterial measurements between South African cadaver and living sample as affected by age, sex, height and weight

Dear Mrs M Naudé

The **Annual Renewal** as supported by documents received between 2020-08-25 and 2020-09-09 for your research, was approved by the Faculty of Health Sciences Research Ethics Committee on 2020-09-09 as resolved by its quorate meeting.

Please note the following about your ethics approval:

- Renewal of ethics approval is valid for 1 year, subsequent annual renewal will become due on 2021-09-18.
- Please remember to use your protocol number (346/2017) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.

Ethics approval is subject to the following:

- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers
MBChB MMed (Int) MPharmMed PhD
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes, Second Edition 2015 (Department of Health)

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APPENDIX C: PUBLISHED ARTICLE

Surg Radiol Anat (2018) 40:39–43
DOI 10.1007/s00276-017-1938-4

ORIGINAL ARTICLE

The validity of arterial measurements in a South African embalmed body population

Marelize Schoeman[1] · Albert van Schoor[1] · Farhana Suleman[2] · Liebie Louw[3] · Peet du Toit[4]

Received: 9 July 2017 / Accepted: 27 October 2017 / Published online: 3 November 2017

Abstract

Introduction Knowledge of the normal arterial diameter at a given anatomical point is the first step toward quantifying the severity of cardiovascular diseases. According to several studies, parameters such as weight, height, age and sex can explain morphometric variations in arterial anatomy that are observed in a population. Before the development of a reference database against which to compare the diameters of arteries in a variety of pathological conditions, the compatibility between embalmed body measurements and computed tomography (CT) measurements must first be established.

Purpose The aim of this study was to compare embalmed body measurements and CT measurements at 19 diff ent arterial sites to establish whether embalmed body measurements are a true reflection of a living population.

Methods A total of 154 embalmed bodies were randomly selected from the Department of Anatomy at the University of Pretoria and 36 embalmed bodies were randomly selected from the Department of Human Anatomy at the University of Limpopo, Medunsa Campus. Dissections were performed on the embalmed body sample and the arterial dimensions were measured with a mechanical dial-sliding caliper (accuracy of 0.01 mm). 30 CT images for each of the 19 arterial sites were retrospectively selected from the database of radiographic images at the Department of Radiology, Steve Biko Academic Hospital. Radiant, a Digital Imaging and Communications in Medicine (DICOM) viewer was used to analyze the CT images.

Results The only statistically significant differences between the embalmed body measurements and CT measurements were found in the left common carotid- and the left subclavian arteries. The null hypothesis of no statistically significant difference between the embalmed body and CT measurements was accepted since the *P* value indicated no significant difference for 87% of the measurements, the exception being the left common carotid- and the left subclavian arteries.

Conclusions With the exception of two measurements, measurements in embalmed bodies and living people are interchangeable and concerns regarding the eff of distortion and shrinkage are unfounded. Even small changes in arterial diameter greatly influence blood flow and blood pressure, which contribute to undesirable clinical outcomes such as aortic aneurysms and aortic dissections. This study completes the first step towards the development of a reference database against which to compare the diameters of arteries in a variety of pathological conditions in a South African population.

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Keywords Arterial measurements · Computed tomography arterial measurements · Arterial dimensions · Morphometric variation

Introduction

Knowledge of the normal arterial diameter at a given anatomical point contributes to quantifying the severity of a cardiovascular disease. Studies on the association between changes in arterial diameter and cardiovascular risk factors have been done in the coronary arteries [5], different aortic segments [2, 4, 7–10] and iliac arteries [4, 7].

Physiological responses related to cardiovascular diseases lead to an increase in arterial diameters. These physiological responses may cause a widespread increase in arterial dimensions that is not limited to the narrowing of only a specific arterial segment. It is, therefore, difficult to establish whether the arterial segments that appear normal are truly normal [3]. This difficulty causes a problem with regard to the conventional radiographic estimation of the severity of a cardiovascular disease. The *percentage of stenosis* is based on a ratio of the diameters of a narrowed arterial segment to a normal arterial segment of a specifi arterial site [3]. Unfortunately, because the normal arterial diameter cannot be accurately assessed in humans, the clinical efficacy of this estimate is diminished.

