An anatomical investigation of the radial artery and its distal segment in a select South African population

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PREFACE

This study is a representation of original work by the author and has not been submitted to other universities in any form. The work is under review in accredited journals in line with the dissertation guidelines of the University of KwaZulu-Natal. Acknowledgement in the text has been made where the work of others was used.

The research described in this project was supervised by Prof. L. Lazarus (Department of Clinical Anatomy, School of Medicine, College of Health Sciences, University of KwaZulu-Natal, South Africa), and Dr R. Harrichandparsad (Department of Neurosurgery, School of Medicine, College of Health Sciences, University of KwaZulu-Natal, South Africa), and was conducted in the above-mentioned institution and the Inkosi Albert Luthuli Central Hospital, Durban, KwaZulu-Natal, South Africa.

DECLARATION

I, Ms Aleisha Jo Singh, declare as follows:

i. The work described in this dissertation has not been submitted to the University of KwaZulu-Natal or other tertiary institutions for the purposes of obtaining an academic qualification, whether by me or any other party.

ii. This dissertation does not contain another person's data, graphs, tables or other information unless specifically acknowledged as being sourced from other persons.

iii. This dissertation does not contain another person's writing unless specifically acknowledged as being sourced from other persons. Where other written sources have been quoted, the information used has been referenced accordingly.

iv. The research reported in this dissertation, unless otherwise indicated, is my original work. My contribution to the project was as follows:

- development and design of research topic and protocol;
- conduction of research methodology;
- collection and analysis of data;
- interpretation of data obtained;
- formulation of manuscript; and
- write-up of the final dissertation.

v. The contribution of others to this project was as follows:
Prof. L. Lazarus (supervisor) and Dr R. Harrichandparsad (co-supervisor):

- development and refining of the research design and plan;
- assistance with the analysis of data and statistical analysis; and
- review of the manuscript and dissertation before submission.

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16 November 2025

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LIST OF ABBREVIATIONS AND ACRONYMS

BMI	Body mass index
BSA	Body surface area
DFRA	Distal forearm radial artery
Fr	French
ICCs	Intraclass correlation coefficients
LDFRA	Left distal forearm radial artery
LSRA	Left snuffbox radial artery
RDFRA	Right distal forearm radial artery
RSRA	Right snuffbox radial artery
SD	Standard deviation
SRA	Snuffbox radial artery

ABSTRACT

The radial artery and its distal segment are increasingly favoured as access points in neuro-interventional procedures via the transradial approach, owing to their accessibility and lower complication rates compared to the transfemoral approach. The success of such procedures is influenced by factors such as vessel diameter, sheath compatibility and anatomical variations. Although the radial artery has been studied extensively in other populations, limited data exist for African cohorts, particularly within the South African population. Therefore, this study aimed to document the anatomical characteristics of the radial artery and its distal segment within a select South African sample.

A mixed-method design was employed, comprising ultrasound investigation in a participant sample (n = 256, 128 adults and 128 paediatric patients) and cadaveric dissection of 30 adult body donors. The study was conducted at a central regional hospital in Durban, South Africa, and at the Department of Clinical Anatomy, University of KwaZulu-Natal. Ultrasound imaging measured the internal diameters of the distal forearm and snuffbox radial arteries, while dissection was used to determine the external and internal diameters, wall thickness at three levels (point of origin, wrist joint and anatomical snuffbox) and the origin of the radial artery.

Ultrasound findings revealed mean diameters of 1.94 ± 0.39 mm for the distal forearm radial artery and 1.33 ± 0.31 mm for the snuffbox radial artery in adults, with males demonstrating significantly larger diameters. Paediatric measurements were notably smaller (1.12 ± 0.32 mm and 0.77 ± 0.20 mm, respectively). Cadaveric analysis demonstrated a progressive tapering of the artery from its point of origin toward the anatomical snuffbox. Approximately 55% of adults and 99% of paediatric patients had distal radial artery diameters less than 2.0 mm – the outer diameter of a 4 French sheath. Variations in the origin of the radial artery were also noted, with 10% displaying a high origin from the axillary artery.

This study contributes to the literature by providing novel morphometric and morphological data based on a select South African population. The findings of the present study may assist clinicians during coronary, cardiovascular, neurological and neuro-interventional procedures within this select population.

CHAPTER 1
INTRODUCTION

1.1 Introduction

Embryologically, the radial artery arises as sprouts from the axial artery (Schoenwolf, Bleyl, Brauer and Francis-West, 2009; Singh, 2020). The radial artery is one of the terminal branches of the brachial artery and originates at the neck of the radius at the apex of the cubital fossa (Moore, Dalley and Agur, 2018; Drake, Vogl, Mitchell and Gray, 2020; Narsinh, Mirza, Caton, Baker, Winkler et al., 2021; Brennan, Zhang and Hacking, 2025). The radial artery courses laterally in the forearm and crosses the floor of the anatomical snuffbox at the wrist, where it lies in close proximity to the scaphoid and trapezium bones (Moore, Dalley and Agur, 2018; Brennan, Zhang and Hacking, 2025). This anatomical pathway is critical for numerous clinical procedures such as radial artery catheterisation, coronary artery bypass grafting and surgical flaps (Mudiraj and Dhobale, 2015; Bundi, Mutua, Cheruiyot, Munguti, von Csefalvay et al., 2022; Rengifo and Lian, 2023; Adnan and Yandrapalli, 2024).

While the radial artery normally originates in the cubital fossa, anatomical variations such as the radial artery arising from the axillary artery or the proximal part of the brachial artery have been documented (Karlsson and Niechajev, 1982; Zhan, Zhao, Sun, Ling and Yip, 2010; Kore and Vishwakarma, 2021; Bundi et al., 2022). Rodriguez-Niedenfuhr, Vázquez, Nearn, Ferreira, Parkin, and Sañudo (2001) standardised the term *brachioradial artery*, which refers to the radial artery originating from the brachial artery, high bifurcation of the brachial artery, radial artery originating from the axillary artery, double brachial artery and continuance of the superficial brachial artery as the radial artery (Haładaj, Wysiadecki, Dudkiewicz, Polgui and Topol, 2018; Narsinh et al., 2021).

The incidence of high origin radial arteries varies across study modalities and population demographics, ranging from 15.6% in cadaveric studies to 24.4% in angiographic studies (Weatherby, 1956; Janevski, 1982). These variations arise during the embryological development of the upper extremity arteries and have significant complications during reconstructive surgeries, coronary and neurological interventions (Narsinh et al., 2021). The radial artery (also known as the forearm radial artery – the conventional access point) and its distal segment (also known as the distal radial artery or the snuffbox radial artery [SRA] – distal access point) are favoured increasingly over the femoral artery for neuro-interventional procedures due to their lower complication rates (Daralammouri, Nazzal, Mosleh, Abdulhaq, Khayyat et al., 2022).

Trans-femoral access during neuro-interventional procedures results in various complications such as pseudoaneurysms and retroperitoneal hematoma, whereas transradial access is associated with fewer complications and reduced costs (Brunet, Chen, Sur, McCarthy, Snelling et al., 2019; Narsinh et al., 2021). However, procedural success depends on the vessel diameter, the presence of arterial loops and sheath compatibility (Narsinh et al., 2021). The diameter of the radial artery varies by location. Various authors have reported that the diameter of the radial artery at the conventional access point is larger than its distal access point. Similarly, various authors have reported that females have a smaller radial artery diameter when compared to males (Velasco, Ono, Nugent, Tarwater and Kumar, 2012; Aykan, Hatem, Kalaycıoğlu, Altıntaş Aykan et al., 2015; Dharma, Kedev, Patel, Rao, Bertrand and Gilchrist, 2017). Numerous studies have reported that body parameters such as height, weight and wrist circumference can influence the size of the radial artery (Okuyan, Hzal, Taçoy and Timurkaynak, 2013; Kotowycz, Johnston, Ivanov, Asif, Almoghairi et al., 2014; Aykan et al., 2015; Alehaideb, Ha, Bickford, Dmytriw, Bhatia et al., 2020; Deora, Sharma, Choudhary, Kaushik, Garg et al., 2022).

Although the distal radial artery is smaller, there is no need to downsize the sheath intended for use to accommodate the size of the distal radial artery (Narsinh et al., 2021). Sheath compatibility is measured using the French (Fr) scale, where 1 Fr equals one–third of the circumference in millimetres (mm) (Mathis, Romans and Divekar, 2020). While sheath size denotes the inner diameter, the outer diameter (typically 1 Fr larger) determines the risk of arterial injury (Mathis, Romans and Divekar, 2020). Radial sheaths mitigate the risk of arterial injury as they have thinner walls; thus, reducing the outer diameter without compromising the inner lumen (Mathis, Romans and Divekar, 2020). According to Bhatia, Kumar and Arafath (2023), to accommodate a 5 Fr sheath, the lower limit of the diameter of the radial artery must be 1.8 mm. Agnoletti, Boudjemline, Largen, Aggoun, Szezepanski et al. (2003) reported using a 3 Fr sheath in newborns for diagnostic and interventional investigations, which resulted in no complications. Saito, Ikei, Hosokawa and Tanaka (1999), reported that there was an increase from 4% to 13% of severe flow reduction of the radial artery when the ratio between the radial artery inner diameter and sheath outer diameter was less than 1.0 mm.

The use of ultrasound guidance during transradial access for neurointerventional procedures leads to a higher success rate, shorter duration, reduced attempts, reduced crossover rates, efficiency of radial artery cannulation and reduced occurrence of complications (such as radial artery occlusion) (Seto, Roberts, Abu-Fadel, Czak, Latif et al., 2015; Pitta and Prasad, 2020; Bhatia, Kumar and Arafath, 2023). According to Peruga, Peruga, Kasprzak, Kręcki, Jankowski et al. (2015), ultrasound can indirectly provide information about the efficacy of the collateral blood supply to the hand and enables the determination of the vessel diameter. Despite extensive documentation of the variations in the origin of the radial artery, there is sparse literature regarding the origin of the radial artery within the South African population. Similarly, morphometric data about the radial artery and its distal segment in the African population are scarce. This study, therefore, aimed to document the anatomical characteristics of the radial artery and its distal segment within a select South African population.

1.1.1 Aim

To document the anatomical characteristics of the radial artery and its distal segment by using ultrasound investigation within select living adult and paediatric participants, as well as by means of dissection within a select adult cadaveric South African population.

1.1.2 Objectives

a) To determine and compare the diameter of the radial artery and its distal segment (including the segment within the anatomical snuffbox) on the right and left sides of the body by means of ultrasound investigation within select living adult and paediatric participants in a South African population, as well as by means of dissection within a select adult body donor cadaveric South African population.

b) To document the standard anatomy and any anatomical variations of the origin of the radial artery on the right and left sides of the body.

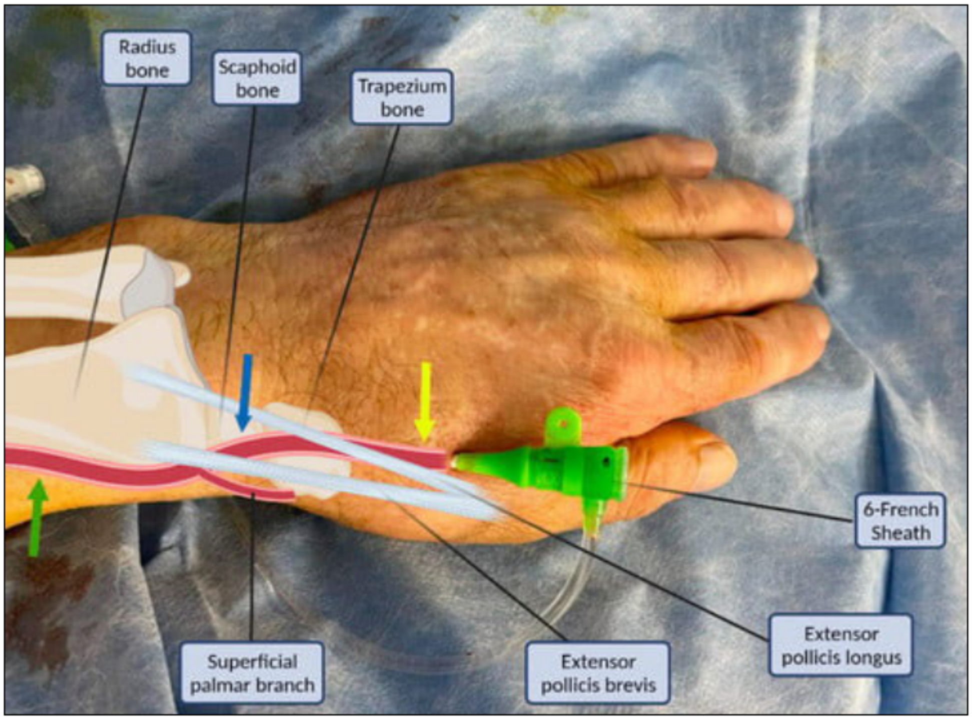
c) To document the demographic and biological factors, such as age, sex, ethnicity, height, weight, and wrist circumference and their relationship to the diameter of the distal radial artery (and the radial artery in the anatomical snuffbox).

1.2 Literature review

1.2.1 Gross anatomy

The radial artery is one of the terminal branches of the brachial artery at the apex of the cubital fossa, which provides vasculature to the elbow joint, lateral side of the index finger, thumb, carpal bones and the postero-lateral side of the forearm (Moore, Dalley and Agur, 2018; Sgueglia, Giorgio, Gaspardone and Babunashvili, 2018; Narsinh et al., 2021; Brennan, Zhang and Hacking, 2023; Marchese, Launico and Geigner, 2025). The radial artery travels between the flexor and extensor groups of muscles in the forearm (Moore, Dalley and Agur, 2018; Narsinh et al., 2021). In the proximal half of the forearm, the radial artery lies deep to the brachioradialis muscle (Drake et al., 2020). While in the middle third of the forearm, the radial artery is laterally related to the radial nerve (superficial branch) (Drake et al., 2020). However, in the distal part of the forearm, the radial artery, which is covered by fascia and skin, lies anterior to the pronator quadratus muscle and lateral to the tendon of flexor carpi radialis (Drake et al., 2020). Proximal to the wrist, the radial artery gives off a superficial palmar branch prior to winding around the lateral aspect of the wrist to exit the forearm (Moore, Dalley and Agur, 2018; Roh and Lee, 2018; Drake et al., 2020; Marchese, Launico and Geiger, 2023).

The radial artery runs across the floor of the anatomical snuffbox, which is composed of the scaphoid and trapezium carpal bones of the hand (Moore, Dalley and Agur, 2018; Roh and Lee, 2018; Brennan, Zhang and Hacking, 2025; Hallett Reid, Jozsa and Ashurst, 2023). The tendons of extensor pollicis longus (medially), abductor pollicis longus (laterally) and extensor pollicis brevis (laterally) demarcate the anatomical snuffbox (Figure 1) (Moore, Dalley and Agur, 2018; Roh and Lee, 2018; Hallett Reid, Jozsa and Ashurst, 2023). The styloid process of the radius forms the proximal border of the anatomical snuffbox (Roh and Lee, 2018). When the radial artery is within the anatomical snuffbox, it is also known as the distal radial artery (Daralammouri et al., 2022; Dawani, Mahajan, Vasudeva and Mishra, 2022). The anatomical snuffbox (also known as the radial fossa) contains a superficial branch of the radial nerve and cephalic vein in addition to the radial artery (Roh and Lee, 2018; Hallett Reid, Jozsa and Ashurst, 2023). The radial artery then enters the palm by running between the two heads of the first dorsal interosseous muscle (Moore, Dalley and Agur, 2018; Roh and Lee, 2018). The artery then courses medially between the transverse and oblique heads of the adductor pollicis muscle (Moore, Dalley and Agur, 2018; Roh and Lee, 2018; Narsinh et al., 2021).



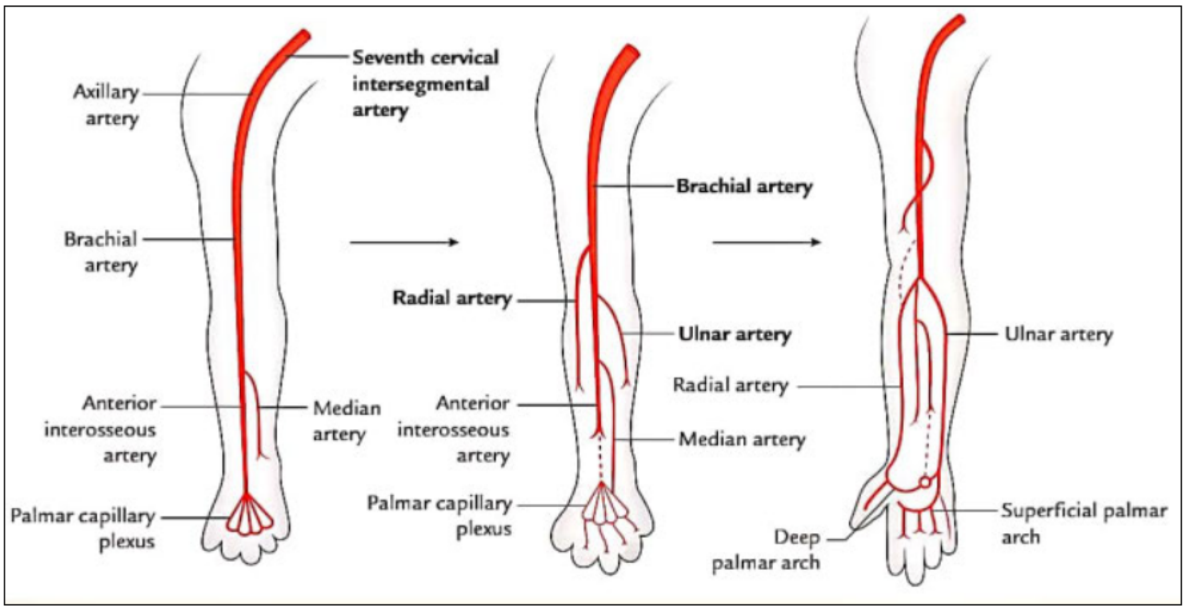
Source: Adapted from Achim, Péter, Kákonyi, Sasi, Nemes et al. (2022)

Figure 1: The course of the radial artery in the anatomical snuffbox

The radial artery terminates by forming the deep palmar arch by anastomosing with the deep palmar branch of the ulnar artery (Moore, Dalley and Agur, 2018; Roh and Lee, 2018; Narsinh et al., 2021; Daralammouri et al., 2022; Dawani et al., 2022). The princeps pollicis artery and three metacarpal arteries arise from the deep palmar arch (Moore, Dalley and Agur, 2018). The princeps pollicis artery may give rise to the radialis indices artery, which runs along the index finger on the lateral side (Moore, Dalley and Agur, 2018; Narsinh et al., 2021). The superficial palmar branch of the radial artery anastomoses with the ulnar artery to form the superficial palmar arch (Moore, Dalley and Agur, 2018). The superficial and deep palmar arches maintain the blood flow to the digits (Daralammouri et al., 2022).

1.2.2 Embryology

The aortic arch develops during the fourth week of embryonic development from the fourth pharyngeal arch (left branch) (Kelley and Ashurst, 2023). During embryonic development, the left subclavian artery develops from the left seventh intersegmental artery (Figure 2) (Rahimi and Geiger, 2023). The right subclavian artery arises from the brachiocephalic artery (also known as the innominate artery), which is one of the three branches of the aortic arch (Rahimi and Geiger, 2023). The right and left subclavian arteries course laterally between the anterior and middle scalene muscles until they reach the first rib (Rahimi and Geiger, 2023). When the subclavian artery passes the lateral border of the first rib, it becomes known as the axillary artery (Rahimi and Geiger, 2023). An axillary sheath covers the axillary artery, which is the continuation of the prevertebral fascia of the neck (Thiel, Munjal and Daly, 2025).



Source: Adapted from Singh (2012)

Figure 2: Development of the radial artery

The axillary artery is divided into three parts based on its relation to the pectoralis minor muscle (Thiel, Munjal and Daly, 2025). At the lower border of the teres major muscle, the axillary artery terminates and becomes known as the brachial artery (Thiel, Munjal and Daly, 2025). The brachial artery courses on the ventral surface of the arm and gives off numerous branches before reaching the cubital fossa (Epperson and Varacallo, 2023). At the apex of the cubital fossa, the brachial artery terminates into the radial and ulnar arteries (Epperson and Varacallo, 2023).

1.2.3 Transradial access for neuro-interventional procedures

The radial artery and its distal segment are used for neuro-interventional procedures such as carotid stenting, aneurysm coiling and arteriovenous malformations (Daralammouri et al., 2022; Bhatia, Kumar and Arafath, 2023). The transradial approach is also a safer and more cost-effective alternative to the transfemoral approach in paediatric patients (Irving, Zaman and Kirk, 2009; Majmundar, Patel, Dodson, Bach, Liu, Tomycz and Khandelwal, 2020). While the radial artery is used during neurointerventional procedures, patient selection is important to prevent complications (Bhatia, Kumar and Arafath, 2023). Factors such as the diameter of the radial artery and the patient's age are crucial in preventing spasms of the radial artery (Narsinh et al., 2021; Bhatia, Kumar and Arafath, 2023). Young adolescent females with small diameters of the radial artery are more prone to radial artery spasm (Bhatia, Kumar and Arafath, 2023).

The radial artery is most prominent approximately two to three centimetres proximal to the styloid process of the radius (Bhatia, Kumar and Arafath, 2023). Hence, the radial artery is mainly accessed proximal to the wrist (the conventional way). The puncture site is located between the tendon of extensor pollicis longus and the tendon of extensor pollicis brevis or the tendon of abductor pollicis longus at the level of the scaphoid carpal bone when the distal segment of the radial artery is being used (Bhatia, Kumar and Arafath, 2023). The right carotid and right vertebral systems are mostly catheterised during transradial access (Nohara and Kallmes, 2003). When the radial artery or its distal segment is used during neuro-interventional procedures, all relevant vessels such as the descending aorta, arch of aorta and right vertebral artery can be accessed (Hobby, Stroebel, Yamada, Johnson, Uflacker, Hannegan and Guimaraes, 2021; Bhatia, Kumar and Arafath, 2023). However, anatomical variations of the radial artery, subclavian artery and aortic arch can increase the difficulty during neuro-interventional procedures (Hobby et al., 2021; Bhatia, Kumar and Arafath, 2023).

1.2.4 Origin of the radial artery

The radial artery is one of the terminal branches of the brachial artery at the neck of the radius in the cubital fossa (Drake et al., 2020; Narsinh et al., 2021). The radial artery travels laterally in the forearm from the cubital fossa to the palm, where it terminates by anastomosing with the ulnar artery to form the deep palmar arch (Drake et al., 2020; Narsinh et al., 2021). However, there are anatomical variations in the origin of the radial artery. These variations are caused during the embryological development of the upper limb arteries (Narsinh et al., 2021). Rodriguez-Niedenfuhr, Vázquez et al.