The solution to this problem is to fi methods such as reference databases according to which we may predict normal arterial diameter at a given anatomical point and to use this diameter as normal reference to calculate the *percentage of stenosis*. At present, data on the normal diameter of human arteries in a South African population are not available in such a methodical format [3]. Although image diagnostic methods such as ultrasound and computed tomography (CT) become more accurate every day, studies using embalmed human bodies, or cadavers, are still an important source for medical knowledge, particularly those studies intending to clarify anatomical–morphological features. Concerns regarding studies using embalmed bodies embrace the possibility that the use of cadaveric tissue to measure arterial diameter may yield measurements that do not accurately reflect a living population. Arteries contain a high percentage of elastic tissue and smooth muscle in the tunica media; for this reason, arteries are not prone to collapse and should accurately reflect their true diameter [1, 6].

A component regarding a living population is often added to embalmed body studies to compare the samples, analyse the comparisons and diff ences and ultimately conclude whether the use of cadaveric tissue is an accurate reflection of the living population.

The aim of this study was to compare embalmed body measurements and CT measurements at diff ent arterial sites to establish whether South African embalmed body measurements are a true reflection of a living South African population.

Materials and methods

Embalmed body sample

All bodies were obtained through legal means and in according to the rules and regulations stated in the South African National Health Act, 61 of 2003. Unclaimed and/or donated bodies were embalmed with a formalin mixture in preparation for teaching and research purposes within the Department of Anatomy, University of Pretoria, South Africa. Ethical clearance to perform this study was obtained from the Faculty of Health Sciences Research Ethics Committee at the University of Pretoria (83/2014).

A total of 154 embalmed bodies were randomly selected from the Department of Anatomy at the University of Pretoria, 36 embalmed bodies were randomly selected from the Department of Anatomy at the University of Limpopo, Medunsa Campus—making up a total sample of 190 embalmed bodies that were examined. Dissections were performed on the embalmed body sample and the arterial dimensions were measured with a mechanical dial-sliding caliper (accuracy of 0.01 mm). The arteries were free of any filling or injection of any fl other than the formalin mixture used during the embalming process. Extreme care was taken not to artificially compress the arteries at the time that any measurement was taken.

The demographic information related to each embalmed body in the Department of Anatomy was obtained from the hospital records. The weight and height were measured post-mortem, pre-embalmment and should, therefore, be an accurate reflection of the weight and height of the individual.

The 190 embalmed bodies were divided into two subgroups, 125 males and 65 females. Embalmed bodies were not excluded due to height, weight or age. The age of the embalmed bodies ranged from 20 to 99 years. Embalmed bodies with known or visible aneurysms, arterial dissections or those who have undergone previous vascular surgery or suffered from any known vascular pathology were excluded from the study.

The relevant arteries were exposed during the dissection of the embalmed bodies in the Department of Anatomy. Where necessary, the arteries were further cleaned prior to the arterial measurements being taken. Without compressing the artery, measurements were taken for the outer diameter at the 19 arterial sites (Table 1).

To minimize intra-observer error, 25% of the measurements were re-taken by the primary investigator. To

Table 1 Measured arterial sites

#	Arterial site
1	Ascending aorta proximal to fibrous pericardium
2	Abdominal aorta at level of celiac trunk
3	Abdominal aorta before terminal bifurcation
4	Left internal carotid artery distal to carotid body
5	Right internal carotid artery distal to carotid body
6	Left common carotid artery at origin
7	Right common carotid artery at origin
8	Left brachial artery before bifurcation
9	Right brachial artery before bifurcation
10	Left subclavian artery at origin
11	Right subclavian artery at origin
12	Left popliteal artery in popliteal fossa
13	Right popliteal artery in popliteal fossa
14	Left femoral artery inferior to inguinal ligament
15	Right femoral artery inferior to inguinal ligament
16	Left common iliac artery at origin
17	Right common iliac artery at origin
18	Left coronary artery at origin
19	Right coronary artery at origin