(2001) proposed the term *brachioradial artery*, which is a unified and precise nomenclature, to describe the previously descriptive terminology for the following (Haładaj et al., 2018; Narsinh et al., 2021):

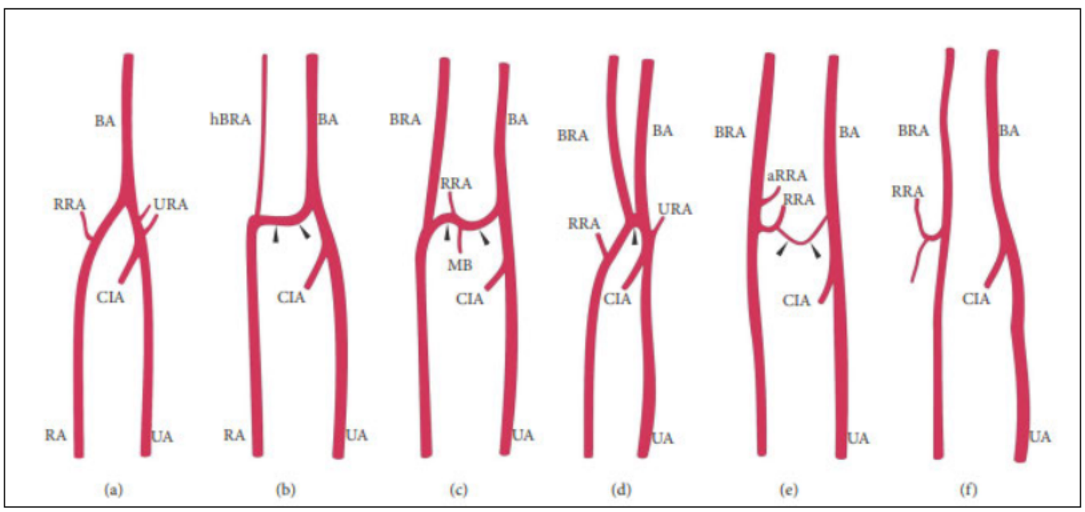
- radial artery originating from the brachial artery,
- high bifurcation of the brachial artery,
- radial artery originating from the axillary artery,
- double brachial artery, and
- continuance of the superficial brachial artery as the radial artery.

Hence, the term *brachioradial artery* refers to the high origin of the radial artery (Rodriguez-Niedenfuhr, Vázquez et al., 2001; Haładaj et al., 2018; Narsinh et al., 2021). Moreover, the radial artery can exhibit a more distal origin, which is under the pronator teres muscle (Venkataram, Ellur, Muninarayana and Joseph, 2016; Wysiadecki, Polguj, Haladaj and Topol, 2017). The radial artery can even be absent (Prues-Latour and Papaloïzos, 2000). *Cubital connection* or *cubital crossover* refers to the anastomosis between the brachioradial artery and the original (or conventional) brachial arteries in the cubital fossa (Narsinh et al., 2021; Glin, Zielinska, Ruzik, Karauda, Konschake and Olewnik, 2023). However, it can be considered a remnant of the connection between the superficial brachial and the primitive axial arteries in the typical origin of the radial artery (which is in the cubital fossa) (Haładaj et al., 2018; Narsinh et al., 2021). There are several variations of the cubital crossover as listed in Table 1.

Table 1: Variations of cubital crossover

Variation	Description
Conventional anatomy (Figure 3a)	The most common course of the radial artery. The radial artery originates as one of the terminal branches of the brachial artery in the cubital fossa. The brachioradial artery is not present.
Dominate type (Figure 3b)	Anastomosis between the brachioradial artery and the original (normal) brachial artery. Characterised by a greater diameter than the brachial segment of the brachioradial artery. The hypoplastic perianastomotic part of the brachioradial artery is present.
Balanced type (Figure 3c)	Anastomosis between the brachioradial artery and the original brachial arteries. Characterised by a similar diameter to the diameter of the brachioradial artery.
Arterial island (Figure 3d)	The brachioradial artery and the original brachial artery create an arterial complex, similar to an island, at the level of the neck of the radius. This terminates in the bifurcation of the radial artery and the ulnar artery.
Minimal type (Figure 3e)	Anastomosis is narrower in diameter than that of the brachioradial artery.
Absence of cubital crossover (Figure 3f)	There is no anastomosis between the brachioradial artery and the original brachial artery within the cubital fossa.

Source: Adapted from Haładaj et al. (2018) and Narsinh et al. (2021)



Source: Adapted from Haladaj et al. (2018)

Figure 3: Variations of cubital crossover (marked by black arrowheads) (a) Conventional anatomy, (b) Dominant type, (c) Balanced type, (d) Arterial island, (e) Minimal type, and (f) Absence of cubital crossover. aRRA: accessory radial recurrent artery; BA: brachial artery; BBA: brachioradial artery; CIA: common interosseous artery; hBRA: hypoplastic perianastomotic part of the brachioradial artery; MB: muscular branch; RA: radial artery; RRA: radial recurrent artery; UA: ulnar artery; URA: ulnar recurrent artery

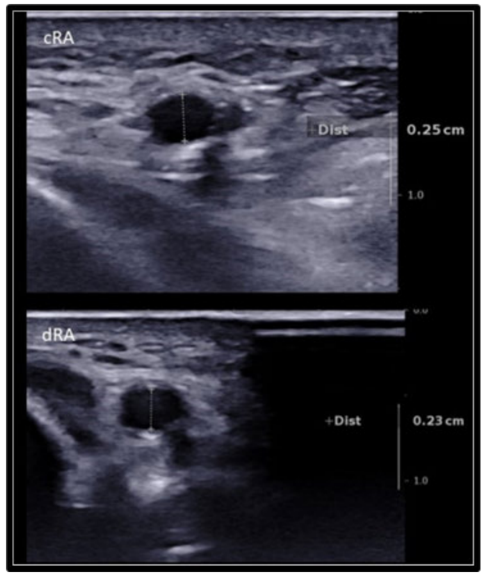
The radial artery loop is located distal to the origin of the radial artery and is characterised by a classic 360° loop or tortuosity greater than 90° (Narsinh et al., 2021). The radial recurrent artery arises from the apex of the radial artery loop (Dossani, Waqas, Tso, Cappuzzo, Popoola et al., 2021). Variations in the origin of the radial artery and the presence of radial artery loops can cause a problem during neuro-interventional procedures and are associated with transradial access failures (Dossani et al., 2021; Narsinh et al., 2021).

1.2.5 Use of ultrasound

The use of ultrasound during transradial access for neuro-interventional procedures leads to a higher success rate, shorter duration, reduced attempts, reduced crossover rates, efficiency of radial artery cannulation and reduced occurrence of complications (such as radial artery occlusion) (Seto et al., 2015; Pitta and Prasad, 2020; Bhatia, Kumar and Arafath, 2023). A meta-analysis conducted by Tang, Wang, Li, Zhao, Xi et al. (2014), indicated that ultrasound guidance increased the first-attempt success rate of radial artery catheterisation (especially when the operators are experienced), reduced the occurrence of hematoma, reduced the mean-attempts to success and mean-time to success. Ultrasound guidance should be used while attempting transradial procedures in paediatric patients due to their smaller-calibre arteries (Majmundar et al., 2020). Ultrasound can indirectly provide information about the efficacy of the collateral blood supply to the hand and enables the determination of the vessel diameter (Peruga et al., 2015). Various authors have used ultrasound guidance to determine the diameter of the radial artery and its distal segment as it is non-invasive (Tables 4, 5, 7, 8, 10 and 11) (Nagai, Abe, Sato, Hozawa, Yuki, Hanashima and Tomoike, 1999; Yoo, Yoon, Ko, Kim, Lee, Hwang and Choe, 2005; Kotowycz et al., 2014; Peruga et al., 2015; Dharma et al., 2017; Alehaideb et al., 2020; Srinivasan, Hadley, Prablek, LoPresti, Chen et al., 2020; Hammami, Zouari, Ben Abdessalem, Sassi, Ellouze et al., 2021; Gündüz, Gunduz, Ates, Ciner, Cakmak et al., 2022).

1.2.6 Diameter

Various authors measure the diameter of the radial artery and its distal segment from the tunica media to the tunica adventitia using ultrasound (Figure 4). The diameter of the radial artery is measured using a vernier calliper in cadavers (Getachew, Astatkie and Lemma, 2018). The range of the diameter of the radial artery is between 1.15 mm to 3.95 mm (Narsinh et al., 2021). The right-sided radial artery is larger in males than in females and smaller in patients of South Asian descent (Kotowycz et al., 2014). In paediatric patients, Jang, Ji, Kim, Lee, Kim, Mossad, and Kim (2020) demonstrated that a subcutaneous administration of nitroglycerine produced a substantially larger increase in the radial artery diameter (25.0 ± 19.5%) than administration of normal saline (1.9 ± 13.1%). The diameter of the radial artery was smaller in those patients who experienced spasm of the radial artery compared to those who did not experience a radial artery spasm (Hammami et al., 2021).



Source: Adapted from Deora et al. (2022)

Figure 4: Measurement of the radial artery at the conventional access site (cRA) and distal access site in the anatomical snuffbox (dRA)

1.2.6.1 Factors that influence the diameter of the radial artery and its distal segment

The success of transradial neurointerventional procedures is contingent upon adequate vessel calibre, yet the diameter of the radial artery exhibits inter-individual variability. Understanding the factors that contribute to this variability is essential for patient selection and procedural planning. Sex-based differences are among the most consistently reported findings, with studies by Velasco et al. (2012) and Dharma et al. (2017) reporting that females were associated with smaller radial artery diameters. However, paediatric data (in children less than or equal to the age of 18 years) reported by Alehaideb et al. (2020) revealed no significant differences in the radial artery diameter between males (1.90 ± 0.50 mm) and females (1.81 ± 0.53 mm).

Anthropometric or body parameters such as body mass index (BMI), weight, wrist circumference, and body surface area (BSA) have been widely investigated as potential predictors of the radial artery calibre. Several studies have reported positive associations between body parameters and the radial artery diameter. Velasco et al. (2012) found that an increase in body mass index (BMI) was associated with larger radial artery diameters. While Alehaideb et al. (2020), in 134 children, observed that the diameter of the radial artery correlated strongly with weight and age. Similarly, Kotowycz et al. (2014) reported male sex, wrist circumference and non-South Asian ancestry as independent predictors of an increased radial artery diameter. Aykan et al. (2015) reported that the independent predictors of the diameter of the radial artery were occupation, shoe size and wrist circumference. In addition, patients who were physically active outdoors were shown to have a larger radial artery compared to those who worked in an office (sedentary) environment (Physically active outdoors: 2.81 ± 0.37 mm; Office/sedentary environment: 2.42 ± 0.45 mm) (Aykan et al., 2015).

Clinical factors influencing the diameter of the radial artery have also been investigated. Beniwal, Bhargava and Kausik (2014) reported that males with hypertension had a larger mean radial artery diameter (2.383 mm) compared to males with no hypertension (2.272 mm) and females (2.37 mm and 2.26 mm). Whereas Loh, Nakao, Tan, Lim, Tan and Chua (2007) reported that factors such as age and diabetes mellitus negatively affected the size of the radial artery. Although Beniwal, Bhargava and Kausik (2014) reported that patients with diabetes (2.305 mm) had smaller (nonsignificant) radial artery diameters compared to those without diabetes (2.329 mm).

Evidence regarding the relationship between anthropometric or body parameters and the diameter of the radial artery remains conflicting. Dharma et al. (2017) found no correlation between the diameter of the radial artery and BMI. Similarly, Ashraf, Panhwar, Habib, Memon, Shamsi and Arif (2010) reported no correlation between the radial artery size and body size parameters such as weight, height, BMI and body surface area (BSA). Velasco et al. (2012) observed no significant association between the radial artery diameter and body parameters such as height, weight, age and BSA. Table 2 shows the factors that influence the diameter of the radial artery and its distal segment reported by various authors.

Table 2: Factors that influence the diameter of the radial artery and its distal segment as reported by various authors

Author (year)	Population	Sample size	Factors that affect the size of the radial artery		
			Positively	Negatively	No correlation/ no change
Loh et al. (2007)	-	327	• Sex • Hyperlipidaemia • Hypertension	• Age • Diabetes mellitus	-
Ashraf et al. (2010)	Karachi	251	• Male sex • Smoking • Diabetes mellitus	-	• Weight • Height • BMI and BSA
Velasco et al. (2012)	American	100	-	-	• Height • Weight • Age • BSA
Okuyan et al. (2013)	-	93	• Body weight • Distal and proximal wrist diameters	-	-
Beniwal, Bhargava and Kausik (2014)	Indian	204	• Hypotension • Sex	-	• BSA and BMI • Height • Weight
Kotowycz et al. (2014)	Canadian	130	• Wrist circumference • Shoe size • BMI and BSA • Height • Weight	-	
Aykan et al. (2015)	-	222	• Height • BMI • Weight • Wrist circumference • Pulse pressure • Shoe size	-	-
Dharma et al. (2017)	Indonesian, Indian, and Macedonian	1 706	• Female sex	-	• BMI
Norimatsu, Kusumoto, Yoshimoto, Tsukamoto, Kuwano et al. (2019)	-	142	• Body weight • BMI (distal radial artery)		• Age • Height (distal radial artery)
Alehaideb et al. (2020)	Canadian	134	• Weight • Age	-	-
Deora et al. (2022)	Indian	1 004	• Weight • Height	• BMI	• Age

1.2.7 *Morphometric variations*

The diameter of the radial artery varies by anatomical location, through the direction of this variation is not consistent across all populations. While the artery is generally described as tapering distally, Hammami et al. (2021) reported that the median diameter of the radial artery was higher in the distal radial group (2.2 mm) than in the traditional (forearm) radial artery group (2.1 mm). Similarly, Naito, Sawaoka, Sasaki, Iida, Sakuraba et al. (2019) observed that the distal radial artery diameter was larger than the diameter of the forearm radial artery in eight patients in a Japanese population. These findings suggest that although proximal-to-distal tapering represents the typical pattern, the diameter of the radial artery may vary along its course, and this can be attributed to the demographics of the study population and the geographical location.

Sex-based differences in the diameter of the radial artery have also been previously reported. Narsinh et al. (2021) found that the mean diameter of the radial artery in the forearm site was larger in males (2.69 ± 0.40 mm) compared to females (2.43 ± 0.38 mm). Similarly, Dharma et al. (2017) reported that females had a smaller radial artery when compared to males. Tables 3 and 4 illustrate the diameter of the radial artery reported by various authors.

Table 3: Diameter of the radial artery at its point of origin as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the radial artery
Shima, Ohno, Michi, Egawa and Takiguchi (1996)	Japanese	Cadaveric	59	2.30 (± 0.50)
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	68	External: 3.48; Internal: 3.26
Mahajan, Shashank, Muthukrshnan, Verma and Razdan (2022)	Indian	Cadaveric	30	External: 3.90
Swetha, Vidya and Hema (2023)	South Indian	Cadaveric	56	4.80

Table 4: Diameter of the radial artery in the distal part of the forearm (at the wrist joint) as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the radial artery
Nagai et al. (1999)	-	Imaging (ultrasound)	162	2.40 (± 0.40)
Yoo et al. (2005)	Korean	Imaging (ultrasound)	1 103	2.60 (± 0.41) (mean)
Loh et al. (2007)	-	Imaging (ultrasonography)	327	2.45 (± 0.54) (mean)
Ashraf et al. (2010)	Karachi	Imaging (ultrasonography)	251	2.25 (± 0.40)
Okuyan et al. (2013)	-	Imaging (angiography)	93	2.30 (± 0.40) (mean)
Beniwal, Bhargava and Kausik (2014)	Indian	Imaging (ultrasonography)	204	2.33 (± 0.40) (mean)
Kotowycz et al. (2014)	Canadian	Imaging (ultrasound)	130	2.44 (± 0.60)
Prakash and Saniya (2014)	Indian	Cadaveric	50	2.14 (± 0.28)
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	68	External: 3.60; Internal: 3.55
Peruga et al. (2015)	Polish	Imaging (ultrasound)	109	2.22 (± 0.35)
Yilmaz, Ozkul, Shin, Im, Yoon and Kim (2015)	Korean	Cadaveric	20	External: 1.77 (± 0.48)
Abazid, Smettei, Mohamed, Kattea, Suresh, et al. (2017)	-	Imaging (ultrasound)	513	2.60 (± 0.48)
Dharma et al. (2017)	Indonesian, Indian, and Macedonian	Imaging (ultrasound)	1 706	2.80 (median)
Kim, Lee, Song, Kim, Lee and Kim (2017)	-	Observational	60 (paediatric)	1.50 (± 0.20)
Sinha, Jha, Mishra, Thakur, Goel et al. (2017)	-	Imaging (ultrasound)	1945	2.56 (± 0.29)
Norimatsu et al. (2019)	-	Imaging (ultrasound)	142	3.10 (± 0.40)
Alehaideb et al. (2020)	Canadian	Imaging (ultrasound)	134 (paediatric)	1.86 (± 0.44) (mean)
Srinivasan et al. (2020)	-	Imaging (angiogram)	47 (paediatric)	2.09 (± 0.44)
Achim, Kákonyi, Jambrik, Nagy, Tóth et al. (2021)	Hungarian	Imaging (ultrasound)	1 240	2.45 (± 0.60)
Hammami et al. (2021)	Tunisian	Imaging (ultrasound)	95	2.10

Meo, Falsaperla, Modica, Calcagno, Libra et al. (2021)	-	Imaging (ultrasound)	700	2.58 (± 0.58)
Varalakshmi (2021)	Indian	Cadaveric	40	External: 2.79 (± 0.68)
Gündüz et al. (2022)	-	Imaging (ultrasonography)	171	2.71 (± 0.66)
Mahajan et al. (2022)	Indian	Cadaveric	30	External: 3.40
Ellis, Thibault, Lencke and Hemric (2025)	American (VA)	Cadaveric	87	External: 3.12 (± 0.56)

Table 5 portrays the diameter of the distal segment of the radial artery (in the anatomical snuffbox) chronologically, as reported by various authors.

Table 5: Diameter of the distal segment of the radial artery reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the distal segment of the radial artery (distal radial artery)
Buturak, Tekturk, Degirmencioglu, Ulus, Surgit et al. (2016)	-	Imaging (ultrasound)	56	2.85 (± 0.44)
Haładaj et al. (2018)	-	Cadaveric	120	External: 2.95 (± 0.43)
Norimatsu et al. (2019)	-	Imaging (ultrasound)	142	2.60 (± 0.50)
Ruzsa, Csavajda, Nemes, Deák, Sótonyi et al. (2020)	-	Imaging (ultrasound)	38	1.90 (± 0.36)
Srinivasan et al. (2020)	-	Imaging (angiogram)	47 (paediatric)	2.09 (± 0.54)
Achim et al. (2021)	Hungarian	Imaging (ultrasound)	1 240	2.30 (± 0.50)
Hammami et al. (2021)	Tunisian	Imaging (ultrasound)	82	2.20
Mavarez, Ripat, Char, Abuchaibe, Galarza et al. (2021)	-	Imaging (ultrasound)	50 (paediatric)	0.76 (± 0.18)
Meo et al. (2021)	-	Imaging (ultrasound)	700	1.99 (± 0.47)
Mahajan et al. (2022)	Indian	Cadaveric	30	External: 2.90
Swetha, Vidya and Hema (2023)	South Indian	Cadaveric	56	4.70
Wang, Shan, Xiao, Zhang, Hou et al. (2024)	-	Cadaveric Imaging (CTA)	26 168	External: 2.53 (± 0.73) External: 2.63 (± 0.69)

CTA: computed tomography angiography

Tables 6 to 8 show the diameter of the radial artery and its distal segment among males and females reported by various authors. It can be deduced from the means that males have a larger radial artery diameter as well as a larger diameter of the distal segment of the radial artery than females.

Table 6: Diameter of the radial artery at its point of origin among males and females reported by various authors

Author (year)	Population	Modality	Sample size	External diameter of radial artery (mm)
Nasr (2012)	Saudi Arabian	Cadaveric	100	Male: Right: 3.30 (± 0.70); Left: 3.30 (± 0.70) Female: Right: 3.07 (± 0.50); Left: 3.02 (± 0.48)
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	68	Male: Right: 3.71 (± 0.91); Left: 3.63 (± 0.84) Female: Right: 3.25 (± 0.69); Left: 3.20 (± 0.66)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	78	Male: Right: 4.45 (± 1.35); Left: 4.41 (± 1.5) Female: Right: 4.36 (± 1.18); Left: 4.49 (± 1.51)
Tariq, Ahmad, Khan, Hakim, Usmanullah and Aman (2020)	Pakistani	Cadaveric	84	Male: Right: 3.26 (± 0.68); Left: 3.64 (± 0.85) Female: Right: 3.26 (± 0.68); Left: 3.21 (± 0.67)

Table 7: Diameter of the radial artery at the wrist joint (distal forearm radial artery) among males and females reported by various authors

Author (year)	Population	Modality	Sample size	Diameter of radial artery (mm)
Nagai et al. (1999)	-	Imaging (ultrasound)	162	Male: 2.50 (± 0.40); Female: 2.20 (± 0.30)
Yoo et al. (2005)	Korean	Imaging (ultrasound)	1 103	Male: 2.69 (± 0.40); Female: 2.43 (± 0.38)
Babuccu, Ozdemir, Hosnuter, Kargi, Söğüt and Ayoglu (2006)	-	Imaging (Doppler system)	45 (paediatric)	Male: 1.57 (± 0.18); Female: 1.39 (± 0.18)
Ashraf et al. (2010)	Karachi	Imaging (ultrasonography)	251	Male: 2.30 (± 0.39); Female: 2.11 (± 0.29)
Nasr (2012)	Saudi Arabian	Cadaveric	100	External: Male: 3.10 (± 0.73); Female: 3.00 (± 0.66)
Okuyan et al. (2013)	-	Imaging (angiography)	93	Male: 2.30 (± 0.38); Female: 2.10 (± 0.42)
Beniwal, Bhargava and Kausik (2014)	Indian	Imaging (ultrasonography)	204	Male: 2.37 (± 0.41); Female: 2.26 (± 0.39)
Prakash and Saniya (2014)	Indian	Cadaveric	50	Male: 2.16 (± 0.28); Female: 2.06 (± 0.29)
Aykan et al. (2015)	-	Imaging (ultrasonography)	222	Male: 2.73 (± 0.39); Female: 2.15 (± 0.35)
Al Talalwah, Getachew and	British	Cadaveric	68	External: Male: Right: 3.59 (± 0.80); Left: 3.62 (± 0.82) Female: Right: 3.04 (± 0.64); Left: 2.99 (± 0.58)

Soames (2015)				Internal: Male: Right: 3.25 (± 0.54); Left: 3.25 (± 0.50) Female: Right: 2.80 (± 0.54); Left: 2.76 (± 0.40)
Dharma et al. (2017)	Indonesian, Indian, and Macedonian	Imaging (ultrasound)	1 706	Male: 2.80; Female: 2.60 (median)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	78	External: Male: Right: 3.36 (± 0.85); Left: 3.10 (± 0.78) Female: Right: 3.10 (± 0.73); Left: 3.01 (± 0.95) Internal: Male: Right: 2.83 (± 1.27); Left: 2.56 (± 1.06) Female: Right: 2.71 (± 0.65); Left: 2.77 (± 0.80)
Naito et al. (2019)	Japanese	Imaging (ultrasound)	120	Male: 2.62 (± 0.60); Female: 2.44 (± 0.51)
Norimatsu et al. (2019)	-	Imaging (ultrasound)	142	Male: 3.20 (± 0.40); Female: 3.00 (± 0.40)
Alehaideb et al. (2020)	Canadian	Imaging (ultrasound)	134 (paediatric)	Male: 1.90 (± 0.50); Female: 1.81 (± 0.53)
Tariq et al. (2020)	Pakistani	Cadaveric	84	External: Male: Right: 3.05 (± 0.65); Left: 3.63 (± 0.83) Female: Right: 3.05 (± 0.65); Left: 2.98 (± 0.59) Internal: Male: Right: 2.81 (± 0.55); Left: 3.26 (± 0.51) Female: Right: 2.81 (± 0.55); Left: 2.77 (± 0.41)
Alasmari (2021)	Saudi Arabian	Cadaveric	16	External: Male: 2.58 (± 1.10); Female: 2.60 (± 0.99)
Hammami et al. (2021)	Tunisian	Imaging (ultrasound)	177	Male: 2.20 (± 0.30); Female: 2.00 (± 0.32) (median)
Deora et al. (2022)	Indian	Imaging (ultrasound)	1 004	Male: 2.60 (± 0.34); Female: 2.42 (± 0.36)

Table 8: Diameter of the distal segment of the radial artery (in the anatomical snuffbox) among males and females as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the distal segment of the radial artery (distal radial artery)
Haładaj et al. (2018)	-	Cadaveric	120	External: Male: 3.14 (± 0.43); Female: 2.75 (± 0.37)
Naito et al. (2019)	Japanese	Imaging (ultrasound)	120	Male: 2.04 (± 0.43); Female: 1.90 (± 0.44)
Norimatsu et al. (2019)	-	Imaging (ultrasound)	142	Male: 2.60 (± 0.50); Female: 2.50 (± 0.50)
Mavarez et al. (2021)	-	Imaging (ultrasound)	50 (paediatric)	Male: 0.73 (± 0.19); Female: 0.81 (± 0.17)

Tables 9 to 11 show the diameter of the radial artery and the distal segment of the radial artery on the right and left sides reported by various authors. It can be deduced from the means that the diameter of the radial artery and its distal segment is similar on the right and left sides of the body.

Table 9: Diameter of the radial artery at its point of origin on the right and left sides reported by various authors

Author (year)	Population	Modality	Sample size	Diameter of radial artery (mm)
Shima et al. (1996)	Japanese	Cadaveric	59	Right: 2.30 (± 0.60); Left: 2.30 (± 0.50)
Mudiraj and Dhobale (2015)	Indian	Cadaveric	90	Right: 2.61 (± 0.61); Left: 2.59 (± 0.64)
Nasr (2012)	Saudi Arabian	Cadaveric	100	External: Right: 3.07 (± 0.49); Left: 3.02 (± 0.48)
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	68	External: Right: 3.52 (± 0.85); Left: 3.45 (± 0.79) Internal: Right: 3.29 (± 0.75); Left: 3.22 (± 0.80)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	78	External: Right: 4.40 (± 1.26); Left: 4.44 (± 1.51) Internal: Right: 3.79 (± 1.44); Left: 3.79 (± 1.78)
Tariq et al. (2020)	Pakistani	Cadaveric	84	External: Right: 3.53 (± 0.86); Left: 3.46 (± 0.78) Internal: Right: 3.28 (± 0.76); Left: 3.23 (± 0.81)
Mahajan et al. (2022)	Indian	Cadaveric	30	External: Right: 4.00 (± 0.75); Left: 3.80 (± 0.76)
Barry, Gun, Chabry, Harmouche, Padurean et al. (2023)	-	Cadaveric	90	Right: 3.16 (± 0.56); Left: 3.17 (± 0.59)

Table 10: Diameter of the distal forearm radial artery (at the wrist joint) on the right and left sides reported by various authors

Author (year)	Population	Modality	Sample size	Diameter of radial artery (mm)
Shima et al. (1996)	Japanese	Cadaveric	59	Right: 2.20 (± 0.60); Left: 2.20 (± 0.60)
Ashraf et al. (2010)	Karachi	Imaging (ultrasonography)	251	Right: 2.30 (± 0.40); Left: 2.20 (± 0.40)
Nasr (2012)	Saudi Arabian	Cadaveric	100	External: Right: 2.76 (± 0.49); Left: 2.74 (± 0.45)
Velasco et al. (2012)	American	Imaging (ultrasound)	100	Right: 2.22 (± 0.35); Left: -
Beniwal, Bhargava and Kausik, (2014)	Indian	Imaging (ultrasonography)	204	Right: 2.33 (± 0.40); Left: 2.32 (± 0.40)
Kotowycz et al. (2014)	Canadian	Imaging (ultrasound)	130	Right: 2.44 (± 0.60); Left: 2.36 (± 0.54)
Aykan et al. (2015)	-	Imaging (ultrasonography)	222	Right: 2.62 (± 0.45); Left: -

Peruga et al. (2015)	Polish	Imaging (ultrasound)	109	Right: 2.17 (± 0.54); Left: 2.25 (± 0.43)
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	68	External: Right: 3.36 (± 0.78); Left: 3.36 (± 0.78) Internal: Right: 3.06 (± 0.58); Left: 3.05 (± 0.52)
Wessel, Hessel, Glaros and Olinger (2015)	-	Cadaveric	140	External: Right: 7.43 (± 11.30); Left: 7.75 (± 11.80)
Yilmaz et al. (2015)	Korean	Cadaveric	20	External: Right: 1.83 (± 0.47); Left: 1.71 (± 0.50)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	78	External: Right: 3.24 (± 0.79); Left: 3.06 (± 0.85) Internal: Right: 2.79 (± 1.10); Left: 2.66 (± 0.94)
Alehaideb et al. (2020)	Canadian	Imaging (ultrasound)	134 (paediatric)	Right: 1.87 (± 0.46); Left: 1.87(± 0.47)
Tariq et al. (2020)	Pakistani	Cadaveric	84	External: Right: 3.37 (± 0.79); Left: 3.37 (± 0.77) Internal: Right:3.07 (± 0.59); Left: 3.06 (± 0.53)
Domagała, Grzelak, Pospiech, Hunter, Klekowski et al. (2021)	-	Imaging (ultrasound)	96	Right: 1.42 (± 0.26); Left: 1.43 (± 0.24)
Deora et al. (2022)	Indian	Imaging (ultrasound)	1 004	Right: 2.56 (± 0.35); Left: 2.50 (± 0.35)
Mahajan et al. (2022)	Indian	Cadaveric	30	External: Right: 3.60 (± 0.58); Left: 3.16 (± 0.17)
Barry et al. (2023)	-	Cadaveric	90	Right: 2.62 (± 0.66); Left: 2.64 (± 0.68)
Ellis et al. (2025)	American (VA)	Cadaveric	87	External: Right: 3.15 (± 0.59); Left: 3.09 (± 0.53)

Table 11: Diameter of the distal segment of the radial artery on the right and left sides as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the distal segment of the radial artery (distal radial artery)
Madssen, Haere and Wiseth (2006)	-	Imaging (ultrasound)	29	Right: 2.58 (±0.38); Left: 2.71 (±0.32)
Mudiraj and Dhobale (2015)	Indian	Cadaveric	90	Right: 2.07 (±0.66); Left: 2.09 (±0.64)
Deora et al. (2022)	Indian	Imaging (ultrasound)	1 004	Right: 2.23 (±0.39); Left: 2.17 (±0.39)
Lee, Son, Go, Kang, Lee et al. (2022)	Korean	Imaging (ultrasound)	1 162	Right: 2.31 (±0.43); Left: 2.35 (±0.45)

Mahajan et al. (2022)	Indian	Cadaveric	30	External: Right: 3.00 (±0.26); Left: 2.87 (±0.24)

Table 12 shows the thickness of the radial artery chronologically as reported by various authors.

Table 12: Thickness of the radial artery as reported by various authors

Author (year)	Population	Modality	Sample size	Thickness of the radial artery at its point of origin (mm)	Thickness of the radial artery at the wrist joint (mm)
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	34	Right: 0.11 (± 0.05); Left: 0.12 (± 0.00)	Right: 0.15 (± 0.10); Left: 0.16 (± 0.13)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	39	Right: 0.37 (± 0.22); Left: 0.34 (± 0.23)	Right: 0.25 (± 0.22); Left: 0.28 (± 0.24)
Tariq et al. (2020)	Pakistani	Cadaveric	42	Right: 0.12 (± 0.06); Left: 0.13 (± 0.00)	Right: 0.16 (± 0.11); Left: 0.17 (± 0.14)

Tables 13 and 14 show the thickness of the radial artery among males and females as reported by various authors.

Table 13: Thickness of the radial artery at its point of origin among males and females as reported by various authors

Author (year)	Population	Modality	Sample size	Thickness of the radial artery at its point of origin (mm)	
				Male	Female
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	34	Right: 0.06 (± 0.11); Left: 0.09 (± 0.02)	Right: 0.19 (± 0.01); Left: 0.15 (± 0.06)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	39	Right: 0.37 (± 0.22); Left: 0.29 (± 0.91)	Right: 0.36 (± 0.21); Left: 0.37 (± 0.27)
Tariq et al. (2020)	Pakistan	Cadaveric	42	Right: 0.18 (± 0.02); Left: 0.08 (± 0.03)	Right: 0.18 (± 0.02); Left: 0.16 (± 0.07)

Table 14: Thickness of the radial artery at the wrist joint among males and females as reported by various authors

Author (year)	Population	Modality	Sample size	Thickness of the radial artery at the wrist joint (mm)	
				Male	Female
Al Talalwah, Getachew and Soames (2015)	British	Cadaveric	34	Right: 0.17 (± 0.13); Left: 0.18 (± 0.16)	Right: 0.12 (± 0.05); Left: 0.12 (± 0.09)
Getachew, Astatkie and Lemma (2018)	Ethiopian	Cadaveric	39	Right: 0.26 (± 0.21); Left: 0.22 (± 0.19)	Right: 0.25 (± 0.23); Left: 0.35 (± 0.28)

Tariq et al. (2020)	Pakistan	Cadaveric	42	Right: 0.13 (± 0.06); Left: 0.19 (± 0.17)	Right: 0.13 (± 0.06); Left: 0.13 (± 0.08)

1.2.8 Morphological variations

The origin of the radial artery is not always from the brachial artery at the neck of the radius in the cubital fossa. The radial artery can originate from the axillary artery or the proximal part of the brachial artery (Karlsson and Niechajev, 1982; Zhan et al., 2010; Kore and Vishwakarma, 2021; Bundi et al., 2022). Various authors have reported variations in the origin of the radial artery (Table 15). The variations in the origin of the radial artery can be attributed to smooth muscle-endothelial interactions, nutritional demands, hemodynamics and genetics (Bundi et al., 2022).

Table 15: Variations in the origin of the radial artery as reported by various authors

Author (year)	Population	Modality	Sample size	Variations in the origin of the radial artery
McComarck, Cauldwell and Anson (1953)	-	Cadaveric	750	High origin of radial artery (2.13%; 16 limbs): proximal ¼ of arm (6.80%); mid-forearm (4.13%); $^{3}/_{4}$ of forearm (0.67%); distal ¼ of forearm (0.54%).
Karlsson and Niechajev (1982)	-	Imaging (angiography)	231	High origin: axillary artery ($^{1}/_{8}$ cases); proximal $^{1}/_{3}$ of brachial artery ($^{5}/_{8}$ cases); middle $^{1}/_{3}$ of brachial artery ($^{2}/_{8}$ cases).
Uglietta and Kadir (1989)	-	Imaging (arteriograms)	100	Radial artery originated from axillary artery (2.00% of sample).
Gonzalez-Compta (1991)	-	Cadaveric	1	High origin of the radial artery from axillary artery bilaterally in a 65-year-old male cadaver.
Golan, Kaus and Szwarc (1994)	-	Cadaveric	4	High division of the brachial artery (4 cadavers) in the medial bicipital sulcus.
Sargon and Celik (1994)	-	Cadaveric	1	Radial artery originated from the axillary artery proximal to the humeral intercondylar line.
Içten, Süllü and Tuncer (1996)	-	Cadaveric	1	High origin: 2.00 cm superior to the confluence point of median nerve's two roots on right side; from brachial artery 3.00 cm distal to the profunda brachii artery's origin on the left side.
Sargon, Tanyeli, Sürücü, Yazar and Arifoğlu (1996)	-	Cadaveric	1	Radial artery originated from the brachial artery on the medial side, 16.70 cm below the coracoid process on the right side.
Sahin and Seelig (2001)	-	Cadaveric	1	Superficial radial artery originated from the brachial artery in the left

				upper limb and from the axillary artery in the right upper limb.
Celik, Görmüs, Aldur and Ozçelik (2001)	-	Imaging (arteriogram)	81	High origin of the radial artery from the brachial artery (87.50% of all variations).
Rodriguez-Niedenfuhr, Burton, Deu and Sañudo (2001)	-	-	224 (embryos)	Brachioradial artery: 14.00% of the sample.
Rodriguez-Niedenfuhr, Vázquez et al. (2001)	-	Cadaveric	384	Brachioradial artery (13.80%): axillary artery in 23.00% of cases; upper $^{1}/_{3}$ brachial artery in 65.40% of cases; middle $^{1}/_{3}$ brachial artery in 7.70% of cases; inferior $^{1}/_{3}$ brachial artery in 3.90% of cases.
Okoro and Jiburum (2003)	Nigerian	Cadaveric	1	Anterior part of the axillary artery on the medial side in a male cadaver, bilaterally.
Rodriguez-Niedenfuhr, Vazquez, Parkin and Sañudo (2003)	-	-	480	Brachioradial artery: 14.20% of sample.
Sarikcioglu and Yildirim (2003)	Turkish	Cadaveric	1	Radial artery originated from the brachial artery near the middle $^{1}/_{3}$ of the humerus on the right side of a male cadaver.
Coskun, Sarikcioglu, Donmez and Sindel (2005)	-	Cadaveric	1	Superficial brachial artery originated from the third part of the axillary artery in a 50-year-old male cadaver on the left side.
Loukas, Louis, Almond and Armstrong (2005)	-	Cadaveric	1	Radial artery originated from the thoraco-acromial trunk.
Yoo et al. (2005)	Korean	Imaging (angiogram)	1 103	High origin: 2.40% of the sample and double radial artery in 0.20% of sample.
Pelin, Zagyapan, Mas and Karabay (2006)	-	Cadaveric	1	Medial side of the brachial artery on the right side.
Valsecchi, Bassileva, Musumeci, Rossini, Tespili et al. (2006)	-	Imaging (angiography)	505	Abnormal origin: (8.30% of sample).
Yang, Gil, Jung and Lee (2008)	Korean	Cadaveric	304	Superficial brachial artery (axillary origin – 12.20% of sample): cubital fossa ($^{8.90}/_{12.20}\%$); continued as the radial artery in the forearm ($^{2.30}/_{12.20}\%$); ended in the upper arm ($^{1.00}/_{12.20}\%$).

Konarik, Knize, Baca and Kachlik (2009)	Czech	Cadaveric	80	Third part of the axillary artery in the left upper limb of a male cadaver.
Lo, Nolan, Fountzopoulos, Behan, Butler et al. (2009)	British	Imaging (arteriography)	1 540	High bifurcating origin: 7.00% of sample and radial artery loop was reported in 2.30% of sample.
Madhyastha, Nayak, Krishnamurthy, D'Costa, Jose and Bhat (2009)	Indian	Cadaveric	1	Upper third of the arm in a right female upper limb.
Waghmare, Tarnekar, Sonatakke, Bokariva and Ingole (2009)	Indian	Cadaveric	1	Second part of the axillary artery in the left upper limb of a male cadaver.
Bhanu, Sankar and Susan (2010)	Indian	Cadaveric	1	Brachioradial artery: brachial artery in the middle of the arm in the right upper extremity of a 52-year-old male cadaver.
Daimi, Siddiqui, and Wabale (2010)	-	Cadaveric	1	Second part of axillary artery in the right upper limb of a male cadaver.
Zhan et al. (2010)	Singaporean Chinese	Cadaveric	1 200	Brachioradial artery: medial side of the upper ⅓ of the brachial artery in a male right upper limb; upper ⅓ of the brachial artery bilaterally in a female cadaver.
Balachandra, Prakash, Padmalatha and Ramesh (2011)	-	Cadaveric	1	Third part of the axillary artery in the left upper limb of a male cadaver.
Bidarkotimath, Avadhani and Kumar (2011)	-	Cadaveric	100	Axillary artery in 1 case.
Bidarkotimath, Avadhani and Kumar (2012)	-	Cadaveric	100	Second part of the axillary artery in 30-year-old male cadaver; brachial artery in middle of the arm (2 cases).
Nasr (2012)	Saudi Arbian	Cadaveric	100	High origin (8.00% of sample): medial side of upper ⅓ of the brachial artery ($^{4}/_{8}$ limbs); lateral side of the upper part of the brachial artery ($^{3}/_{8}$ limbs); anterior aspect of second part of the axillary artery ($^{1}/_{8}$ limbs).
Yagain, Dave and Anadkat (2012)	-	Cadaveric	1	Third part of the axillary artery in the right upper limb of a female cadaver.
Ghosh, Roy, Kundu and Mukherjee (2013)	-	Cadaveric	1	10.50 cm below the lower border of the teres major muscle from the medial side of the brachial artery bilaterally.

Shiny Vinila, Sangeeta, Sanikop and Venkateshu (2013)	-	Cadaveric	1	Superficial brachioradial artery: third part of the axillary artery in the right upper limb of a female cadaver.
Bondage, More and Gangane (2014)	Indian	Cadaveric	1	Brachial artery in the proximal ⅓ of the right upper limb of a male cadaver.
Hassan, Abdelmegid, Hasan-Ali, Warda, Mahfouz and Alkhateeb (2016)	Egyptian	Imaging (arteriography)	650	High bifurcating origin: 6.20% of sample and full radial loop in 1.20% of sample.
Mudiraj and Dhobale (2015)	-	Cadaveric	90	High origin in 3 specimens and high origin from the brachial artery in 12 specimens.
Ostojić, Bulum, Ernst, Strozzi and Marić-Bešić (2015)	-	Imaging (angiography)	602	High origin: 5.10% of sample.
Agarwal, Lalwani and Babu (2016)	Indian	Cadaveric	16	Third part of the axillary artery in 3.12% of sample.
Das, Rai, Das, and Mehrotra (2016)	Indian	Cadaveric	1	Third part of the axillary artery in the left upper limb of a male cadaver.
Deepa and Martin (2016)	-	Cadaveric	102	Brachial artery in the mid-arm on the right side in a 65-year-old male cadaver; trifurcation of the brachial artery at mid-arm level on the left side in a 65-year-old male cadaver.
Lee, Moon, Park, Kim and Choi (2016)	Korean	Cadaveric	1	From the thoraco-acromial artery in the right upper limb of a 73-year-old male cadaver.
Reddy, Gajbe, Fulzele and Singh (2016)	-	Cadaveric	32	Brachial artery in the middle of the arm, 6.50 cm above the intercondylar line of the humerus, in the left upper extremity of two male cadavers; the brachial artery 7.20 cm above the intercondylar line of humerus in right upper extremity of a female cadaver.
Rao and Rao (2016)	-	Cadaveric	1	Brachial artery in the middle third of the right arm in a middle-aged male cadaver.
Sucharitha, Hema and Phanindra (2016)	Indian	Cadaveric	1	Brachial artery 60.00 mm above the inter-epicondylar line of humerus in right upper extremity of a female cadaver.
Wysiadecki et al. (2017)	-	Cadaveric	1	Originated deep to the pronator teres muscle in the right upper limb.
Gandhi and Lakshmi (2018)	Indian	Cadaveric	18	Right brachial artery on anteromedial surface 13.50 cm above the

				intercondylar line and right brachial artery on anteromedial surface 19.00 cm above the intercondylar line.
Haładaj et al. (2018)	-	Cadaveric	120	High origin (9.20% of sample): axillary artery (2 cases); brachial artery (9 cases).
Lalitha and Lakshmi Devi (2018)	-	Cadaveric	96	Third part of the axillary artery in the two upper limbs; the medial side of the brachial artery in the middle of the arm bilaterally in one cadaver; the lateral side of the brachial artery in middle of the arm in one upper limb.
Polfer, Sagino, Giladi and Higgins (2018)	-	Imaging (angiograms)	26	Axillary artery in 3 patients; proximal part of the brachial artery in 2 patients; mid-brachium in 5 patients.
Kadel, Hada and Sedhain (2019)	Nepali	Cadaveric	53	Axillary artery in 1.88% of the sample; upper ⅓ of the arm in 5.66% of the sample; middle third of arm in 3.77% of the sample; lower part of the arm in 1.88% of sample.
Sharma, Prasad, Ansari, Ravi and Singh (2019)	-	Cadaveric	12	Brachial artery in the middle third of the arm in 1 right upper extremity; brachial artery in the upper third of the arm in 1 right upper extremity.
Syed, Akram and Faruqi (2019)	-	Cadaveric	1	Third part of the axillary artery on the right side of a cadaver.
Alves, de Azevedo and Fazan (2020)	-	Cadaveric	1	Brachial artery in the upper ⅓ of the right arm in a male cadaver.
Chauhan and Yadav (2020)	-	Cadaveric	1	Brachial artery in the proximal ⅓ of the left arm in a male cadaver.
Clarke, Skrzat, Shane Tubbs, Iwanaga, Mazurek and Wysiadecki (2021)	-	Cadaveric	1	Distal 16% of the arm's length in the right upper limb.
Kore and Vishwakarma (2021)	-	Cadaveric	51	Axillary artery (left side) in 1 upper limb; brachial artery at midarm level (left side) in 1 upper limb, and brachial artery in proximal part of arm (right side) in 2 upper limbs.
Sophia, Singh, Xalxo, Yadav, Agarwal, Singh and Jain (2021)	Indian	Cadaveric	48	Brachial artery above intercondylar line of the humerus in 3 upper extremities and pentafurcation of the brachial artery in 1 upper limb.
Bundi et al. (2022)	Kenyan	Cadaveric	62	High origin (8 upper limbs): middle $^{1}/_{3}$ of the brachial artery in 4 upper extremities; brachial artery below the lower border of the teres major muscle in 1 upper limb; brachial artery at the same level as the

				profunda brachii artery in 1 upper limb; third part of the axillary trunk in 2 upper limbs.
Barry et al. (2023)	-	Cadaveric	90	High origin from the axillary artery: 1.11% of the sample.
Rathi (2023)	Indian	Cadaveric	1	In the mid-arm, in 1 specimen, approximately 70.00 mm proximal to the elbow crease.
Shilpa, Rani Raphael, Rajad, Manju and Tejaswi (2024)	Kerala	Cadaveric	60	High origin (from the axillary artery): in 6.70% of the sample.

1.2.9 Clinical relevance

The radial artery and its distal segment are used during coronary procedures and as an alternative for diagnostic or therapeutic interventions (Daralammouri et al., 2022; Bhatia, Kumar and Arafath, 2023). A study by Goland, Domitrovic, Doroszuk, Garbugino and Ypa (2019) demonstrated success when the distal radial artery was used for therapeutic and diagnostic neuro-endovascular procedures. The distal radial artery has many benefits when used for coronary intervention, such as a low rate of occlusion, faster haemostasis, it is more convenient for the operator and patient, improved left-sided aortocoronary graft access, and no equipment is needed to stabilise the patient's left arm (Daralammouri et al., 2022). Selective cerebral angiography can be conducted using the transradial approach instead of the trans-brachial and transfemoral approaches as it is safer and less invasive (Matsumoto, Hokama, Nagashima, Orz, Toriyama, Hongo and Kobayashi, 2000). The trans-brachial and transfemoral approach during selective cerebral angiography can sometimes lead to pulmonary embolism due to prolonged focal compression (Matsumoto et al., 2000). According to Schenke, Viertel, Prog, Joghetaei, Matthiesen et al. (2020) and Mhanna, Beran, Nazir, Al-Abdouh, Barbarawi et al. (2021), using the distal radial artery for coronary angiography and interventions is associated with a lower risk of complications and a high success rate.

Transradial access has more benefits than transfemoral access, such as better patient satisfaction, fewer complications (such as a lower risk of occlusion of the radial artery), lower hospital costs and shorter hospital stays (Beyer, Ng, Singh, Zimmet, Shunk et al., 2013; Brunet et al., 2019; Goland et al., 2019; Pitta and Prasad, 2020; Mhanna et al., 2021; Narsinh et al., 2021; Bhatia, Kumar and Arafath, 2023). There are more advantages when using the distal radial artery, such as lower risk of complications, enhanced patient care, faster per-procedural management, reduced incidence of radial artery occlusion and operator comfort (Brunet et al., 2019; Hammami et al., 2021; Daralammouri et al., 2022). Levy, Boulos, Fessler, Bendok, Ringer et al. (2002), reported that patients were not constrained to bed rest and had shorter observation times after transradial cerebral angiography. According to Chen, Brunet, Sur, Yavagal, Starke and Peterson (2020), there is decreased access site complications and increasing patient preference for the transradial approach for cerebrovascular angiography. However, despite there being more benefits to radial access (or transradial access), there are also some challenges, such as inexperience, challenges with the smaller diameter of the radial artery, complications such as radial artery perforation, occlusion or dissection and a lack of radial hardware for neuro-intervention (Beniwal, Bhargava and Kausik, 2014; Narsinh et al., 2021; Bhatia, Kumar and Arafath, 2023).