Table 2 Embalmed body sample *vs.* CT sample (age and sex)

Measurement	*P* value
Ascending aorta proximal to fibrous pericardium	0.0665
Abdominal aorta at level of celiac trunk	0.6250
Abdominal aorta before terminal bifurcation	0.5000
Left internal carotid artery distal to carotid body	0.0547
Right internal carotid artery distal to carotid body	0.1914
Left common carotid artery at origin	**0.0156**
Right common carotid artery at origin	0.0742
Left brachial artery before bifurcation	*
Right brachial artery before bifurcation	*
Left subclavian artery at origin	**0.0273**
Right subclavian artery at origin	0.2188
Left popliteal artery in popliteal fossa	0.6250
Right popliteal artery in popliteal fossa	0.3500
Left femoral artery inferior to inguinal ligament	0.8125
Right femoral artery inferior to inguinal ligament	0.4375
Left common iliac artery at origin	0.7500
Right common iliac artery at origin	0.5000
Left coronary artery at origin	*
Right coronary artery at origin	*

*See "Limitations"

minimize inter-observer error, 20% of the measurements were also re-taken by a separate, independent individual.

CT sample

For the second part of the study, 30 CT images for each of the 19 arterial sites were retrospectively selected from the database of radiographic images at the Department of Radiology, Steve Biko Academic Hospital. The demographic information, related to each patient, was obtained from this database and included age and sex.

To allow for comparisons to be made, CT scans of patients between the ages of 15 and 65 years, of both sexes were included.

The patient scans were screened and selected by a consultant radiologist and the CT images of patients with known or visible arterial aneurysms, arterial dissections or those who have undergone previous vascular surgery or suffered from any known vascular pathology were excluded from this study.

Radiant, a Digital Imaging and Communications in Medicine (DICOM) viewer was used to analyze the CT images. Using the on-screen measuring function, calibrated for each image, the outer diameter of each of the 19 arterial sites was recorded.

The 19 arterial sites were identified as a representation of the arteries of the human body. Elastic arteries, which are close to the heart and defi as low-resistance pathways were included, as well as muscular arteries, which are more distal, active in vasoconstriction and less distensible [6].

Results

To establish whether there is a statistical significant difference between the measurements of the embalmed body sample and the CT sample, representing a living South African sample, *t* tests were performed. Embalmed bodies and CT patients were matched for age and sex and 22 matching pairs were found (Table 2). Embalmed bodies and CT patients were also matched to age alone and 29 matching pairs were found (Table 3).

Table 2 shows the *P* values found when comparing the embalmed body measurements to the CT measurements for the specifi age and sex matched pairs. A *P* value smaller than 0.05 (in bold) indicates a statistically significant difference.

Table 3 shows the *P* values found when comparing the embalmed body measurements to the CT measurements for the specific age matched pairs. A *P* value smaller than 0.05 (in bold), indicates a statistical significant difference.

Pearson's correlation tests were performed to determine the accuracy (intra-observer error) and repeatability (inter-observer error) of the measurements. An *r* value of 0.999819208 indicated a very strong ($r > 0.8$) correlation

Table 3 Embalmed body sample vs. CT sample (age)

Measurement	*P* value
Ascending aorta proximal to fibrous pericardium	**0.0051**
Abdominal aorta at level of celiac trunk	0.2500
Abdominal aorta before terminal bifurcation	0.4375
Left internal carotid artery distal to carotid body	0.1094
Right internal carotid artery distal to carotid body	0.2891
Left common carotid artery at origin	**0.0156**
Right common carotid artery at origin	0.0756
Left brachial artery before bifurcation	*
Right brachial artery before bifurcation	*
Left subclavian artery at origin	**0.0156**
Right subclavian artery at origin	0.2188
Left popliteal artery in popliteal fossa	1.0000
Right popliteal artery in popliteal fossa	0.1250
Left femoral artery inferior to inguinal ligament	0.8125
Right femoral artery inferior to inguinal ligament	0.4688
Left common iliac artery at origin	0.8125
Right common iliac artery at origin	0.8135
Left coronary artery at origin	*
Right coronary artery at origin	*