While the distal radial artery has a smaller diameter, and due to the compression of the distal radial artery on the surface of the scaphoid and trapezium carpal bones, there is shorter haemostasis when the distal radial artery is used (Daralammouri et al., 2022). The distal radial artery is more susceptible to puncture-mediated vasospasm as it has a smaller diameter than the forearm radial artery (Daralammouri et al., 2022). Prolonged occlusion flow-mediated dilatation was used by Doubell, Kyriakakis, Weich, Herbst, Pedoraro et al. (2019), which showed a reduction in puncture attempts and cannulation failure, as well as decreased radial artery pulsation loss during coronary angiography during the transradial approach. Factors such as the anthropometric characteristics of the selected population and the operator's expertise influence accessing the radial artery in the anatomical snuffbox (that is, the distal radial artery) (Hammami et al., 2021; Daralammouri et al., 2022). However, there are benefits in accessing the distal radial artery in the anatomical snuffbox, such as no compromise to the formation of the palmar arches, patient comfort due to the position of the hand and a reduced incidence of ischemia of the hand (Narsinh et al., 2021; Bhatia, Kumar and Arafath, 2023).

The main advantage is due to the fact that the superficial palmar branch of the radial artery arises proximal to the anatomical snuffbox (Dawani et al., 2022). However, if occlusion of the radial artery occurs in the anatomical snuffbox, then blood flow to the deep palmar arch and the dorsal metacarpal arteries will be jeopardised (Dawani et al., 2022). This will also have an adverse effect on the blood supply to the interossei muscles (Dawani et al., 2022). According to Dadarwal, Garg, Kapoor, Tewari, Kumar et al. (2022), there are multiple limitations when using the proximal radial artery (also known as the radial artery or forearm radial artery), such as the risk of occlusion of the radial artery, risk of bleeding in the forearm, arterial puncture challenge despite using ultrasound guidance due to the depth of the radial artery, as well as intensifying chronic joint pain due to the need to supinate the forearm.

Satti, Vance, Golwala and Eden (2017), reported that 24 out of 25 patients indicated that they preferred radial access over femoral access. While Monteiro, Cappuzzo, Aguirre, Vakharia, Levy et al. (2022), found that 70.4% of patients preferred the transradial approach due to the recovery time, pain and bruising. The transradial approach can be safely performed if the ulnar collateral circulation is sufficient (Okuyan et al., 2013). According to Schartz, Young and Guerin (2021), the transradial approach has a 91% success rate in paediatric patients. Similarly, a study conducted by Irving, Zaman and Kirk (2009) showed a success rate of 85% in paediatric patients via the transradial approach.

1.2.9.1 Puncture time and number of attempts

The distal radial artery approach, while offering advantages presents distinct technical challenges compared to conventional forearm access. Multiple studies have documented increased procedural difficulty with the distal radial artery approach, including higher puncture attempts, longer cannulation time, and prolonged access time (Dadarwal et al., 2022; Daralammouri et al., 2022; Bhatia, Kumar and Arafath, 2023). Dadarwal et al. (2022) further reported higher pain scores when the distal radial artery was used. Despite these challenges, the distal radial artery approach is the preferred option when the patient is obese, as the radial artery is located deeper, which results in a supination of the forearm problem, and a higher risk of hematoma or ischemia of the hand (Bhatia, Kumar and Arafath, 2023).

Despite the increased cannulation time when the distal radial artery is used, it can be reduced with ultrasound guidance during puncture attempts, training and practice (Mhanna et al., 2021). The success rates for the distal radial artery access are nevertheless high, with Daralammouri et al. (2022) reporting a 98% puncture success rate and Schenke et al. (2020) documenting a 95% success rate and a low crossover rate (8%). Importantly, procedural difficulty does not necessarily correlate with patient discomfort, Daralammouri et al. (2022) found no correlation between the puncture attempts and the puncture pain, as well as between the puncture duration and the puncture pain. Furthermore, Seto et al. (2015), reported that there were no significant differences in the rate of operator-reported spasm, patient pain scores or bleeding complications.

1.2.9.2 Sheath size

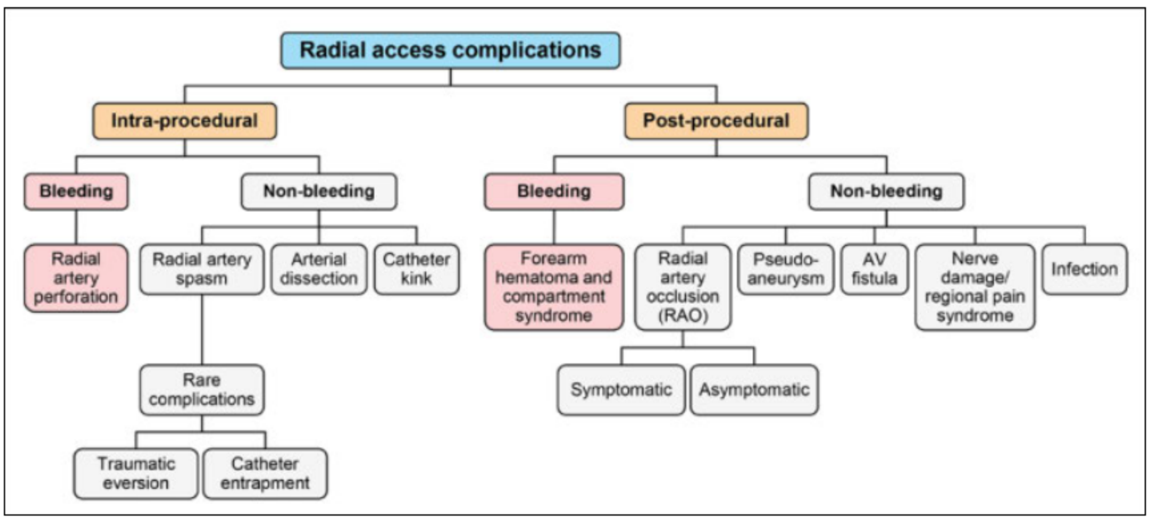
Two diameters are present in a vascular sheath, namely the inner and outer diameters, which are measured using the French (Fr) scale (Mathis, Romans and Divekar, 2020). With reference to the French scale, 1 Fr equates to one-third of the circumference in millimetres (Mathis, Romans and Divekar, 2020). Therefore, the sheath size relates to its inner diameter and corresponds to the largest outer diameter of the medical device that can pass through it (Mathis, Romans and Divekar, 2020). The radial sheaths have a thinner wall, which is beneficial as it reduces the outer diameter by 1 Fr when compared to conventional sheaths, and there is no compromise to the inner diameter (Mathis, Romans and Divekar, 2020). According to Bhatia, Kumar and Arafath (2023), there is no difference in the hardware or sheath size between the forearm radial artery and the distal radial artery. However, to minimise the risk of arterial injury in infants, the smallest sheath size is recommended (Mathis, Romans and Divekar, 2020). The radial artery in adults is similar in size to the femoral artery in infants (Mathis, Romans and Divekar, 2020). According to Mathis, Romans and Divekar (2020), it is the outer diameter that determines the risk, as the sheath size relates to the internal diameter.

According to Bhatia, Kumar and Arafath (2023), to accommodate a 5 Fr sheath, the lower limit of the diameter of the radial artery must be 1.8 mm. The outer diameter of a 4 Fr radial sheath is 1.610 ± 0.006 mm and is approximately the same when compared to the outer diameter of a conventional 3 Fr sheath, which is 1.644 ± 0.016 mm (Mathis, Romans and Divekar, 2020). Agnoletti et al. (2003) reported using a 3 Fr in newborns for diagnostic and interventional investigations, which resulted in no complications. With reference to infants, the 4 Fr radial sheath is similar to the 3 Fr or 3.3 Fr conventional sheaths, which are recommended for infant catheterisation as they have the same outer diameter (Mathis, Romans and Divekar, 2020). By using a 6 Fr sheath, easy entry and manipulation of the coronary artery angiography and percutaneous coronary intervention with simple or complex lesions were possible (Daralammouri et al., 2022).

Saito et al. (1999) demonstrated that severe flow reduction of the radial artery increased from 4% to 13% when the ratio between the radial artery inner diameter and sheath outer diameter was less than 1.0 mm. Velasco et al. (2012), observed that 42%, 20% and 5% of patients had radial artery diameters larger than 5 Fr, 6 Fr and 7 Fr sheaths, respectively, in a Texan population. Prior to the insertion of a catheter, a radial artery angiogram is conducted after the sheath has been inserted to visualise any loops, spasms or anatomical variations (Bhatia, Kumar and Arafath, 2023). Despite the need to use the smallest sheath size, other factors such as the sheath material, competency of the haemostatic valve, sheath length and sheath performance should be considered when choosing a sheath (Mathis, Romans and Divekar, 2020).

1.2.9.3 Complications that result from radial artery and distal radial artery access for neuro-intervention

Failure to access the radial artery can be caused by multiple factors such as puncture failure, hematoma caused at the puncture site, radial artery spasm (which can range from mild to severe), perforation, prior radial artery blockage, pseudoaneurysm, radial artery rupture or dissection or tortuosity or occlusion, or fistula formation (Daralammouri et al., 2022; Bhatia, Kumar and Arafath, 2023). Transradial access complications can be classified as intraprocedural (that occurs during the procedure) and postprocedural (that occurs after the procedure) (Figure 5) (Sandoval, Bell and Gulati, 2019).



Source: Adapted from Sandoval, Bell and Gulati (2019)

Figure 5: Transradial complications classification

A common complication of transradial access is occlusion of the radial artery (Bhatia, Kumar and Arafath, 2023). During a follow-up, occlusion of the radial artery can be re-canalised (Bhatia, Kumar and Arafath, 2023). Daralammouri et al. (2022) reported no instances of radial artery occlusion when the distal radial artery was used. While Mhanna et al. (2021), found a significantly lower risk of radial artery occlusion in the group of patients whose distal radial artery was used. Similarly, Schenke et al. (2020) documented a low rate of proximal and distal radial artery occlusion. Hammami et al. (2021)

detected radial artery occlusion in three patients from the traditional radial artery group via ultrasound and none in the distal radial artery group. Radial artery occlusion has been reported in 0% to 3.1% of patients undergoing transradial access via the anatomical snuffbox, compared to less than 5% of patients when the forearm radial artery is utilised (Daralammouri et al., 2022).

In contrast, Chen et al. (2020) reported one case of radial artery narrowing and six cases of occlusion of the radial artery. Radial artery occlusion has been reported in 0% to 3.1% of patients undergoing transradial access via the anatomical snuffbox, compared to less than 5% of patients when the forearm radial artery is utilised (Daralammouri et al., 2022). The pathogenesis of radial artery occlusion involves multiple mechanisms, including the status of the palmar arches (complete or incomplete), and rarely, thromboembolic phenomenon and endothelial injury (Bhatia, Kumar and Arafath, 2023). To reduce the incidence of radial artery occlusion Bhatia, Kumar and Arafath. (2023) suggested a patent haemostasis technique.

Transradial access, while generally safe, is associated with a range of minor and major complications. Patient discomfort (such as numbness) has been reported when the distal radial artery was used, potentially due to the needle causing irritation to the periosteum of the scaphoid and trapezium carpal bones or the radial nerve and lateral cutaneous nerve of the forearm, which are sensory nerves that are close to the puncture site (Daralammouri et al., 2022).

Daralammouri et al. (2022) observed minor complications, such as vasospasm, in three patients whose forearm radial artery was used and four patients whose distal radial artery was used. However, there are different ways to avoid radial artery spasms, such as minimising attempts, avoiding aggressive manipulation, use of local anaesthetic and administering nitro-glycerine or verapamil (Daralammouri et al., 2022). Hammami et al. (2021) used a mixture of heparin and isosorbide to prevent thrombosis and vasospasm. When severe, vasospasm may necessitate conversion to an alternative access route; Brunet et al. (2019) reported that seven patients were transferred to transfemoral access approach due to radial artery spasm and the inability to advance the wire

Other documented complications include hematoma, severe pain, access failure of the brachial artery, skin desquamation and transient radial artery spasm (Levy et al., 2002). Active occlusion arterial injury occurred in 4.3% of paediatric cardiac catheterisations in a study by Glatz, Shah, McCarthy, Geisser, Daniels et al. (2013). While Matsumoto et al. (2000) experienced no major vascular complications during selective cerebral angiography via the transradial approach.

1.3 Materials and methods

1.3.1 Methodology

This study employed ultrasound imaging for the participant cohort at the Inkosi Albert Luthuli Central Hospital, Durban, South Africa and anatomical dissection for the cadaveric group at the Department of Clinical Anatomy, University of KwaZulu-Natal. The participant cohort included two subsets: subset A (adults) and subset B (paediatric patients). All data were anonymised and statistically analysed to identify any significant relationships between the variables.

1.3.1.1 Inclusion criteria

Participant cohort: This study included patients of all groups, sexes and ethnicities who were present in the adult and paediatric neurosurgery clinics or departments at the Inkosi Albert Luthuli Central Hospital, Durban, South Africa. Furthermore, it also included mothers accompanying their children to the paediatric clinic.

Cadaveric sample: This study included adult body donor cadavers from the University of KwaZulu-Natal of all age groups, sexes and ethnicities.

1.3.1.2 Exclusion criteria

Participant cohort: This study excluded patients with a history of surgery or procedures conducted via the transradial approach. It also excluded patients not present in the neurosurgery adult and paediatric neurosurgery clinics or departments at the Inkosi Albert Luthuli Central Hospital, Durban, South Africa.

Cadaveric sample: The study excluded cadavers with signs of surgical intervention and damage to the radial artery.

1.3.2 Morphology of the radial artery

The origin of the radial artery was determined in the cadaveric sample. The origin of the radial artery was classified relative to the inter-epicondylar line of the humerus as:

- Above the inter-epicondylar line: For these cases, the distance from the point of origin of the radial artery to the inter-epicondylar line of the humerus was measured using a suture string. The external and internal diameters of the radial artery were measured at the point of origin. The course of the artery in these cases was noted.

- Below the inter-epicondylar line: For these cases, the level of origin of the radial artery was recorded relative to the anatomical landmarks on the radius bone.

- Along the inter-epicondylar line.

The inter-epicondylar line of the humerus was defined as the transverse line connecting the medial and lateral epicondyles of the humerus. The axillary artery was defined as a vessel extending from the lateral border of the first rib to the inferior margin of the teres major muscle. The brachial artery was considered to begin distal to the teres major muscle. The lower border of the teres major muscle demarcated the transition point between the axillary and brachial arteries. A radial artery was classified as arising from the axillary artery if its origin was proximal to the lower border of the teres major muscle. The relation between the vessel and the pectoralis minor muscle was noted. A brachial artery origin was classified when the radial artery emerged distal to the lower border of the teres major muscle.

1.3.3 Morphometry of the radial artery

The diameter of the radial artery was determined in both the participant cohort and cadaveric samples.

1.3.3.1 Participant cohort

Ultrasound images of the distal forearm radial artery (DFRA) were acquired approximately 2 cm proximal to the styloid process of the radius on the palmar surface of the forearm, as well as of the SRA. The diameters of the DFRA and SRA were measured from the luminal interface to the outer vessel wall utilising the Hitachi-Aloka Noblus ultrasound system (L55 linear probe; 13–5 MHz).

1.3.3.2 Cadaveric sample

The internal and external diameters of the radial artery were measured bilaterally at three measurement points, at its point of origin from the brachial artery, at the wrist joint and in the anatomical snuffbox. The external diameter of the artery was measured first, after which the artery was incised at each specific measurement point. Thereafter, the internal (luminal) diameter of the artery was recorded. The bilateral wall thickness of the radial artery was calculated as half ($\frac{1}{2}$) the difference between the average external and internal diameters measured at three points, namely at its point of origin from the brachial artery, at the wrist joint and in the anatomical snuffbox.

1.3.4 Ethical considerations

Ethical approval was obtained from the Biomedical Research Ethics Committee of the University of KwaZulu-Natal (reference number: BREC/00006978/2024). Gatekeeper permission and ethical clearance were obtained from the Department of Clinical Anatomy at the University of KwaZulu-Natal, the Inkosi Albert Luthuli Central Hospital and the KwaZulu-Natal Department of Health (KZ_202408_014). Furthermore, the Director of Neurophysiology Services at the Inkosi Albert Luthuli Central Hospital gave permission for the use of the ultrasound machine (Hitachi-Aloka Noblus ultrasound system; manufactured in Japan) during times when it did not impact clinical services.

1.3.4.1 Informed consent

This study was conducted in compliance with the Protection of Personal Information Act. For the participant cohort, all adult patients, as well as mothers or guardians who accompanied their children to the paediatric clinic, gave their informed consent. For the cadaveric sample, written informed consent was secured from the University of KwaZulu-Natal’s Body Donor Programme.

1.3.4.2 Confidentiality and management of data

Patient and body donors' identification data were anonymised to maintain confidentiality. All data are saved in password-protected folders on a hard drive that is stored in a locked cupboard and is only accessible by the investigators. The data will be destroyed after a period of five years.

1.3.5 Variables

1.3.5.1 Demographic factors

Demographic information such as age, sex and ethnicity were documented. This data was obtained from the patients, parents or guardians in the participant sample and from the technical staff for the cadaveric sample.

1.3.5.2 Internal diameter of the radial artery and its distal segment

The internal or luminal diameter was measured in triplicate using the ultrasound machine in the participant sample and by means of dissection in the cadaveric sample.

1.3.5.3 External diameter of the radial artery and its distal segment

The external diameter was measured in triplicate from the luminal space to the outer side of the vessel by means of dissection in the cadaveric sample.

1.3.5.4 Thickness of the radial artery and its distal segment

The thickness was calculated as half $(\frac{1}{2})$ the difference between the average external and internal diameters in the cadaveric sample.

1.3.5.5 Origin of the radial artery

The origin of the radial artery was classified relative to the inter-epicondylar line of the humerus in the cadaveric sample.

1.3.5.6 Wrist circumference

The circumference of the wrist was measured from Lister's tubercle on the distal end of the radius, and over the distal part of the ulna, using a tape measure on the right and left sides of the body in both the participant and cadaveric cohorts.

1.3.5.7 Height

The height was measured from the plantar surface of the patient's foot to the vertex of their head (in a standing position) in the participant sample.

1.3.5.8 Weight

Patients' weight was measured using a weighing scale in the participant sample.

1.3.5.9 Body surface area

The BSA of patients was calculated using the Mosteller formula for paediatric patients (Formula 1) and the Du Bois and Du Bois formula for adult patients (Formula 2) (Flint, Das and Hall, 2025).

$$BSA\ (m^2) = \sqrt{\frac{height(cm) \times weight(kg)}{3600}}$$

Formula 1: Mosteller formula

$$BSA\ (m^2) = [weight(kg)]^{0.425} \times [height(cm)]^{0.725} \times 0.007184$$

Formula 2: Du Bois and Du Bois formula

1.3.5.10 Body mass index

The BMI was calculated using the standard formula (Formula 3) (Zierle-Ghost and Jan, 2023).

$$BMI = \frac{weight(kg)}{[height(m)]^2}$$

Formula 3: Body mass index formula

1.3.5.11 Baseline characteristics

Baseline characteristics such as shoe size, occupational environment (for adults only), history of hypertension, history of diabetes mellitus and history of smoking were also recorded in the participant sample.

1.3.5.12 Sheath size

In the participant sample, the outer diameter of standard sheaths was adapted from Beniwal, Bhargava and Kausik (2014). The radial artery diameter, as described by Hobby et al. (2021), guided the sheath size in the cadaveric sample.

1.3.6 Sample size

The proposed study was conducted at the Inkosi Albert Luthuli Central Hospital and the Department of Clinical Anatomy at the University of KwaZulu-Natal. The study included only those patients and body donor cadavers that met the inclusion criteria. The study cohort, therefore, comprised 128 adults (subset A) and 128 paediatric patients (subset B), as well as 30 adult body donor cadavers.

1.3.7 Statistical analysis

The data were summarised by means of descriptive statistics, while frequencies and percentages were used for categorical data. The data were assessed for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Normally distributed data were presented as means and standard deviations (SDs) and analysed using a *t*-test, Levene's test for equality of variances, Pearson's correlation test, analysis of variance and chi-square test. For abnormal distributed data, numerical measurements were presented as medians and interquartile ranges and analysed using the Mann-Whitney U test. Moreover, post-hoc and intraclass correlation coefficient tests were also conducted. A significant *p*-value of 0.05 was set. IBM SPSS Statistics V. 30 was used for the analysis. All statistical methods and analyses were carried out in consultation with a university biostatistician.

1.4 Structure of the dissertation

This master's dissertation was prepared according to the guidelines outlined by the College of Health Sciences, University of KwaZulu-Natal, South Africa. Specific methodologies employed for the participant and cadaveric samples of this study are detailed in the respective manuscripts to address the objectives. The dissertation used the Harvard referencing system, except for the manuscripts, which have been structured and formatted according to the guidelines of the respective scientific journals. The structural outline of the dissertation is as follows:

1.4.1 Chapter 1: Introduction

This chapter provides a background and a comprehensive literature review of the radial artery, as well as an overview of the study. It also presents the aims, objectives and methodology within this chapter. Figures related to the materials and methods are not included in this chapter, as they have been incorporated within the respective manuscripts in subsequent chapters.

1.4.2 Chapter 2: Scientific manuscript 1

This chapter comprises an original scientific manuscript titled: *Ultrasound imaging of the radial artery for neuro-intervention*. This manuscript investigated the anatomical characteristics of the distal forearm and snuffbox radial arteries using ultrasound investigation within a select South African population. This manuscript was submitted to the *World Neurosurgery: X Journal* and is currently under review (manuscript number: WNSX-D-25-00180).

1.4.3 Chapter 3: Scientific manuscript 2

This chapter comprises an original scientific manuscript titled: *Morphometric analysis of the radial artery in a select South African sample*. This manuscript investigated the morphometric characteristics of the radial artery in a select sample of adult donor South African cadavers. This manuscript was submitted to the *Anatomia, Histologia, Embryologia Journal* and is currently under review (manuscript ID: 9977730).

1.4.4 Chapter 4: Scientific manuscript 3

This chapter comprises an original scientific manuscript titled: *A cadaveric investigation of the radial artery origin and its anatomical variations*. This manuscript investigated the origin of the radial artery in 30 adult cadaveric specimens and has been published in *Translational Research in Anatomy* (Impact factor 0.431, Q2). DOI: https://doi.org/10.1016/j.tria.2025.100416

1.4.5 Chapter 5: Synthesis

This chapter further discusses the main findings of Chapters 2, 3 and 4, and concludes the findings of the anatomy of the radial artery and its distal segment in this study. It also outlines and highlights the limitations encountered and recommendations for future research. Following this chapter are the appendices.

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BRIDGING TEXT

From Chapter 1 to Chapter 2

Chapter 1 provided an overview of previous literature on the morphology and morphometry of the radial artery and its distal segment. This chapter describes the clinical relevance and overview of the methodology.

CHAPTER 2
SCIENTIFIC MANUSCRIPT 1

Contributions of this chapter

This chapter is comprised of a scientific manuscript that investigated the anatomical characteristics in terms of the diameter of the distal forearm and snuffbox radial arteries using ultrasound investigation as well as the factors that affect those diameters within a select South African population. The results of this study were compared across demographic factors and laterality to determine any statistically significant relationships. The manuscript was formatted according to the guidelines of the journal.

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TITLE PAGE

Article title: Ultrasound imaging of the radial artery for neuro-intervention

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2.1 Abstract

Background: The distal forearm and snuffbox radial arteries are increasingly preferred over the femoral artery for neurointerventional procedures due to fewer complications. However, vessel diameter variability and sheath compatibility remain critical considerations. While previous studies have examined these arteries, there is limited literature on these vessels within the African population. This study aimed to investigate the anatomical characteristics of the distal forearm and snuffbox radial arteries using ultrasound within a select South African population.

Methods: This study included 256 patients (Subset A: 128 adults; Subset B: 128 paediatrics) at a central regional hospital in Durban, South Africa. Ultrasound measurements of the distal forearm and snuffbox radial arteries were recorded bilaterally.

Results: The average diameter of the distal forearm radial artery was 1.94 ± 0.39mm, with males exhibiting significantly larger diameters than females (2.12 ± 0.39mm *vs.* 1.82 ± 0.34mm, $p < 0.001$) in subset A. The average diameter of the snuffbox radial artery was 1.33 ± 0.31mm. In subset B, the average diameter of the distal forearm radial artery was 1.12 ± 0.32mm and the average diameter of the snuffbox radial artery was 0.77 ± 0.20mm. Body surface area, height, and wrist circumference correlated with the vessel diameter, while BMI showed no significant association. A total of 55% of the adults and 99% of the paediatric patients had distal forearm radial artery diameters less than 2.0mm (the outer diameter of a 4Fr sheath).

Conclusions: The present study's findings may assist the clinician during transradial neurointerventional procedures within this select population.

Keywords: Distal forearm radial artery – Snuffbox radial artery – Adult – Paediatric – South African population

2.2 INTRODUCTION

Transfemoral access during neuro-interventional procedures is associated with complications such as femoral arteriovenous fistula, femoral pseudoaneurysm, and retroperitoneal hematoma.[1]As a safer and more cost-effective alternative, the distal forearm and snuffbox radial arteries are increasingly being utilized.[2,3]The radial artery is more prominent approximately two to three centimetres proximal to the styloid process of the radius, making this the conventional access site.[4]Alternatively, the distal radial artery (also known as the snuffbox radial artery or the distal segment of the radial artery) can be accessed between the tendon of extensor pollicis longus and the tendon of extensor pollicis brevis or the tendon of abductor pollicis longus at the level of the scaphoid carpal bone.[4]

However, procedural success depends on several anatomical and technical factors such as the vessel diameter, radial artery loops, and the sheath size.[5]The diameter of the forearm radial artery has been reported to range between 1.15 to 3.95mm.[5]Despite the snuffbox radial artery's smaller diameter compared to the proximal radial artery, standard sheath sizes can generally be used without modification.[5]Various authors have reported that the diameter of the radial artery at the conventional access point is larger than its distal access point, and that females have a smaller radial artery diameter when compared to males.[6-8]Numerous studies have reported that body parameters such as height, weight, and wrist circumference can influence the size of the radial artery.[7,9-12]

The compatibility of vascular sheaths with the diameter of the radial artery is critical for procedural success. Sheath sizes are measured using the French (Fr) scale, where 1Fr equals to one–third of the circumference in millimeters.[13]While sheath size denotes the inner diameter, the outer diameter (typically 1Fr larger) determines the risk of arterial injury.[13]Radial sheaths mitigate the risk of arterial injury as they have thinner walls; thus, reducing the outer diameter without compromising the inner lumen.[13]According to Bhatia et al.[4], to accommodate a 5Fr sheath the lower limit of the diameter of the radial artery must be 1.8mm. Agnoletti et al.[14] reported using a 3Fr sheath in newborns for diagnostic and interventional investigations, which resulted in no complications. In a study by Saito et al.[15], the incidence of severe radial artery flow reduction increased from 4% to 13% when the ratio of the artery's inner diameter to the sheath's outer diameter was less than 1.0.

Ultrasound guidance during transradial access for neurointerventional procedures has been shown to improve success rates, shorten procedure time, reduce the number of puncture attempts and crossover rates, enhance the efficiency of radial artery cannulation, and lower the risk of complications such as radial artery occlusion.[4,16,17] A meta-analysis by Tang et al.[18] demonstrated that ultrasound guidance significantly improved the first-attempt success rate of radial artery catheterization—particularly among experienced operators—while also reducing the incidence of hematoma, the average number of attempts required, and the time to successful cannulation. Moreover, ultrasound guidance is recommended for trans-radial procedures in paediatric patients due to the smaller calibre of their arteries.[19] According to Peruga et al.[20] ultrasound can indirectly provide information about the efficacy of the collateral blood supply to the hand and enables the determination of the vessel diameter.

Several authors have utilized ultrasound guidance to assess the diameter of the radial artery and its distal segment due to its non-invasive nature.[8,10,11,20-25] However, there remains limited literature focusing on these arterial segments within African populations. This study therefore aimed to address this gap by investigating the anatomical characteristics of the distal forearm and snuffbox radial arteries using ultrasound imaging in a select South African cohort.

2.3 MATERIALS AND METHODS

The study included both adult (subset A) and paediatric (subset B) participants who attended the neurosurgery clinics for adults and children at a central regional hospital in Durban, South Africa. Institutional ethical approval (BREC/00006978/2024) as well as authorization from the Department of Health (KZ_202408_014) in the province was obtained. Furthermore, permission was also obtained from the Director of Neurophysiology services at the hospital for use of the ultrasound machine (Hitachi - Aloka Noblus ultrasound system; manufactured in Japan) during times where it did not impact on clinical services.

The study included patients of all age groups, sexes, and ethnicities who attended the adult and paediatric neurosurgery clinic at the hospital. Furthermore, parents accompanying their children to the clinic were also included. Patients with a history of surgery or procedures that were conducted via the trans-radial approach were excluded from the present study. Informed consent was obtained from all adult patients as well as parents or guardians who accompanied their children to the paediatric clinic.

All ultrasound measurements were obtained prior to any interventional procedure in a neutral, resting position to establish baseline anatomical characteristics. All measurements were taken in triplicate by a single observer and recorded manually on data sheets that were later transferred to a password protected Excel spreadsheet. The morphometric parameters were analysed as follows:

Wrist circumference: The circumference of the wrist was measured from Lister's tubercle on the distal end of the radius, and over the distal part of the ulnar using a tape measure on the right and left sides of the body.

Diameter of the distal forearm radial artery: Ultrasound images of the diameter of the distal forearm radial artery (DFRA) on the right (RDFRA) and left (LDFRA) sides of the body were taken approximately 2cm proximal to the styloid process of the radius on the palmar side of the forearm. The diameter of the DFRA was measured from the luminal space to the outer side of the vessel using the Hitachi- Aloka Noblus ultrasound system (L55 linear probe; 13 – 5 MHz).

Diameter of the snuffbox radial artery: Ultrasound images of the diameter of the snuffbox radial artery (SRA) were taken on the right (RSRA) and left (LSRA) sides of the body. The diameter of the SRA was measured from the luminal space to the outer side of the vessel using the Hitachi- Aloka Noblus ultrasound system.

Height: The height was measured from the plantar surface of the patient's foot to the vertex of their head (in a standing position).

Weight: Patients' weight was measured using a weighing scale.

Body surface area (BSA): The body surface area of patients were calculated using the Mosteller formula for paediatric patients (Formula 1) and the Du Bois and Du Bois formula (Formula 2) for adult patients.

Body mass index (BMI): The body mass index was calculated using the standard formula (Formula 3).

Baseline characteristics such as shoe size, occupation environment (for adults only), history of hypertension, history of diabetes mellitus, and history of smoking were also recorded. The outer diameter of standard sheaths were adapted from Beniwal et al.[26].

Formula 1: Mosteller formula

$$BSA\ (m^2) = \sqrt{\frac{height(cm) \times weight(kg)}{3600}}$$

Formula 2: Du Bois and Du Bois formula

$$BSA\ (m^2) = [weight(kg)]^{0.425} \times [height(cm)]^{0.725} \times 0.007184$$

Formula 3: Body mass index formula

$$BMI = \frac{weight(kg)}{[height(m)]^2}$$

Statistical analysis

Descriptive statistics were used to summarise the data, while frequencies and percentages were used for categorical data. Numerical data was expressed by means and standard deviations (SD). Demographic factors as well as clinical factors were examined using Levene's test for equality of variances, T-test, Anova, Chi square test, and Pearson's correlation test. Moreover, post-hoc and intraclass correlation coefficient tests were also conducted. A significant p-value of 0.05 was set. IBM SPSS Statistics V. 30 was used for the analysis.

2.4 RESULTS

A total of two hundred and fifty-six (n = 256) patients were included in this study with two subsets viz., adult (n = 128) (subset A), and paediatric (n = 128) (subset B). The intraclass correlation coefficients (ICCs) demonstrated excellent reliability for all measured variables. Single-measures ICCs ranged from 0.959 to 1.000, while average-measures ICCs ranged from 0.986 to 1.000 ($p < 0.001$). High inter-item correlations (≥ 0.956) between repeated attempts confirmed the measurement consistency.

Demographics

The age of the patients in subset A ranged between 18 and 79 years with an average age of 45 ± 15 years (Table 1). This subset was predominantly female (59.4%) and consisted of 64.1% Black, 21.1% Indian, 10.9% White, and 3.9% Mixed-race (refers to a group of heterogenous people described in a South African context) adult patients (Table 1). The age of the patients in subset B ranged between 29 days to 17 years. This subset was predominantly male (57.8%), and consisted of 89.1% Black, 7.0% Indian, 2.3% White, and 1.6% Mixed-race paediatric patients (Table 1).

Table 1: Demographic distribution of the sample

Parameter				
Subset A				
Sex	**Male** 52 (40.60%)		**Female** 76 (59.40%)	
Ethnicity	**Black** 82 (64.10%)	**Indian** 27 (21.10%)	**White** 14 (10.90%)	**Mixed-race** 5 (3.90%)
Age	**Mean ± SD** 45 ± 15	**Median** 46	**Min – Max** 18 – 79	
Subset B				
Sex	**Male** 74 (57.80%)		**Female** 54 (42.20%)	
Ethnicity	**Black** 114 (89.10%)	**Indian** 9 (7.00%)	**White** 3 (2.30%)	**Mixed-race** 2 (1.60%)

Baseline characteristics

The baseline characteristics in subsets A and B are summarised in the below table (Table 2). The diameter of the DFRA in subset A ranged between 1.2 to 3.2mm, while the diameter of the SRA ranged between 0.8 to 2.5mm. The diameter of the DFRA in subset B ranged between 0.6 to 2.3mm, while the diameter of the SRA ranged between 0.4 to 1.6mm.

Table 2: Baseline characteristics of the sample

Parameter	**Mean (±SD)**	
	Subset A	**Subset B**
Height (m)	1.67 (0.09)	1.08 (0.33)
Weight (kg)	82.66 (19.05)	21.60 (14.89)
Body surface area (m^2)	1.91 (0.21)	0.83 (0.40)
Body mass index (kg/m^2)	29.68 (7.13)	18.89 (6.33)
Wrist circumference on the right side (mm)	178.85 (13.05)	128.23 (22.47)
Wrist circumference on the left side (mm)	178.95 (13.16)	128.05 (22.23)
Average diameter of the DFRA (mm)	1.94 (0.39) (range: 1.20 – 3.20)	1.12 (0.32) (range: 0.60 - 2.30)
Average diameter of the SRA (mm)	1.33 (0.31) (range: 0.80 - 2.50)	0.77 (0.20) (range: 0.40 – 1.60)

Diameter of the DFRA and SRA according to sex

In subset A, the average diameter of the DFRA was 2.12 ± 0.39mm in males and 1.82 ± 0.34mm in females. Statistical tests revealed a significant difference between the diameter of the RDFRA and LDFRA among males and females ($p < 0.001$) (Table 3). Males had larger diameters of the SRA than females. There was a statistically significant difference between the diameter of the RSRA among males (1.41 ± 0.35mm) and females (1.28 ± 0.31mm) ($p = 0.034$) (Table 3). There was no statistically significant difference between the diameter of the LSRA among males and females (p = 0.11) (Table 3). In subset B, the average diameter of the DFRA was 1.10 ± 0.28mm in males and 1.15 ± 0.36mm in females. The average diameter of the SRA was 0.77 ± 0.19mm in males and 0.77 ± 0.21mm in females (Table 3). There was no statistically significant difference between the average diameters of the DFRA and SRA bilaterally among males and females (Table 3).

Table 3: Diameter of the DFRA and SRA according to sex

Parameter (mm)	Mean (±SD)		*P* value	Total (n = 128) Mean (±SD)
Subset A	**Male (n = 52)**	**Female (n = 76)**		
Diameter of RDFRA	2.13 (0.38)	1.82 (0.34)	**<0.001**	1.95 (0.39)
Diameter of LDFRA	2.11 (0.40)	1.82 (0.34)	**<0.001**	1.94 (0.39)
Diameter of RSRA	1.41 (0.35)	1.28 (0.31)	**0.034**	1.34 (0.33)
Diameter of LSRA	1.38 (0.28)	1.30 (0.28)	0.11	1.33 (0.28)
Subset B	**Male (n = 74)**	**Female (n = 54)**		
Diameter of the RDFRA	1.11 (0.28)	1.13 (0.35)	0.71	1.12 (0.31)
Diameter of the LDFRA	1.08 (0.29)	1.16 (0.37)	0.17	1.12 (0.32)
Diameter of the RSRA	0.77 (0.19)	0.78 (0.22)	0.89	0.78 (0.20)
Diameter of the LSRA	0.77 (0.20)	0.77 (0.20)	0.92	0.77 (0.20)

Diameter of DFRA and SRA according to ethnicity

In subset A, there was a statistically significant difference between the diameter of the RSRA among different ethnic groups (p = 0.029) (Table 4). A post-hoc analysis (Turkey HSD) was conducted and the mean difference between the diameter of the RSRA among the White and Black ethnic groups were statistically significant (p = 0.02) (Table 1 in Appendix A). There was no statistically significant difference between the diameter of the RDFRA (p = 0.29) and the LDFRA (p = 0.88) among the different ethnic groups. Similarly, there was no statistically significant difference between the diameter of the LSRA among the different ethnic groups (p = 0.94).

In subset B, there was no statistically significant difference between the average diameters of the DFRA and SRA bilaterally among the different ethnic groups (Table 4).

Table 4: Diameter of the DFRA and SRA according to different ethnic groups

Parameter (mm)	Mean (±SD)				*P* value
Subset A	**Black (n = 82)**	**Indian (n = 27)**	**White (n = 14)**	**Mixed-race (n = 5)**	
Diameter of the RDFRA	1.90 (0.37)	1.99 (0.42)	2.09 (0.47)	2.06 (0.29)	0.29
Diameter of the LDFRA	1.92 (0.39)	1.96 (0.34)	1.98 (0.49)	2.02 (0.33)	0.88
Diameter of the RSRA	1.28 (0.31)	1.38 (0.33)	1.56 (0.40)	1.30 (0.17)	**0.029**
Diameter of the LSRA	1.32 (0.29)	1.36 (0.29)	1.32 (0.28)	1.34 (0.22)	0.94
Subset B	**Black (n = 114)**	**Indian (n = 9)**	**White (n = 3)**	**Mixed-race (n = 2)**	
Diameter of the RDFRA	1.11 (0.31)	1.24 (0.30)	1.17 (0.51)	1.00 (0.14)	0.60
Diameter of the LDFRA	1.10 (0.32)	1.24 (0.30)	1.23 (0.60)	1.10 (0.14)	0.58
Diameter of the RSRA	0.78 (0.20)	0.77 (0.19)	0.83 (0.35)	0.75 (0.07)	0.96
Diameter of the LSRA	0.76 (0.19)	0.77 (0.19)	0.90 (0.46)	0.90 (0.14)	0.53

Diameter of DFRA and SRA according to age groups

In subset A, there was no statistically significant difference between the diameters of the DFRA and SRA on the right and left sides among the different age groups (Table 5). In subset B, there was a statistically significant difference between the average diameters of the DFRA and SRA bilaterally among the different age groups (Table 5).

Table 5: Diameter of DFRA and SRA according to different age groups

Parameter (mm)	Mean (±SD)				*P* value
Subset A	**18 – 24 years (n = 11)**	**25 – 34 years (n = 29)**	**35 – 44 years (n = 21)**	**45+ years (n = 67)**	
Diameter of the RDFRA	1.96 (0.31)	1.86 (0.38)	2.03 (0.43)	1.95 (0.39)	0.47
Diameter of the LDFRA	1.94 (0.42)	1.83 (0.36)	2.05 (0.41)	1.95 (0.38)	0.28
Diameter of the RSRA	1.26 (0.30)	1.29 (0.37)	1.37 (0.32)	1.36 (0.32)	0.66
Diameter of the LSRA	1.35 (0.27)	1.23 (0.24)	1.38 (0.28)	1.35 (0.30)	0.20
Subset B	**< 12 months (n = 22)**	**1 – 3 years (n = 39)**	**4 – 6 years (n = 23)**	**7+ years (n = 44)**	
Diameter of the RDFRA	0.92 (0.24)	1.07 (0.31)	1.09 (0.23)	1.28 (0.31)	**< 0.001**
Diameter of the LDFRA	0.90 (0.23)	1.04 (0.30)	1.13 (0.22)	1.29 (0.35)	**< 0.001**
Diameter of the RSRA	0.67 (0.15)	0.74 (0.17)	0.83 (0.18)	0.83 (0.23)	**0.004**
Diameter of the LSRA	0.64 (0.14)	0.74 (0.18)	0.80 (0.16)	0.84 (0.23)	**< 0.001**

A post-hoc analysis comparing the RDFRA and LDFRA as well as the RSRA and LSRA to age was conducted (Please see Table 2 in Appendix A).

Smoking, Hypertension, and Diabetes

In subset A, the average diameter of the RSRA between smokers (1.44 ± 0.37mm) and non-smokers (1.30 ± 0.31mm) was statistically significant (p = 0.04) (Table 6). The average diameter of the RSRA was larger in diabetic patients (1.51 ± 0.35mm) than non-diabetic patients (1.31 ± 0.32mm) and this difference was statistically significant (p = 0.021) (Table 6). The average diameter of the LSRA was larger in diabetic patients (1.50 ± 0.28mm) than non-diabetic patients (1.30 ± 0.27mm), and this difference was statistically significant (p = 0.007) (Table 6). There was a statistically significant association between diabetes mellitus and the average diameter of the RSRA (Wald Chi Square = 9.98, p = 0.002) and LSRA (Wald Chi Square = 4.89, p = 0.027).

All the patients in subset B did not have diabetes mellitus and did not smoke. The average diameters of the DFRA and SRA in subset B were larger but not statistically significant in hypertensive patients as summarized in Table 7. The average diameter of the DFRA and SRA between hypertensive and non-hypertensive patients were not statistically significant on the right and left sides (Table 7).

Table 6: Diameter of DFRA and SRA among smokers and non-smokers; hypertensive and non-hypertensive patients; diabetic and non-diabetic patients in subset A

Parameter (mm)	Mean (±SD)			Mean (±SD)			Mean (±SD)		
	Smoker (n = 32)	Non-smoker (n = 96)	*P* value	Hypertensive (n = 30)	Non-hypertensive (n = 98)	*P* value	Diabetic (n = 17)	Non-diabetic (n = 111)	*P* value
Diameter of RDFRA	2.02 (0.37)	1.92 (0.40)	0.23	1.94 (0.42)	1.95 (0.38)	0.99	1.98 (0.38)	1.94 (0.39)	0.72
Diameter of LDFRA	1.97 (0.39)	1.93 (0.39)	0.57	1.99 (0.38)	1.92 (0.39)	0.44	2.01 (0.30)	1.93 (0.40)	0.44
Diameter of RSRA	1.44 (0.37)	1.30 (0.31)	**0.04**	1.30 (0.30)	1.35 (0.34)	0.55	1.51 (0.35)	1.31 (0.32)	**0.021**
Diameter of LSRA	1.34 (0.31)	1.32 (0.27)	0.73	1.39 (0.31)	1.31 (0.27)	0.20	1.50 (0.28)	1.30 (0.27)	**0.007**

Table 7: Diameter of DFRA and SRA among hypertensive and non-hypertensive patients in subset B

Parameter	Mean (±SD)		*P* value
	Non-hypertensive (n = 123)	Hypertensive (n = 5)	
Diameter of the RDFRA (mm)	1.11 (0.31)	1.34 (0.26)	0.11
Diameter of the LDFRA (mm)	1.11 (0.33)	1.18 (0.13)	0.66
Diameter of the RSRA (mm)	0.77 (0.20)	0.86 (0.09)	0.33
Diameter of the LSRA (mm)	0.77 (0.20)	0.86 (0.11)	0.30

Shoe size

The diameters of the RDFRA, LDFRA, RSRA, and LSRA in both Subsets A and B were compared to shoe size and the results are summarized in Table 3 of Appendix A.

Occupational environment

The diameters of the RDFRA, LDFRA, RSRA, and LSRA in Subset A was compared to occupational environment and the results are summarized in Table 4 of Appendix A. In subset B, all patients were unemployed.

Correlation

The diameters of the RDFRA, LDFRA, RSRA, and LSRA were correlated to body surface area, body mass index, height, wrist circumference, and weight. These results appear in Table 5 of Appendix A. Furthermore, the diameters of the DFRA and SRA were correlated to each other. In subset A, there was a moderate correlation between the average diameter of the RDFRA and the average diameter of the LDFRA, RSRA, and LSRA. There was a weak correlation between the average diameter of the LDFRA and the average diameter of the RSRA ($r = 0.20$, $p = 0.02$). There was a moderate correlation between the average diameter of the LDFRA and the average diameter of the LSRA ($r = 0.58$, $p < 0.001$). There was a moderate correlation between the average diameter of the RSRA and the average diameter of the LSRA ($r = 0.39$, $p < 0.001$).

In subset B, there was a strong correlation between the average diameter of the RDFRA and average diameter of LDFRA ($r = 0.9$, $p < 0.001$). There was a moderate correlation between the average diameter of RDFRA and average diameter of the RSRA ($r = 0.58$, $p < 0.001$) and LSRA ($r = 0.60$, $p < 0.001$) (Table 6; Appendix A). Similarly, there was a moderate correlation between the average diameter of LDFRA, and average diameter of RSRA ($r = 0.62$, $p < 0.001$) and LSRA ($r = 0.64$, $p < 0.001$). There was a strong correlation between the average diameter of the RSRA and average diameter of LSRA ($r = 0.82$, $p < 0.001$).

Sheath size

In subset A, the diameter of the DFRA was less than 2.0mm (outer diameter of a 4Fr sheath) in 54.69% of patients on the right and in 56.25% of patients on the left (Table 8). There were 32 patients whose RDFRA diameter was between 2 and 2.3mm, and 29 patients whose LDFRA diameter was between

2 and 2.3mm. The diameter of the SRA was less than 2.0mm in 96.88% of patients on the right and 98.44% of patients on the left. In 3 patients the RSRA was between 2 and 2.3mm and in 2 patients the LSRA was between 2 and 2.3mm (outer diameter of a 5Fr sheath).

In subset B, the diameter of the DFRA was less than 2.0mm (outer diameter of a 4Fr sheath) in 99.22% of patients on the right and 98.44% of patients on the left (Table 8). One patient presented with a LDFRA between 2 and 2.3mm (outer diameter of 5Fr sheath); another patient presented with a RDFRA between 2.3 – 2.6mm, and one patient's LDFRA was between 2.3 – 2.6mm (outer diameter of 6Fr sheath). The diameter of the SRA was less than 2.0mm in 100% of patients.