*See "Limitations"

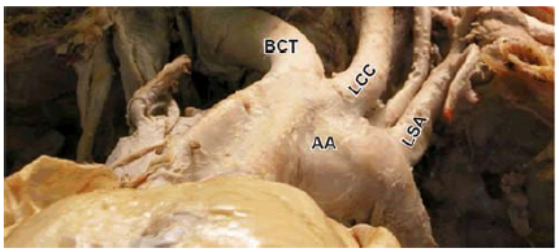

Fig. 1 Aortic arch in embalmed body. *AA* aortic arch, *BCT* Brachiocephalic trunk, *LCC* left common carotid artery, *LSA* left subclavian artery

for repeatability and an *r* value of 0.999951921 indicated a very strong ($r > 0.8$) correlation for accuracy.

Discussion

The null hypothesis of no statistically significant difference between the embalmed body and CT measurements was accepted since the *P* value indicated no signifi diff - ence for 87% of the measurements, the exception being the left common carotid- and the left subclavian arteries.

These arteries are found on the left side of the neck, branching from the arch of the aorta (Fig. 1). Since the origin of these two arteries differ from the origin of the same arteries of the right side of the neck, and it is the only two arteries showing a statistical significant difference between embalmed body and CT measurements (taken at origin), the notion that the embalming process might have affected the structure of the brachiocephalic trunk (and its branches) as the first branch of the arch of the aorta was considered. This is probably unlikely as the pressure or speed of the embalming process would have resulted in more differences between the two samples. It is possible that when comparing the embalmed body measurements with a larger CT sample, the differences might not be significant. This theory will be tested in future studies.

The collected arterial dimensions with no statistical signifi diff ence observed between the embalmed body sample and CT sample, will form the basis of an arterial reference data set that will be extended during future research. This will allow the prediction of the normal arterial diameter at a given anatomical point and for it to be used as normal reference to calculate the *percentage of stenosis*.

An extensive arterial dimension database for a South African population might provide better insight into the normal and abnormal diameters of the diff ent arteries affected. This knowledge could contribute to early diagnosis of various cardiovascular diseases and arterial abnormalities.

Limitations

If not indicated in the records, it is impossible to determine whether the embalmed bodies or CT patients suffered from conditions such as elevated blood pressure, atherosclerosis, diabetes mellitus or high cholesterol during life. It is also unclear whether they were smokers or suffered from other risk factors that could have accelerated age-related changes in the structure and function of arterial anatomy. The use of a large embalmed body sample should minimize the influence of such factors.

Full-body CT images are scarce and therefore the 30 CT images for 15 of the 19 arterial sites were collected from 65 patients. The left and right brachial arteries and the left and right coronary arteries were not measured on CT because these areas are only visible on a CT image when specifically scanned, searching for pathology–pathology that could possibly influence the dimensions of these arteries. For future studies, the CT sample will be enlarges, eliminating possible discrepancies leading to the differences found between embalmed body- and CT samples.

Conclusion

This study completed the first step towards the development of a embalmed body-based arterial reference data set that

will provide us with a quantitative estimate of the severity of cardiovascular diseases in a South African population. Such a database would aid in the assessment of arterial changes with the advancement of age as well as the assessment of arterial dimensions within groups with different demographic data.

The non-collapsing nature of arteries of the embalmed body sample was validated by the results of this study, making cadaveric research possible and valid. Arterial measurements in embalmed bodies and living people are interchangeable and concerns regarding the effect of distortion and shrinkage are unfounded.

Acknowledgements This study would not have been possible without the assistance, guidance and special skills of the following people: Andries Masenge from the Department of Statistics, University of Pretoria; Zarina Lockhat from the Department of Radiology, University of Pretoria. The authors hereby also acknowledge those who donated their bodies, whom without this research would not have been possible.

Compliance with ethical standards

Funding This work was supported by the South African National Research Foundation and the University of Pretoria Research Development Program.

Conflict of interest The authors declare no conflict of interest.

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