Table 8: Diameter of DFRA and SRA in comparison to outer diameter of standard sheaths in subset A and B

Diameter (mm)	RDFRA	LDFRA	Total DFRA	RSRA	LSRA	Total SRA
SUBSET A						
< 2.0 (4F outer diameter)	70 (54.69%)	72 (56.25%)	142 (55.47%)	124 (96.88%)	126 (98.44%)	250 (97.66%)
2.0 – 2.3 (5F outer diameter)	32 (25.00%)	29 (22.66%)	61 (23.83%)	3 (2.34%)	2 (1.56%)	5 (1.95%)
2.3 – 2.6 (6F outer diameter)	17 (13.28%)	15 (11.72%)	32 (12.50%)	1 (0.78%)	0 (0.00%)	1 (0.39%)
2.6 – 2.8 (7F outer diameter)	5 (3.91%)	8 (6.25%)	13 (5.08%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
>2.8	4 (3.13%)	4 (3.13%)	8 (3.13%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
SUBSET B						
< 2.0 (4F outer diameter)	127 (99.22%)	126 (98.44%)	253 (98.83%)	128 (100%)	128 (100%)	256 (100%)
2.0 – 2.3 (5F outer diameter)	0 (0.00%)	1 (0.78%)	1 (0.39%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
2.3 – 2.6 (6F outer diameter)	1 (0.78%)	1 (0.78%)	2 (0.78%)	0 (0.00%)	0 (0.00%)	0 (0.00%)
2.6 – 2.8 (7F outer diameter)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	0 (0.00%)

2.5 DISCUSSION

Diameter of the DFRA and SRA

The average diameter of the DFRA reported in the present study was smaller than the findings of various authors as shown in Table 9. Badal et al.[27]; and Demirkiran and Aydin[28] reported a larger average baseline diameter of the radial artery compared to the findings of the present study.

Furthermore, Oshima et al.[29]; Mizukoshi et al.[30] and Lee et al.[31] also reported a larger average diameter of the radial artery compared to the findings of this study.

In a study conducted by Shlimon et al.[32], the average luminal diameter of the radial artery was larger in both the control and abdominal aortic aneurysm groups compared to the present study's findings. Li et al.[33] reported a larger average diameter of the radial artery in ethnic Han Chinese and ethnic Zhuang Chinese. In subset B, the average diameter of the DFRA was 1.12 ± 0.32mm. This finding was slightly smaller than the average diameter of the radial artery reported by Kim et al.[34] in a paediatric sample. However, a larger average diameter of the radial artery was reported by Srinivasan et al.[23] in a paediatric sample as shown in Table 9.

The average diameter of the SRA in subset A was 1.33 ± 0.31mm, which contradicts the findings of Buturak et al.[35]; and Norimatsu et al.[36] in which they reported larger average diameters of the SRA (Table 10). Demirkiran and Aydin[28] reported a larger average baseline diameter of the SRA compared to the findings of the present study. Hammami et al.[24] reported that the median diameter of the SRA in a Tunisian population was 2.2mm whilst Oshima et al.[29] reported a larger average diameter of this artery compared to our study.

In subset B, the average diameter of the SRA was 0.77 ± 0.20mm, similar to findings of Mavarez et al.[37] but differed from Srinivasan et al.[23] who reported a larger average diameter of this artery. The average diameter of the DFRA in subset A ranged between 1.2 to 3.2mm. This finding coincides with the ranges reported by Yoo et al.[22]; Yilmaztepe and Yilmaz[38]; and Narsinh et al.[5]. In subset B, the average diameter of the DFRA ranged between 0.6 to 2.3mm.

The average diameter of the DFRA was 2.12 ± 0.39mm and 1.82 ± 0.34mm in males and females, respectively in subset A. This finding contradicts the findings of authors as described in Table 11, in which larger average diameters of the radial artery in males and females were reported. The differences between the diameter of the radial artery among males and females compared to previous studies can be attributed to the distribution of males and females in this subset as subset A was predominantly female (59.4%). In subset B, the average diameter of the DFRA was 1.10 ± 0.28mm and 1.15 ± 0.36mm in males and females respectively. This finding contradicts the findings of Babuccu et al.[39]; and Alehaideb et al.[11], in which larger average diameters of the SRA in males and females were reported in a paediatric sample. Differences in diameters of the SRA in males and females can be attributed to the fact that subset B was predominantly male (57.8%).

In Subset A, the average diameter of the SRA was 1.39 ± 0.31mm and 1.29 ± 0.29mm in males and females, respectively. This finding contradicts the findings of Naito et al.[40]; Norimatsu et al.[36]; and Mavarez et al.[37] who reported larger average diameters of the SRA (Table 12). In this study, females had a smaller average DFRA diameter when compared to males, concurring with that reported by Nagai et al.[21]; Yoo et al.[22]; Mizukoshi et al.[30]; Ashraf et al.[41]; Okuyan et al.[9]; Beniwal et al.[26]; Aykan et al.[7]; Kim et al.[42]; Dharma et al.[8]; Naito et al.[40]; Norimatsu et al.[36]; Hammami et al.[24]; and Deora et al.[12] Similarly, Narsinh et al.[5] reported that females (2.43 ± 0.38mm) had a smaller mean diameter of the DFRA when compared to males (2.69 ± 0.40mm). In subset B, the average diameter of the SRA was 0.77 ± 0.19mm and 0.77 ± 0.21mm in males and females, respectively. This finding contradicts the finding of Alehaideb et al.[11] who reported a larger average diameter of the SRA in males and females in a paediatric sample.

Table 9: Diameter of the radial artery in the distal part of the forearm as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the radial artery
Nagai et al., 1999[21]	-	Imaging (ultrasound)	162	2.40 (±0.40)
Yoo et al., 2005[22]	Korean	Imaging (ultrasound)	1103	2.60 (±0.41) (mean)
Loh et al., 2007[43]	-	Imaging (ultrasonography)	327	2.45 (±0.54) (mean)
Ashraf et al., 2010[41]	Karachi	Imaging (ultrasonography)	251	2.25 (±0.40)
Okuyan et al., 2013[9]	-	Imaging (angiography)	93	2.30 (±0.40) (mean)
Beniwal et al., 2014[26]	Indian	Imaging (ultrasonography)	204	2.33 (±0.40) (mean)
Kotowycz et al., 2014[10]	Canadian	Imaging (ultrasound)	130	2.44 (±0.60)
Peruga et al., 2015[20]	Polish	Imaging (ultrasound)	109	2.22 (±0.35)
Abazid et al., 2017[44]	-	Imaging (ultrasound)	513	2.60 (±0.48)
Dharma et al., 2017[8]	Indonesian, Indian, and Macedonian	Imaging (ultrasound)	1706	2.80 (median)
Kim et al., 2017[34]	-	Observational	60 (paediatric)	1.50 (±0.20)
Sinha et al., 2017[45]	-	Imaging (ultrasound)	1945	2.56 (±0.29)
Norimatsu et al., 2019[36]	-	Imaging (ultrasound)	142	3.10 (±0.40)
Alehaideb et al., 2020[11]	Toronto	Imaging (ultrasound)	134 (paediatric)	1.86 (±0.44) (mean)
Srinivasan et al., 2020[23]	-	Imaging (angiogram)	47 (paediatric)	2.09 (±0.44)
Achim et al., 2021[46]	Hungarian	Imaging (ultrasound)	1240	2.45 (±0.60)
Hammami et al., 2021[24]	Tunisian	Imaging (ultrasound)	95	2.10
Meo et al., 2021[47]	-	Imaging (ultrasound)	700	2.58 (±0.58)
Gündüz et al., 2022[25]	-	Imaging (ultrasonography)	171	2.71 (±0.66)

Table 10: Diameter of the distal segment of the radial artery as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the distal segment of the radial artery (distal radial artery)
Buturak et al., 2016[35]	-	Imaging (ultrasound)	56	2.85 (±0.44)
Norimatsu et al., 2019[36]	-	Imaging (ultrasound)	142	2.60 (±0.50)
Ruzsa et al., 2020[48]	-	Imaging (ultrasound)	38	1.90 (±0.36)
Srinivasan et al., 2020[23]	-	Imaging (angiogram)	47 (paediatric)	2.09 (±0.54)
Achim et al., 2021[46]	Hungarian	Imaging (ultrasound)	1240	2.30 (±0.50)
Hammami et al., 2021[24]	Tunisian	Imaging (ultrasound)	82	2.20
Mavarez et al., 2021[37]	-	Imaging (ultrasound)	50 (paediatric)	0.76 (±0.18)
Meo et al., 2021[47]	-	Imaging (ultrasound)	700	1.99 (±0.47)

Table 11: Diameter of the radial artery among males and females in the distal part of the forearm as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter of radial artery (mm)
Nagai et al., 1999[21]	-	Imaging (ultrasound)	162	Male: 2.50 (±0.40) Female: 2.20 (±0.30)
Yoo et al., 2005[22]	Korean	Imaging (ultrasound)	1103	Male: 2.69 (±0.40) Female: 2.43 (±0.38)
Babuccu et al., 2006[39]	-	Imaging (doppler system)	45 (paediatric)	Male: 1.57 (±0.18) Female: 1.39 (±0.18)
Ashraf et al., 2010[41]	Karachi	Imaging (ultrasonography)	251	Male: 2.30 (±0.39) Female: 2.11 (±0.29)
Okuyan et al., 2013[9]	-	Imaging (angiography)	93	Male: 2.30 (±0.38) Female: 2.10 (±0.42)
Beniwal et al., 2014[26]	Indian	Imaging (ultrasonography)	204	Male: 2.37 (±0.41) Female: 2.26 (±0.39)
Aykan et al., 2015[7]	-	Imaging (ultrasonography)	222	Male: 2.73 (±0.39) Female: 2.15 (±0.35)
Dharma et al., 2017[8]	Indonesian, Indian, and Macedonian	Imaging (ultrasound)	1706	Male: 2.80 Female: 2.60 (median)
Naito et al., 2019[40]	Japanese	Imaging (ultrasound)	120	Male: 2.62 (±0.60) Female: 2.44 (±0.51)
Norimatsu et al., 2019[36]	-	Imaging (ultrasound)	142	Male: 3.20 (±0.40) Female: 3.00 (±0.40)
Alehaideb et al., 2020[11]	Toronto	Imaging (ultrasound)	134 (paediatric)	Male: 1.90 (±0.50) Female: 1.81 (±0.53)
Hammami et al., 2021[24]	Tunisian	Imaging (ultrasound)	177	Male: 2.20 (±0.30) Female: 2.00 (±0.32) (median)
Deora et al., 2022[12]	Indian	Imaging (ultrasound)	1004	Male: 2.60 (±0.34) Female: 2.42 (±0.36)

Table 12: Diameter of the distal segment of the radial artery among males and females as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the distal segment of the radial artery (distal radial artery)
Naito et al., 2019[40]	Japanese	Imaging (ultrasound)	120	Male: 2.04 (±0.43) Female: 1.90 (±0.44)
Norimatsu et al., 2019[36]	-	Imaging (ultrasound)	142	Male: 2.60 (±0.50) Female: 2.50 (±0.50)
Mavarez et al., 2021[37]	-	Imaging (ultrasound)	50 (paediatric)	Male: 0.73 (±0.19) Female: 0.81 (±0.17)

In subset A, the average diameter of the RDFRA and LDFRA were 1.95 ± 0.39mm and 1.94 ± 0.39mm respectively, which contradicts the findings of various authors (Table 13) as they reported larger average diameters of the radial artery on the right and left sides. Domagała et al.[49] reported a smaller diameter of the radial artery on the right and left sides compared to the findings of the present study. In an ultrasound study conducted by Kim et al.[42], a larger average diameter of the radial artery at 3 different segments (i.e., cun, guan and chi) was reported on the right and left sides compared to the present study's findings. The average diameter of the RSRA and LSRA were 1.34 ± 0.33mm, and 1.33 ± 0.28mm respectively, which contradicts the findings of authors as summarized in Table 14. In an angiographic study conducted by Kim et al.[50], a larger diameter of the LSRA was noted in a Korean population.

The average diameter of the RDFRA ranged between 1.2 to 3.2mm, while the diameter of the LDFRA ranged 1.2 to 3.0mm in subset A, concurring with the findings of Ashraf et al.[41], in which the diameter of the right radial artery ranged between 1.4 to 3.6mm; whilst the left ranged between 1.2 to 3.1mm. In this study, the average diameter of the RDFRA and LDFRA (Table 3) contradicted that reported by Deora et al.[12], and Lee et al.[51] who noted larger average diameters of the radial artery on the right and left sides in males and females in Indian and Korean populations, respectively. In this study, the average diameter of the RSRA and LSRA (Table 3) contradicted that reported by Deora et al.[12], and Lee et al.[51] who noted larger average diameters of the SRA on the right and left sides were reported in males and females on the right side in an Indian and Korean population, respectively.

In subset A, the average diameter of the DFRA was statistically larger in males on the right and left sides which coincided with the findings reported by Kotowycz et al.[10] in a Canadian population. The average diameter of the SRA was larger in males on the right and left sides (the left side was not statistically significant). This finding coincides with the findings of Deora et al.[12], and Lee et al.[51] in which males had a statistically larger diameter of the distal segment of the radial artery when compared to females. In a study conducted by Yilmaztepe and Yilmaz[38], the baseline diameter of the radial artery was statistically smaller in females compared to males.

In subset A, the average diameter of the DFRA was larger than the average diameter of the SRA which coincided with the findings of Norimatsu et al.[36], who reported that the diameter of the proximal radial artery was larger than the diameter of the distal segment of the radial artery. Similarly, Hadjivassiliou et al.[52] reported that the left radial artery was larger at the conventional access site at the wrist than the distal segment of the radial artery in the anatomical snuffbox. However, in a study conducted by Hammami et al.[24] the median diameter of the radial artery was higher in the distal radial group (2.2mm) than the traditional (forearm) radial artery group (2.1mm). Similarly, Naito et al.[40] reported that the diameter of the SRA was larger than the diameter of the DFRA in eight patients in a Japanese population.

The differences between the diameter of the DFRA and SRA can be attributed to the demographics of the sample and the geographical location. According to Lee et al.[51], the inconsistent values of the diameters of the radial artery and its distal segment can be attributed to the contrasting definitions of the vessel diameter among various investigators. The smaller size of the distal segment of the radial artery compared to the radial artery leads to challenges in vascular access such as increased risk of spasm and injury, and higher risk of radial artery occlusion.[3,12,53]

Table 13: Diameter of the radial artery on the right and left sides in the distal part of the forearm as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter of radial artery (mm)
Ashraf et al., 2010[41]	Karachi	Imaging (ultrasonography)	251	Right: 2.30 (±0.40) Left: 2.20 (±0.40)
Velasco et al., 2012[6]	Texan	Imaging (ultrasound)	100	Right: 2.22 (±0.35) Left: -
Beniwal et al., 2014[26]	Indian	Imaging (ultrasonography)	204	Right: 2.33 (±0.40) Left: 2.32 (±0.40)
Kotowycz et al., 2014[10]	Canadian	Imaging (ultrasound)	130	Right: 2.44 (±0.60) Left: 2.36 (±0.54)
Aykan et al., 2015[7]	-	Imaging (ultrasonography)	222	Right: 2.62 (±0.45) Left: -
Peruga et al., 2015[20]	Polish	Imaging (ultrasound)	109	Right: 2.17 (±0.54) Left: 2.25 (±0.43)
Alehaideb et al., 2020[11]	Toronto	Imaging (ultrasound)	134 (paediatric)	Right: 1.87 (±0.46) Left: 1.87(±0.47)
Domagała et al., 2021[49]	-	Imaging (ultrasound)	96	Right: 1.42 (±0.26) Left: 1.43 (±0.24)
Deora et al., 2022[12]	Indian	Imaging (ultrasound)	1004	Right: 2.56 (±0.35) Left: 2.50 (±0.35)

Table 14: Diameter of the distal segment of the radial artery on the right and left sides as reported by various authors

Author (year)	Population	Modality	Sample size	Diameter (mm) of the distal segment of the radial artery (distal radial artery)
Madssen et al., 2006[54]	-	Imaging (ultrasound)	29	Right: 2.58 (±0.38) Left: 2.71 (±0.32)
Deora et al., 2022[12]	Indian	Imaging (ultrasound)	1004	Right: 2.23 (±0.39) Left: 2.17 (±0.39)
Lee et al., 2022[51]	Korean	Imaging (ultrasound)	1162	Right: 2.31 (±0.43) Left: 2.35 (±0.45)

Factors that affect the diameter of the DFRA and SRA

Occupational environment

In subset A, patients who described a quiet occupational environment and those who were physically active had larger average diameters of the DFRA as opposed to those patients who were unemployed. These findings do not concur with Aykan et al.[7] who reported that only physically active patients had a larger radial artery (2.81 ± 0.37mm) as opposed to those who had a sedentary lifestyle.

Hypertension

This study reports larger average diameters of the DFRA and SRA in non-hypertensive patients (Table 6), concurring with the findings of Deora et al.[12] When these findings in subset A were compared to previous literature, hypertensive patients presented with larger diameters.[26,32] Loh et al.[43] reported that sex, hypertension, and hyperlipidemia positively affected the size of the radial artery diameter (Table 15). It is interesting to note that in subset B of our study, the average diameter of the DFRA and SRA were larger in hypertensive (paediatric) patients.

Diabetes mellitus

In subset A, the average diameter of the DFRA was larger in diabetic patients than non-diabetic patients, contradicting the findings of Ashraf et al.[41]; Beniwal et al.[26]; Yilmaztepe and Yilmaz[38]; and Deora et al.[12] who reported that non-diabetic patients had a larger average diameter. This study reports larger SRA diameters in diabetic patients, which contradicts that reported by Deora et al.[12] According to Ashraf et al.[41], the larger luminal diameter in non-diabetic patients might have significance in the decision to harvest the radial artery for bypass grafting and for coronary interventions. The difference between the diameter of the DFRA and SRA of diabetic and non-diabetic patients compared to previous studies can be attributed to the small number of diabetic patients in the present study. Loh et al.[43] and Li et al.[33] reported that diabetes mellitus negatively affected the diameter of the radial artery (Table 15). No patients had diabetes mellitus in subset B.

Smoking

In subset A, the average diameter of the DFRA was larger in smokers than non-smokers which compares favourably to Ashraf et al.[41] and Deora et al.[12] but not with Shlimon et al.[32], who reported a smaller luminal diameter of this artery. Furthermore, the average diameter of the SRA was larger in smokers than non-smokers, coinciding with the findings of Deora et al.[12] According to Loh et al.[43], smoking did not significantly influence the diameter of the radial artery. No patients were smoking in subset B.

Body surface area and body mass index

In subset A, there was a weak but statistically significant positive correlation between body surface area and the average diameter of the DFRA, bilaterally, coinciding with Kotowycz et al.[10]; and Lee et al.[31] On the other hand, Ashraf et al.[41] and Beniwal et al.[26] reported no significant correlation between the diameter of the radial artery and body surface area (Table 5 in Appendix A).

In subset A, there was no significant correlation between body mass index and the average diameter of the DFRA, which coincides with the reports of Ashraf et al.[41]; Beniwal et al.[26]; Aykan et al.[7]; Dharma et al.[8]; Yilmaztepe and Yilmaz[38] but differed from the findings reported by Kotowycz et al.[10]; and Domagała et al.[49] who noted a correlation between the diameter of the radial artery and body mass index. There was no significant correlation between body mass index and the average diameters of the SRA, which contradicted with the findings reported by Norimatsu et al.[36] who noted a positive correlation between body mass index and the diameter of the SRA. Babuccu et al.[39] noted a correlation between the diameter of the radial artery and body mass index in a paediatric sample, which differed from our findings.

There was no significant correlation between weight and the average diameters of the DFRA and SRA which coincides with findings of Ashraf et al.[41]; and Beniwal et al.[26] but differed from the findings of Li et al.[33]; Kotowycz et al.[10]; Aykan et al.[7]; Yilmaztepe and Yilmaz[38]; Domagała et al.[49]; Norimatsu et al.[36]; and Deora et al.[12] In paediatric patients (subset B), there was a moderate correlation between weight and average diameters of the DFRA and SRA , concurring with Babuccu et al.[39]

In subset A, there was a moderate significant correlation between height and the average diameter of the DFRA which contradicts Kotowycz et al.[10]; Aykan et al.[7]; Yilmaztepe and Yilmaz[38]; Ashraf et al.[41]; and Beniwal et al.[26] In subset B, there was a moderate correlation between height and the average diameters of the DFRA and SRA, coinciding with Babuccu et al.[39]

Wrist circumference

Our study found a correlation in the diameter of the DFRA and SRA with wrist circumference, concurring with Kotowycz et al.[10]; and Aykan et al.[7]

Shoe size

In this study, there was a moderate correlation between shoe size and the average diameter of the DFRA, coinciding with Kotowycz et al.[10]; and Aykan et al.[7] (Table 5 of Appendix A). In subset B, there was a weak correlation between shoe size and the average diameter of the DFRA and SRA.

Ethnicity and age

In this study, the largest average diameter of the RDFRA was noted in the White ethnic group, which contradicts the findings of Kotowycz et al.[10] who reported that patients from the Black ethnic group had the largest right radial artery diameter. The differences can be attributed to the distribution of patients among the different ethnic groups. There was no significant correlation between age and the average diameters of the DFRA and SRA. In subset B, the largest average diameter of the DFRA was noted in the Indian ethnic group.

Table 15: Factors that influence the diameter of the radial artery and its distal segment as reported by various authors

Author (year)	Population	Sample size	Factors that affect the size of the radial artery		
			Positively	**Negatively**	**No correlation/no change**
Loh et al., 2007[43]	-	327	• Sex • Hyperlipidaemia • Hypertension	• Age • Diabetes mellitus	-
Ashraf et al., 2010[41]	Karachi	251	• Male sex • Smoking • Diabetes mellitus	-	• Weight • Height • Body mass index and body surface area
Velasco et al., 2012[6]	Texan	100	-	-	• Height • Weight • Age • Body surface area
Okuyan et al., 2013[9]	-	93	• Body weight • Distal and proximal wrist diameters	-	-
Beniwal et al., 2014[26]	Indian	204	• Hypotension • Sex	-	• Body surface area and body mass index • Height • Weight
Kotowycz et al., 2014[10]	Canadian	130	• Wrist circumference • Shoe size • Body mass index and body surface area • Height • Weight	-	-
Aykan et al., 2015[7]	-	222	• Height • Body mass index • Weight • Wrist circumference • Pulse pressure • Shoe size	-	-
Dharma et al., 2017[8]	Indonesian, Indian, and Macedonian	1706	• Female sex	-	• Body mass index
Norimatsu et al., 2019[36]	-	142	• Body weight • Body mass index (distal radial artery)		• Age • Height (distal radial artery)
Alehaideb et al., 2020[11]	Toronto	134	• Weight • Age	-	-
Deora et al., 2022[12]	Indian	1004	• Weight • Height	• Body mass index	• Age

Sheath size

In subset A, 55% of patients exhibited DFRA diameters less than 2.0mm. This finding contrasts with earlier findings of Kotowycz and Džavík[55]; and Beniwal et al.[26] who observed significantly lower incidence of narrow diameters. There were 24% of patients whose DFRA diameter was between 2.0 – 2.3mm, which is slightly higher than the findings of Beniwal et al.[26] in an Indian population. In a study conducted by Kotowycz and Džavík[55], the 5Fr sheath was used in over 20% of cases (21 procedures). Whilst Yoo et al.[22] reported that the radial artery diameter was larger than the outer diameter of a 5Fr sheath in 82.7% for transradial coronary procedures. In a study conducted by Achim et al.[46], the 5Fr sheath was used most frequently.

In this study, 21% of patients had a larger diameter than 5Fr sheaths, which contradicts the findings of Velasco et al.[6] who reported that 42% of the patients had a larger diameter than 5Fr sheaths. 13% of patients exhibited DFRA diameters between 2.3 – 2.6mm, which contradicts the findings of Beniwal et al.[26] who reported that 32.8% of patients had radial artery diameters between 2.3 and 2.6mm (6Fr outer diameter). Li et al.[33] reported that the diameter of the radial artery was at least as large as a 6Fr Cordis sheath in 86.1% of males and 57% of females. In a study conducted by Kotowycz and Džavík[55], the 6Fr sheath was used in over 70% of cases (68 procedures). Aykan et al.[7] reported that 86.5% of the sample was suitable for the 6Fr Radifocus sheath. Velasco et al.[6] reported that 20% of patients in a Texan population had larger radial artery diameters than 6F sheaths.

In this study, 5% of patients exhibited DFRA diameters between 2.6 – 2.8mm (7Fr outer diameter). This finding contradicts the findings of Beniwal et al.[26] who reported that 17.6% of patients had radial artery diameters between 2.6 and 2.8mm. Li et al.[33] reported that the diameter of the radial artery was at least as large as a 7Fr Cordis sheath in 59.3% in males and 24.9% females. In a study conducted by Kotowycz and Džavík[55], the 7Fr sheath was used in less than 10% of cases (3 procedures). 3% of patients had larger DFRA diameters than 7Fr sheath, which is slightly lower than the findings reported by Velasco et al.[6] in a Texan population. The diameter of the SRA was less than 2.0mm in 97.66% of patients. In subset B, the diameter of the DFRA was less than 2.0mm in 98.8% of patients. The diameter of the SRA was less than 2.0mm in all the patients.

Procedural tips, clinical decision-making tools and direct comparison to standard practices

When considering sheath compatibility, it is essential to recognize that the outer diameter of sheaths with the identical Fr sizes can vary substantially among different manufacturers and product lines. Although the Fr scale denotes the inner diameter, it is the sheath's outer diameter that ultimately determines the risk of arterial injury, spasm, and occlusion.[13] This becomes particularly pertinent in the context of radial access, where specialised thin-wall sheaths are designed to reduce the outer diameter without compromising the inner lumen.[13] Our study utilized the outer diameter values from Beniwal et al.[26] ; however, our findings indicated that 55% of adults and 99% of paediatric patients had a DFRA diameter of less than 2.0mm (the outer diameter of a 4Fr sheath). This underscores a critical need for meticulous pre-procedural planning. For a significant portion of this select population, especially in the paediatric cohort, the use of the smallest feasible sheath size is imperative. Furthermore, although the hardware remains consistent for both the forearm and snuffbox access, the consistently smaller calibre of the SRA necessitates heightened vigilance in selecting the sheath's outer diameter.[4] Despite the need to use the smallest sheath size, other factors such as the sheath material, competency of the haemostatic valve, sheath length, and sheath performance should also be taken into consideration when choosing an appropriate sheath.[13] Ultimately, operators should utilize pre-procedural ultrasound imaging to ensure that the selected sheath's outer diameter is compatible with the patient's vessel anatomy, thereby ensuring safety and efficacy for a successful neurointerventional procedure.

The high prevalence of small-calibre radial arteries in our cohort, notably in the snuffbox region and among paediatric patients, underscores the importance of vessel dilation strategies for procedural success. Several pre-procedural maneuvers have been described to promote vasodilation, including the administration of vasodilators (such as nitro-glycerine, verapamil), as well as mechanical techniques such as haemostasis release and patent haemostasis.[3,4,28] The routine use of vasodilators could potentially increase the number of patients suitable for transradial access and reduce the risk of spasm and occlusion, particularly in populations with smaller baseline vessel sizes like the present study.

Although this study was designed to define baseline anatomy rather than procedural outcomes, our findings have important implications for clinical practice. The high prevalence of distal radial artery diameters below 2.0mm supports the routine use of ultrasound guidance when planning access sites. All patients should undergo pre-procedural ultrasound mapping of the DFRA and SRA, to enable the selection of the largest suitable access site and the appropriate sheath size. Furthermore, the observed correlation between the vessel size and factors such as height, weight, BSA, BMI, and wrist circumference provides clinicians with simple, non-invasive predictors to identify patients at higher risk of having small radial arteries.

Limitations

We did not access the vessel diameter under the conditions of procedural stress in the angiography suite, where factors such as anxiety and vasospasm could lead to a smaller functional diameter. Thus, operators should be aware that the actual vessel size during cannulation might be slightly less than the baseline values reported in this study. This study was conducted at a single center and excluded patients with a history of surgery or procedures that were conducted via the trans-radial approach; therefore, the anatomical changes of the radial artery before and after procedures were not documented.

2.6 CONCLUSION

This study investigated the anatomical characteristics of the distal forearm and snuffbox radial arteries within a select adult and paediatric South African population. Adult patients exhibited larger distal forearm radial artery diameters than paediatric patients, with males having larger diameters than females. The diameter of the snuffbox radial artery was smaller than the diameter of the distal forearm radial artery. Notably, 55% of adults and 99% of paediatric patients had distal forearm radial artery diameters less than 2.0mm, while the diameter of the snuffbox radial artery was less than 2mm in 97% of adults and all the paediatric patients. The present study's findings can assist the clinician during neuro-interventional procedures within this select adult and paediatric South African population. For future research, the anatomical characteristics of the distal forearm and snuffbox radial arteries should be recorded at multiple centers, and a longitudinal study should be conducted to evaluate procedural outcomes and radial artery changes (such as occlusion or spasm) over time in patients undergoing trans-radial interventions, as these findings can improve procedural success and safety. Future studies should also investigate the changes in the radial artery diameter before and after various vasodilators in adult and paediatric patients, as this may minimize vascular complications and may optimize sheath compatibility during neurointerventional procedures.

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Ethical statement

This study was conducted in accordance with the 1964 Helsinki Declaration and its later amendments as well as with the ethical standards of the institutional and national research committee. Ethical approval was obtained from the institutional ethics committee (BREC/00006978/2024).

Informed consent statement

Informed consent was obtained from all adult patients as well as parents or guardians who accompanied their children to the paediatric clinic. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request.

Data availability statement

All the data are available from the corresponding author upon reasonable request.

Conflict of interest

The authors declare that they have no conflicts of interest to report.

CRediT authorship contribution statement

Aleisha J Singh: All persons listed as authors have contributed substantially to the conceptualization, writing - original draft, writing – review and editing.

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AI statement

No such technologies were used.

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2.8 APPENDIX A – SUPPLEMENTARY DATA

Table 1: Post-hoc analysis based on the diameter of the RSRA according to different ethnic groups in subset A

Dependent variable	Ethnicity (I)	Ethnicity (J)	Mean difference (I-J)	*P* value
Diameter of the RSRA (mm)	Black	Mixed-race	-0.02	1.00
		Indian	-0.10	0.53
		White	-0.27*	**0.02**
	Mixed-race	Black	0.02	1.00
		Indian	-0.08	0.95
		White	-0.26	0.42
	Indian	Black	0.10	0.53
		Mixed-race	0.08	0.95
		White	-0.18	0.35
	White	Black	0.27*	**0.02**
		Mixed-race	0.26	0.42
		Indian	0.18	0.35

*The mean difference is significant at the 0.05 level.

Table 2: Post-hoc analysis based on the diameter of the DFRA and SRA according to different age groups in subset B

Dependent variable	Age group (I)	Age group (J)	Mean difference (I-J)	*P* value
Diameter of the RDFRA (mm)	<12 months	1 – 3 years	-0.15	0.06
		4 – 6 years	-0.16	0.06
		7+ years	-0.36*	**<0.001**
	1 – 3 years	<12 months	0.15	0.06
		4 – 6 years	-0.02	0.81
		7+ years	-0.21*	**<0.001**
	4 – 6 years	<12 months	0.16	0.06
		1 – 3 years	0.02	0.81
		7+ years	-0.20*	**0.01**
	7+ years	<12 months	0.36*	**<0.001**
		1 – 3 years	0.21*	**<0.001**
		4 – 6 years	0.20*	**0.01**
Diameter of the LDFRA (mm)	<12 months	1 – 3 years	-0.14	0.08
		4 – 6 years	-0.23*	**0.01**
		7+ years	-0.40*	**<0.001**
	1 – 3 years	<12 months	0.14	0.08
		4 – 6 years	-0.09	0.24
		7+ years	-0.26*	**<0.001**
	4 – 6 years	<12 months	0.23*	**0.01**
		1 – 3 years	0.09	0.24
		7+ years	-0.17*	**0.03**
	7+ years	<12 months	0.40*	**<0.001**
		1 – 3 years	0.26*	**<0.001**
		4 – 6 years	0.17*	**0.03**
Diameter of the RSRA (mm)	<12 months	1 – 3 years	-0.07	0.17
		4 – 6 years	-0.16*	**0.01**
		7+ years	-0.17*	**0.001**
	1 – 3 years	<12 months	0.07	0.17
		4 – 6 years	-0.09	0.08
		7+ years	-0.10*	**0.03**
	4 – 6 years	<12 months	0.16*	**0.01**
		1 – 3 years	0.09	0.08
		7+ years	-0.01	0.87
	7+ years	<12 months	0.17*	**0.001**
		1 – 3 years	0.10*	**0.03**
		4 – 6 years	0.01	0.87
Diameter of the LSRA (mm)	<12 months	1 – 3 years	-0.10*	**0.05**
		4 – 6 years	-0.16*	**0.01**
		7+ years	-0.20*	**<0.001**
	1 – 3 years	<12 months	0.10*	**0.05**
		4 – 6 years	-0.06	0.24
		7+ years	-0.1*	**0.02**
	4 – 6 years	<12 months	0.16*	**0.01**
		1 – 3 years	0.06	0.24
		7+ years	-0.04	0.40
	7+ years	<12 months	0.20*	**<0.001**
		1 – 3 years	0.10*	**0.02**
		4 – 6 years	0.04	0.40

*Mean difference is significant at the 0.05 level

Table 3: Diameter of the DFRA and SRA according to different shoe sizes

Parameter	Subset A			Subset B		
	Shoe size	Mean (±SD)	*P* value	Shoe size	Mean (±SD)	*P* value
Diameter of RDFRA (mm)	1 (n = 0)	-	**<0.001**	1 (n = 9)	1.14 (0.26)	0.18
	2 (n = 0)	-		2 (n = 18)	1.04 (0.35)	
	3 (n = 5)	1.64 (0.50)		3 (n = 17)	1.09 (0.25)	
	4 (n = 10)	1.84 (0.36)		4 (n = 17)	1.21 (0.24)	
	5 (n = 17)	1.68 (0.24)		5 (n = 18)	1.33 (0.36)	
	6 (n = 23)	1.85 (0.28)		6 (n = 11)	0.97 (0.25)	
	7 (n = 30)	1.94 (0.32)		7 (n = 2)	1.25 (0.64)	
	8 (n = 24)	2.05 (0.35)		8 (n = 3)	1.10 (0.20)	
	9 (n = 16)	2.30 (0.46)		9 (n = 2)	1.05 (0.07)	
	10 (n = 1)	2.60		10 (n = 3)	1.30 (0.10)	
	11 (n = 2)	2.25 (0.78)		11 (n = 3)	0.97 (0.15)	
	12 (n = 0)	-		12 (n = 3)	1.13 (0.12)	
	13 (n = 0)	-		13 (n = 3)	1.30 (0.56)	
Diameter of LDFRA (mm)	1 (n = 0)	-	**<0.001**	1 (n = 9)	1.13 (0.21)	0.23
	2 (n = 0)	-		2 (n = 18)	1.05 (0.34)	
	3 (n = 5)	1.64 (0.51)		3 (n = 17)	1.06 (0.30)	
	4 (n = 10)	1.75 (0.15)		4 (n = 17)	1.18 (0.33)	
	5 (n = 17)	1.77 (0.30)		5 (n = 18)	1.35 (0.34)	
	6 (n = 23)	1.80 (0.32)		6 (n = 11)	0.98 (0.26)	
	7 (n = 30)	1.94 (0.34)		7 (n = 2)	1.35 (0.78)	
	8 (n = 24)	2.09 (0.41)		8 (n = 3)	1.17 (0.15)	
	9 (n = 16)	2.24 (0.41)		9 (n = 2)	1.05 (0.07)	
	10 (n = 1)	2.20		10 (n = 3)	1.27 (0.21)	
	11 (n = 2)	2.30 (0.57)		11 (n = 3)	1.07 (0.21)	
	12 (n = 0)	-		12 (n = 3)	1.00 (0.20)	
	13 (n = 0)	-		13 (n = 3)	1.17 (0.57)	
Diameter of RSRA (mm)	1 (n = 0)	-	0.07	1 (n = 9)	0.76 (0.12)	0.85
	2 (n = 0)	-		2 (n = 18)	0.73 (0.16)	
	3 (n = 5)	1.08 (0.18)		3 (n = 17)	0.78 (0.20)	
	4 (n = 10)	1.34 (0.30)		4 (n = 17)	0.82 (0.26)	
	5 (n = 17)	1.17 (0.28)		5 (n = 18)	0.80 (0.24)	
	6 (n = 23)	1.30 (0.30)		6 (n = 11)	0.76 (0.17)	
	7 (n = 30)	1.34 (0.36)		7 (n = 2)	0.80 (0.42)	
	8 (n = 24)	1.44 (0.37)		8 (n = 3)	0.77 (0.06)	
	9 (n = 16)	1.43 (0.28)		9 (n = 2)	0.85 (0.21)	
	10 (n = 1)	1.90		10 (n = 3)	1.00 (0.26)	
	11 (n = 2)	1.45 (0.07)		11 (n = 3)	0.87 (0.15)	
	12 (n = 0)	-		12 (n = 3)	0.80 (0.10)	
	13 (n = 0)	-		13 (n = 3)	0.70 (0.17)	
Diameter of LSRA (mm)	1 (n = 0)	-	0.12	1 (n = 9)	0.77 (0.13)	0.97
	2 (n = 0)	-		2 (n = 18)	0.73 (0.18)	
	3 (n = 5)	1.16 (0.25)		3 (n = 17)	0.77 (0.23)	
	4 (n = 10)	1.34 (0.21)		4 (n = 17)	0.82 (0.19)	
	5 (n = 17)	1.25 (0.29)		5 (n = 18)	0.79 (0.27)	
	6 (n = 23)	1.25 (0.25)		6 (n = 11)	0.75 (0.16)	
	7 (n = 30)	1.32 (0.28)		7 (n = 2)	0.75 (0.35)	

8 (n = 24)	1.44 (0.31)	8 (n = 3)	0.87 (0.12)
9 (n = 16)	1.36 (0.27)	9 (n = 2)	0.85 (0.21)
10 (n = 1)	1.50	10 (n = 3)	0.90 (0.26)
11 (n = 2)	1.70 (0.14)	11 (n = 3)	0.80 (0.26)
12 (n = 0)	-	12 (n = 3)	0.77 (0.15)
13 (n = 0)	-	13 (n = 3)	0.70 (0.17)

Table 4: Diameter of DFRA and SRA according to occupational environment in subset A

Parameter	Mean (±SD)			*P* value
	Unemployed (n = 86)	Physically active/outdoors (n = 29)	Quiet environment (n = 13)	
Diameter of the RDFRA (mm)	1.91 (0.38)	1.99 (0.45)	2.06 (0.30)	0.32
Diameter of the LDFRA (mm)	1.90 (0.37)	2.01 (0.43)	2.05 (0.41)	0.21
Diameter of the RSRA (mm)	1.35 (0.36)	1.32 (0.26)	1.25 (0.29)	0.53
Diameter of the LSRA (mm)	1.32 (0.29)	1.35 (0.29)	1.32 (0.23)	0.88

Table 5: Heatmap to show correlation in subset A

	Height (m)	Weight (kg)	Body surface area	Body mass index	Average wrist circumference on right side (mm)	Average wrist circumference on left side (mm)	Average diameter of the RDFRA (mm)	Average diameter of the LDFRA (mm)	Average diameter of the RSRA (mm)	Average diameter of the LSRA (mm)
Height (m)	1.00	0.15	0.50	-0.30	0.43	0.43	0.50	0.38	0.37	0.21
Weight (kg)	0.15	1.00	0.93	0.89	0.61	0.60	0.10	0.12	0.08	0.14
Body surface area	0.50	0.93	1.00	0.67	0.70	0.69	0.27	0.25	0.21	0.20
Body mass index	-0.30	0.89	0.67	1.00	0.39	0.38	-0.13	-0.05	-0.09	0.04
Average wrist circumference on right (mm)	0.43	0.61	0.70	0.39	1.00	0.99	0.23	0.36	0.16	0.27
Average wrist circumference on left (mm)	0.43	0.60	0.69	0.38	0.99	1.00	0.22	0.35	0.15	0.25
Average diameter of RDFRA (mm)	0.50	0.10	0.27	-0.13	0.23	0.22	1.00	0.64	0.59	0.39
Average diameter of LDFRA (mm)	0.38	0.12	0.25	-0.05	0.36	0.35	0.64	1.00	0.20	0.58
Average diameter of RSRA (mm)	0.37	0.08	0.21	-0.09	0.16	0.15	0.59	0.20	1.00	0.39
Average diameter of LSRA (mm)	0.21	0.14	0.20	0.04	0.27	0.25	0.39	0.58	0.39	1.00

*Peach indicates weak correlation, green indicates moderate correlation, blue indicates strong correlation, and purple indicates weak negative correlation

Table 6: Heatmap to show the correlation in subset B

	Height (m)	Weight (kg)	Body surface area	Body mass index	Average wrist circumference on right side (mm)	Average wrist circumference on left side (mm)	Average diameter of the RDFRA (mm)	Average diameter of the LDFRA (mm)	Average diameter of the RSRA (mm)	Average diameter of the LSRA (mm)
Height (m)	1.00	0.91	0.96	-0.11	0.90	0.90	0.39	0.45	0.34	0.35
Weight (kg)	0.91	1.00	0.99	0.20	0.88	0.87	0.37	0.44	0.38	0.38
Body surface area	0.96	0.99	1.00	0.11	0.91	0.91	0.38	0.45	0.36	0.37
Body mass index	-0.11	0.20	0.11	1.00	0.07	0.07	-0.02	0.00	0.09	0.08
Average wrist circumference on right side (mm)	0.90	0.88	0.91	0.07	1.00	1.00	0.40	0.39	0.37	0.40
Average wrist circumference on left side (mm)	0.90	0.87	0.91	0.07	1.00	1.00	0.40	0.39	0.37	0.39
Average diameter of the RDFRA (mm)	0.39	0.37	0.38	-0.02	0.40	0.40	1.00	0.90	0.58	0.60
Average diameter of the LDFRA (mm)	0.45	0.44	0.45	0.00	0.39	0.39	0.90	1.00	0.62	0.64
Average diameter of the RSRA (mm)	0.34	0.38	0.36	0.09	0.37	0.37	0.58	0.62	1.00	0.82
Average diameter of the LSRA (mm)	0.35	0.38	0.37	0.08	0.40	0.39	0.60	0.64	0.82	1.00

*Peach indicates weak correlation, green indicates moderate correlation, blue indicates strong correlation, and purple indicates weak negative correlation

BRIDGING TEXT

From Chapter 2 to Chapter 3

Chapter 2 provided an analysis of the anatomical characteristics of the radial artery and its distal segment using ultrasound investigation within a select adult (Subset A) and paediatric (Subset B) South African population. The data acquired provided an understanding of the anatomy of the distal forearm and snuffbox radial arteries, as well as the factors that affect these diameters.

CHAPTER 3
SCIENTIFIC MANUSCRIPT 2

Contributions of this chapter

This chapter is comprised of a scientific manuscript that investigated the morphometry of the radial artery in a select sample of adult donor South African cadavers. The results were compared on the basis of demographical factors and laterality and compared to previous literature. The manuscript was formatted according to the guidelines of the journal.

The following manuscript has been submitted and is currently under review in the Anatomia, Histologia, Embryologia journal.

Title: Morphometric analysis of the radial artery in a select South African sample

Authors: A. J. Singh, R. Harrichandparsad, L. Lazarus

Journal: Anatomia, Histologia, Embryologia

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TITLE PAGE

Morphometric analysis of the radial artery in a select South African sample

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3.1 Abstract

The radial artery is a vital access point for various cardiovascular and neurological interventions yet detailed morphometric studies in African populations are limited. This study aimed to investigate the radial artery dimensions in thirty adult body donors cadavers housed in the Department of Clinical Anatomy, University of KwaZulu-Natal, Durban, South Africa. The external and internal diameters, along with wall thickness of the radial artery, were measured at three anatomical sites viz. the point of origin, at the wrist joint, and in the anatomical snuffbox bilaterally using a digital vernier caliper in sixty upper limb specimens (BREC/00006978/2024). There was a progressive distal tapering pattern, with the external diameters of the radial artery decreasing from its point of origin to the anatomical snuffbox. The internal diameter of the radial artery was 2.98 ± 0.76mm at the origin, 2.20 ± 0.75mm at the wrist joint, and 1.75 ± 0.69mm in the anatomical snuffbox. The thickness of the radial artery also decreased distally, from its point of origin to the anatomical snuffbox. There were no statistically significant differences between sexes or laterality. In 32% of the upper limbs, the internal radial artery diameters fell within the range suitable for a 5 French (5Fr) sheath at the wrist, while 38% showed similar results in the anatomical snuffbox. The findings of this study can contribute to the existing knowledge in this field and may help clinicians during cardiovascular and neurological interventional procedures within this select sample.

Keywords: Forearm radial artery; Snuffbox radial artery; Donors; Adult; Morphometry; South African sample

3.2 Introduction

The radial artery develops embryologically from the axial artery (Schoenwolf, Bleyl, Brauer and Francis-West, 2009; Singh, 2020). At the apex of the cubital fossa, the radial artery arises as one of the terminal branches of the brachial artery which provides vasculature to the lateral side of the index finger, thumb, carpal bones; elbow joint; and the postero-lateral side of the forearm (Moore, Dalley and Agur, 2018; Sgueglia, Giorgio, Gaspardone and Babunashvili, 2018; Narsinh et al., 2021; Brennan, Zhang and Hacking, 2025; Marchese, Launico and Geigner, 2025). The radial artery travels between the flexor and extensor groups of muscles in the forearm, lying deep to the brachioradialis muscle in the proximal half of the forearm (Moore, Dalley and Agur, 2018; Drake, Vogl, Mitchel and Gray, 2020; Narsinh et al., 2021).

In the middle third of the forearm, the radial artery is laterally related to the radial nerve (superficial branch) (Drake et al., 2020). While distally, the radial artery, which is covered by fascia and skin, lies anterior to pronator quadratus muscle and lateral to the tendon of the flexor carpi radialis (Drake et al., 2020). Proximal to the wrist, the radial artery branches into a superficial palmar branch before winding around the lateral aspect of the wrist, where is traverses the anatomical snuffbox – a region bounded by the tendons of the extensor pollicis longus muscle, abductor pollicis longus muscle, and the extensor pollicis brevis muscle (Moore et al., 2018; Roh and Lee, 2018; Drake et al., 2020; Marchese et al., 2023; Hallett Reid, Jozsa and Ashurst, 2023).

The radial artery courses through the anatomical snuffbox in close proximity to the scaphoid and trapezium carpal bones (Moore, Dalley and Agur, 2018; Roh and Lee, 2018; Daralammouri, Nazzal, Mosleh, Abdulhaq, Khayyat et al., 2022; Dawani, Mahajan, Vasudeva and Mishra, 2022; Hallett Reid et al., 2023; Brennan et al., 2025). This anatomical relationship establishes the snuffbox as a critical landmark for both anatomical education and clinical interventions, including cardiovascular and neurological procedures.

The diameter of the radial artery is a critical morphometric parameter with direct clinical implications, as it influences the success of trans-radial interventions, vascular grafts, and catheterization procedures (Alasmari, 2021; Narsinh et al., 2021; Daralammouri et al., 2022; Bhatia, Kumar and Arafath, 2023). Therefore, knowledge of the diameter of the radial artery is crucial as it assists the clinician in selecting various sheath sizes during trans-radial coronary interventions and enhances microsurgical techniques (Nasr, 2012).

While numerous studies have documented the diameter of the radial artery in various populations, data from the African continent, and Southern Africa in particular, remain scarce. Furthermore, data including the anatomical snuffbox, a site of growing clinical interest for distal radial access, is limited. Therefore, this study aimed to document the morphometric characteristics of the radial artery in terms of the external and internal diameters and wall thickness at the point of origin, wrist joint, and in the anatomical snuffbox in a select sample of adult donor South African cadavers.

3.3 Materials and methods

This study was conducted on thirty adult embalmed donor cadavers in the Department of Clinical Anatomy at the University of KwaZulu-Natal, South Africa. Institutional ethical approval was obtained from the ethics committee (BREC/00006978/2024).

3.3.1 Inclusion and Exclusion criteria

Adult body donor cadavers of both sexes, and all population groups obtained from the University of KwaZulu-Natal were included in this study. Cadavers with signs of surgical intervention and damage to the radial artery were excluded.

3.3.2 Study procedure

The radial artery was dissected as per standardised protocol (Detton and Tank, 2017). Measurements were obtained in triplicate using a digital vernier caliper (EIS Digital Vernier 150mm). Measurements were recorded by a single observer and transferred to a password-protected Excel spreadsheet. The morphometric parameters were analyzed as follows:

Wrist circumference: The bilateral wrist circumference was measured using a flexible tape measure. The tape was positioned around the wrist at the level of the distal radio-ulnar joint, passing over Lister's tubercle on the dorsal aspect of the radial bone and the styloid process of the ulnar bone.

Diameter of the radial artery: The internal and external diameters of the radial artery were measured bilaterally at three measurement points i.e., at its point of origin from the brachial artery (Fig. 1), at the wrist joint, and in the anatomical snuffbox (Fig. 2). The external diameter of the artery was measured first, after which the artery was incised at each specific measurement point. Then the internal (luminal) diameter of the artery was recorded.

Thickness of the radial artery: The bilateral wall thickness of the radial artery was calculated as half $(\frac{1}{2})$ the difference between the average external and internal diameters measured at three points i.e., at its point of origin from the brachial artery, at the wrist joint, and in the anatomical snuffbox.

Sheath size selection: The sheath sizing was guided by the radial artery diameter, as described by Hobby et al. (2021).

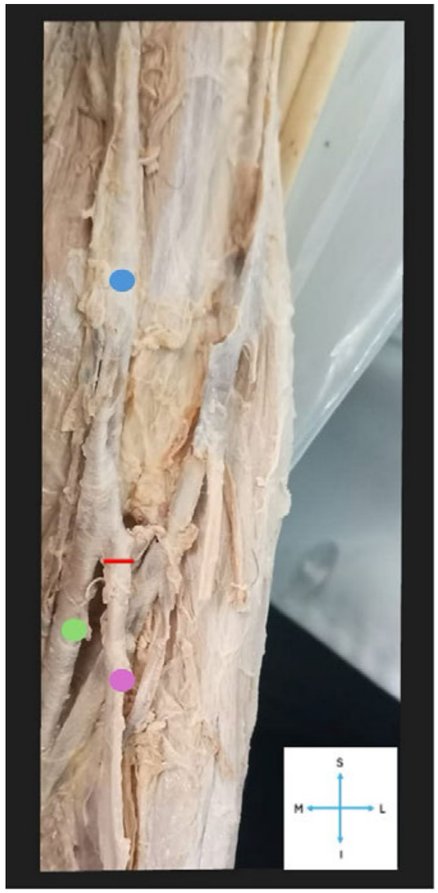

Figure 1: Measurement of radial artery at the point of origin (indicated by the red line). Blue dot: Brachial artery; Green dot: Ulnar artery; Pink dot: Radial artery

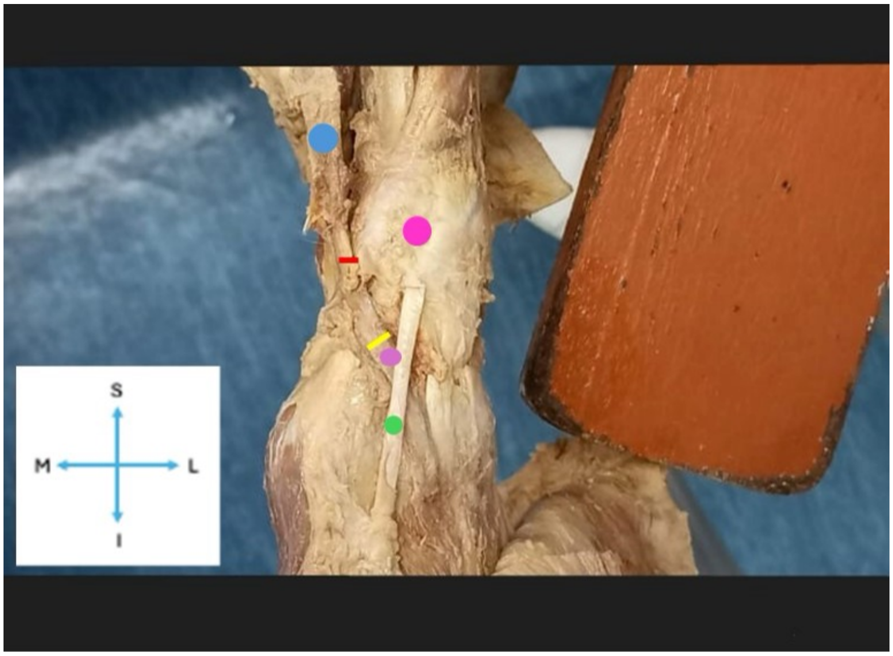

Figure 2: Measurement of radial artery at wrist joint (indicated by the red line) and in the anatomical snuffbox (indicated by the yellow line). Blue dot: Radial artery; Purple dot: Radial artery in the anatomical snuffbox; Pink dot: Extensor retinaculum; Green dot: Tendon of extensor pollicis longus muscle

3.3.3 Statistical analysis

The data was assessed for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Normally distributed data were presented as means and standard deviations (SD) and analysed using a T-test, Levene's test for equality of variances, and Pearson's correlation test. For non-normally distributed data, numerical measurements were presented as medians and interquartile ranges and analysed using the Mann-Whitney U test. Reliability was assessed using the intraclass correlation coefficient test. A p-value of ≤ 0.05 was considered statistically significant. All analyses were performed using IBM SPSS Statistics software (version 30).

3.4 Results

A total of thirty adult donor cadavers (n = 60 upper limbs) were used in this study. The reliability analysis revealed excellent consistency across the three attempts, with Cronbach's Alpha values ranging from 0.997 to 1.000. The inter-item correlations were consistently high and the intraclass correlation coefficients (ICCs) for both single measures and average measures confirmed the strong agreement between the attempts ($p < 0.001$).

The age of the adult donor cadavers ranged between 52 to 99 years, with an average age of 77 ± 11 years. The sample was predominantly female (53.3%), and all the donor cadavers in this study were of the White South African population group. The morphometric parameters of the radial artery are summarised according to laterality (Table 1) and sex (Table 2).

Table 1: Diameter and thickness of the radial artery according to laterality (mm)

Body side	Radial artery	Mean (±SD)		*P* value
		Male	Female	
Right side (External)	Point of origin	5.21 (2.23) *	4.56 (0.98) *	0.07
	Wrist joint	4.01 (0.72) *	3.79 (0.48) *	0.38
	Snuffbox	3.05 (0.82)	3.25 (0.89)	0.53
Left side (External)	Point of origin	4.73 (0.99)	5.40 (1.51)	0.16
	Wrist joint	3.89 (0.63) *	3.81 (0.69) *	0.59
	Snuffbox	3.11 (0.88)	3.47 (1.06)	0.32
Right side (Internal)	Point of origin	2.79 (0.68)	3.28 (0.89)	0.10
	Wrist joint	2.07 (0.77)	2.35 (0.71)	0.32
	Snuffbox	1.71 (0.64)	1.81 (0.74)	0.68
Left side (Internal)	Point of origin	2.90 (0.71)	3.00 (0.75)	0.71
	Wrist joint	2.08 (0.84)	2.33 (0.67)	0.37
	Snuffbox	1.72 (0.82)	1.74 (0.60)	0.94
Right side	Point of origin	1.22 (0.61)	0.97 (0.60)	0.28
(Thickness)	Wrist joint	0.75 (0.32)	0.84 (0.45)	0.55

	Snuffbox	0.63 (0.43) *	0.59 (0.51) *	0.69
Left side	Point of origin	1.20 (0.59)	0.92 (0.42)	0.14
(Thickness)	Wrist joint	0.82 (0.44)	0.89 (0.32)	0.63
	Snuffbox	0.86 (0.50)	0.69 (0.35)	0.29

*Median (IQR)

Table 2: Diameter and thickness of the radial artery according to sex (mm)

Radial artery		Mean (±SD)			*P* value
		Right side	Left side	Total	
External	Point of origin	4.95 (1.05) *	5.12 (1.70) *	5.02 (1.51) *	0.97
	Wrist joint	3.90 (0.76) *	3.88 (0.68) *	3.88 (0.71) *	0.99
	Snuffbox	3.14 (0.85)	3.28 (0.97)	3.21 (0.91)	0.56
Internal	Point of origin	3.02 (0.81)	2.95 (0.72)	2.98 (0.76)	0.73
	Wrist joint	2.20 (0.75)	2.20 (0.76)	2.20 (0.75)	0.98
	Snuffbox	1.76 (0.68)	1.73 (0.72)	1.75 (0.69)	0.90
Thickness	Point of origin	1.00 (0.60) *	0.92 (0.69) *	0.95 (0.67) *	0.97
	Wrist joint	0.80 (0.39)	0.86 (0.38)	0.83 (0.38)	0.52
	Snuffbox	0.62 (0.47) *	0.74 (0.57) *	0.67 (0.55) *	0.34

*Median (IQR)

Correlation

There was a strong correlation between the external diameter of the left radial artery in the anatomical snuffbox and the internal diameter of the left radial artery at the wrist joint ($r = 0.73$, $p < 0.001$). There was a strong correlation between the internal diameter of the left radial artery at the wrist joint and the internal diameter of the left radial artery at the point of origin ($r = 0.87$, $p < 0.001$), as well as the internal diameter of the right radial artery at the wrist joint ($r = 0.75$, $p < 0.001$).

There was a strong correlation between the internal diameter of the right radial artery in the anatomical snuffbox and the internal diameter of the right radial artery at the wrist joint ($r = 0.86$, $p < 0.001$). There was a strong correlation between the internal diameter of the left radial artery in the anatomical snuffbox and the internal diameter of the left radial artery at the wrist joint ($r = 0.82$, $p < 0.001$) and at the point of origin ($r = 0.78$, $p < 0.001$), as well as the internal diameter of the right radial artery in the anatomical snuffbox ($r = 0.72$, $p < 0.001$).

Sheath size

The internal diameter of the radial artery was less than 1.8mm in 33% of the sample at the wrist joint and in 50% of the sample in the anatomical snuffbox. The internal diameter of the radial artery ranged from 1.8mm to 2.6mm (which corresponds to a 5Fr regular sheath) in 32% of the sample at the wrist joint and in 38% of the sample in the anatomical snuffbox. Meanwhile, the internal diameter of the radial artery was between 2.6mm and 3.1mm (6Fr regular sheath) in 20% of the sample at the wrist joint and 8% in the anatomical snuffbox. The internal diameter of the radial artery was greater than 3.1mm in 15% of the sample at the wrist joint and in 3% of the sample in the anatomical snuffbox.

3.5 Discussion

The morphometric characteristics of the radial artery possess substantial clinical significance for cardiovascular interventions and neuro-interventions. Alasmari (2021) indicated that understanding the diameter of the radial artery is essential for enhancing the success rate during transradial coronary interventions. Al Talalwah, Getachew and Soames (2015) observed that clinicians must be cognizant of the diameter, thickness, and variability of the radial artery, as numerous surgical and invasive procedures are performed in the cubital region, which can help minimize iatrogenic complications. Nasr (2012) asserted that the diameter of the radial artery markedly influences the success of angiographic, graft replacement, catheterization, and bypass operations. Therefore, awareness of the diameter of the radial artery is crucial as it assists cardiologists and radiologists in selecting various sheath sizes during transradial coronary interventions and enhances microsurgical techniques. This present study aimed to document the morphometric characteristics in terms of the diameter of the radial artery at the point of origin, at the wrist joint, and in the anatomical snuffbox.

The findings of the present study on the external diameter of the radial artery at the point of origin contradict the findings of various authors as shown in cadaveric studies in Table 3. In our study, the external diameter of the radial artery was greater on the left side than the right side which coincides with the findings reported by Getachew, Astatkie and Lemma (2018).

Table 3: External diameter of the radial artery at the point of origin

Author (year)	Population	Sample size	Diameter (mm) of the radial artery			
			Body side (R: Right, L: Left)	Average	Sex	
					Male	Female
Nasr (2012)	Saudi Arabian	100	R: 3.07 (±0.49) L: 3.02 (±0.48)	-	R: 3.30 (±0.70) L: 3.30 (±0.70)	R: 3.07 (±0.50) L: 3.02 (±0.48)
Al Talalwah et al. (2015)	British	68	R: 3.52 (±0.85) L: 3.45 (±0.79)	3.48	R: 3.71 (±0.91) L: 3.63 (±0.84)	R: 3.25 (±0.69) L: 3.20 (±0.66)
Getachew et al. (2018)	Ethiopian	78	R: 4.40 (±1.26) L: 4.44 (±1.51)	-	R: 4.45 (±1.35) L: 4.41 (±1.50)	R: 4.36 (±1.18) L: 4.49 (±1.51)
Tariq et al. (2020)	Pakistani	84	R: 3.53 (±0.86) L: 3.46 (±0.78)	-	R: 3.26 (±0.68) L: 3.64 (±0.85)	R: 3.26 (±0.68) L: 3.21 (±0.67)
Mahajan, Shashank, Muthukrshnan, Verma and Razdan (2022)	Indian	30	R: 4.00 (±0.75) L: 3.80 (±0.76)	3.90	-	-

The findings of the present study on the external diameter of the radial artery at the wrist joint differs from the findings reported by various authors as shown in cadaveric studies in Table 4. Similarly, the external diameter of the radial artery at the wrist joint according to sex and laterality reported in the present study contrast with the findings of various authors in Table 4.

Table 4: External diameter of the radial artery at the wrist joint

Author (year)	Population	Sample size	Diameter (mm) of the radial artery			
			Body side (R: Right, L: Left)	Average	Sex	
					Male	Female
Nasr (2012)	Saudi Arabian	100	R: 2.76 (±0.49) L: 2.74 (±0.45)	-	R: 3.10 (±0.70) L: 3.10 (±0.73)	R: 2.76 (±0.49) L: 2.74 (±0.45)
Al Talalwah et al. (2015)	British	68	R: 3.36 (±0.78) L: 3.36 (±0.78)	3.60	R: 3.59 (±0.80) L: 3.62 (±0.82)	R: 3.04 (±0.64) L: 2.99 (±0.58)
Wessel, Hessel, Glaros and Olinger (2015)	-	140	R: 7.43 (±11.30) L: 7.75 (±11.80)	-	-	-
Yilmaz, Ozkul, Shin, Im, Yoon and Kim (2015)	Korean	20	R: 1.83 (±0.47) L: 1.71 (±0.50)	1.77 (±0.48)	-	-
Getachew et al. (2018)	Ethiopian	78	R: 3.24 (±0.79) L: 3.06 (±0.85)	-	R: 3.36 (±0.85) L: 3.10 (±0.78)	R: 3.10 (±0.73) L: 3.01 (±0.95)
Tariq et al. (2020)	Pakistani	84	R: 3.37 (±0.79) L: 3.37 (±0.77)	-	R: 3.05 (±0.65) L: 3.63 (±0.83)	R: 3.05 (±0.65) L: 2.98 (±0.59)
Alasmari (2021)	Saudi Arabian	16	-	-	R: 2.40 (±0.20) L: 2.10 (±0.60)	R: 2.50 (±0.30) L: 2.20 (±0.50)
Varalakshmi (2021)	Indian	40	-	2.79 (±0.68)	-	-
Mahajan et al. (2022)	Indian	30	R: 3.60 (±0.58) L: 3.16 (±0.17)	3.40	-	-
Ellis, Thibault, Lencke and Hemric (2025)	American (VA)	87	R: 3.15 (±0.59) L: 3.09 (±0.53)	3.12 (±0.56)	-	-

The findings of our study on the external diameter of the radial artery in the anatomical snuffbox differs from the findings reported by Haładaj, Wysiadecki, Dudkiewicz, Polgui and Topol (2018); Mahajan et al. (2022); and Wang et al. (2024) in which they reported a smaller average external diameter of the radial artery in the anatomical snuffbox in their cadaveric sample (Table 5). Mahajan et al. (2022) reported a smaller average external diameter of the radial artery in the anatomical snuffbox bilaterally within an Indian population compared to the findings of the present study.

Table 5: External diameter of the radial artery in the anatomical snuffbox

Author (year)	Population	Sample size	Diameter (mm) of the radial artery
Haładaj et al. (2018)	-	120	2.95 (±0.43)
Mahajan et al. (2022)	Indian	30	2.90
Wang et al. (2024)	-	26	2.53 (±0.73)
Present study	South African	60	3.21 (±0.91)

In the present study, the diameter of the radial artery decreased from the point of origin to the anatomical snuffbox. This finding coincides with the finding of Getachew et al. (2018) who reported that the size of the radial artery decreased from proximal (point of origin) to distal (anatomical snuffbox).

The internal diameter of the radial artery at the point of origin reported in this study differs from the findings reported by Al Talalwah et al. (2015); and Swetha, Vidya and Hema (2023) in which a larger average internal diameter of the radial artery at the point of origin was reported in the British and South Indian cadaveric studies respectively. Shima, Ohno, Michi, Egawa and Takiguchi (1996) reported a smaller internal diameter of the radial artery at the point of origin in a Japanese population compared to the findings of the present study.

Al Talalwah et al. (2015); Getachew et al. (2018); Tariq et al. (2020); and Barry, Gun, Chabry, Harmouche, Padurean et al. (2023) reported a larger average internal diameter of the radial artery at the point of origin bilaterally compared to the findings of the present study (Table 6). Mudiraj and Dhobale (2015) reported a smaller average internal diameter of the radial artery at the point of origin bilaterally compared to the findings of the present study. The average internal diameter of the radial artery at the point of origin in males, as reported in the present study bilaterally, was smaller than the findings of various authors (Table 6). The average internal diameter of the radial artery at the point of origin in females, as reported in the present study bilaterally, coincides with the findings of Al Talalwah et al. (2015); and Tariq et al. (2020).

Table 6: Internal diameter of the radial artery at the point of origin

Author (year)	Population	Sample size	Diameter (mm) of the radial artery			
			Body side (R: Right, L: Left)	Average	Sex	
					Male	Female
Shima et al. (1996)	Japanese	59	R: 2.30 (±0.60) L: 2.30 (±0.50)	2.30 (±0.50)	-	-
Mudiraj and Dhobale (2015)	Indian	90	R: 2.61 (±0.61) L: 2.59 (±0.64)	-	-	-
Al Talalwah et al. (2015)	British	68	R: 3.29 (±0.75) L: 3.22 (±0.80)	3.26	R: 3.58 (±0.68) L: 3.44 (±0.88)	R: 2.87 (±0.67) L: 2.90 (±0.54)
Getachew et al. (2018)	Ethiopian	78	R: 3.79 (±1.44) L: 3.79 (±1.78)	-	R: 3.66 (±1.65) L: 3.48 (±2.08)	R: 3.93 (±1.16) L: 4.17 (±1.29)
Tariq et al. (2020)	Pakistani	84	R: 3.28 (±0.76) L: 3.23 (±0.81)	-	R: 2.88 (±0.68) L: 3.45 (±0.89)	R: 2.88 (±0.68) L: 2.91 (±0.55)
Barry et al. (2023)	-	90	R: 3.16 (±0.56) L: 3.17 (±0.59)	-	-	-
Swetha et al. (2023)	South Indian	56	-	4.80	-	-
Present study	South African	60	R: 3.02 (±0.81) L: 2.95 (±0.72)	2.98 (±0.76)	R: 3.28 (±0.89) L: 3.00 (±0.75)	R: 2.79 (±0.68) L: 2.90 (±0.71)

The present study found the average internal diameter of the radial artery at the wrist joint to be 2.20 ± 0.75mm. As summarised in Table 7, our finding is larger than that reported by Prakash and Saniya (2014) in an Indian population, but smaller than the findings reported by Al Talalwah et al. (2015) in a British population. The findings of this study according to sex and laterality does not align with the findings reported by various authors in cadaveric studies in Table 7.

Table 7: Internal diameter of the radial artery at the wrist joint

Author (year)	Population	Sample size	Diameter (mm) of the radial artery			
			Body side	Average	Sex	
					Male	Female
Shima et al. (1996)	Japanese	59	R: 2.20 (±0.60) L: 2.20 (±0.60)	-	-	-
Prakash and Saniya (2014)	Indian	50	-	2.14 (±0.28)	-	-
Al Talalwah et al. (2015)	British	68	R: 3.06 (±0.58) L: 3.05 (±0.52)	3.55	R: 3.25 (±0.54) L: 3.25 (±0.50)	R: 2.80 (±0.54) L: 2.76 (±0.40)
Getachew et al. (2018)	Ethiopian	78	R: 2.79 (±1.10) L: 2.66 (±0.94)	-	R: 2.83 (±1.27) L: 2.56 (±1.06)	R: 2.71 (±0.65) L: 2.77 (±0.80)
Tariq et al. (2020)	Pakistani	84	R:3.07 (±0.59) L: 3.06 (±0.53)	-	R: 2.81 (±0.55) L: 3.26 (±0.51)	R: 2.81 (±0.55) L: 2.77 (±0.41)
Barry et al. (2023)	-	90	R: 2.62 (±0.66) L: 2.64 (±0.68)	-	-	-
Present study	South African	60	R: 2.20 (±0.75) L: 2.20 (±0.76)	2.20 (±0.75)	R: 2.35 (±0.71) L: 2.33 (±0.67)	R: 2.07 (±0.77) L: 2.08 (±0.84)

The internal diameter of the radial artery in the anatomical snuffbox reported in our study does not align with the findings of Swetha et al. (2023) as a larger internal diameter was reported in South Indian cadavers. Mudiraj and Dhobale (2015) reported a larger average internal diameter of the radial artery in the anatomical snuffbox bilaterally in an Indian population compared to the findings of the present study.

The thickness of the radial artery at the point of origin in our study differs from the findings of various authors in cadaveric studies as shown in Table 8. The radial artery thickness was greater on the right side in this study, which concurs with the finding of Getachew et al. (2018). Males exhibited a larger thickness of the radial artery at the point of origin compared to females bilaterally. This finding contradicts the findings reported by Al Talalwah et al. (2015) in which females exhibited a larger thickness of the radial artery bilaterally.

Table 8: Thickness of the radial artery at the point of origin

Author (year)	Population	Sample size	Thickness of the radial artery (mm)		
			Body side	Sex	
				Male	Female
Al Talalwah et al. (2015)	British	68	Right: 0.11 (±0.05) Left: 0.12 (±0.00)	Right: 0.06 (±0.11) Left: 0.09 (±0.02)	Right: 0.19 (±0.01) Left: 0.15 (±0.06)
Getachew et al. (2018)	Ethiopian	78	Right: 0.37 (±0.22) Left: 0.34 (±0.23)	Right: 0.37 (±0.22) Left: 0.29 (±0.91)	Right: 0.36 (±0.21) Left: 0.37 (±0.27)
Tariq et al. (2020)	Pakistani	84	Right: 0.12 (±0.06) Left: 0.13 (±0.00)	Right: 0.18 (±0.02) Left: 0.08 (±0.03)	Right: 0.18 (±0.02) Left: 0.16 (±0.07)

In this study, the average thickness of the radial artery at the wrist joint was 0.80 ± 0.39mm on the right side and 0.86 ± 0.38mm on the left side. This finding differs from the findings reported by Al Talalwah et al. (2015) in a British population, Getachew et al. (2018) in an Ethiopian population, and Tariq et al. (2020) in a Pakistani population (Table 9). The radial artery thickness was greater on the left side in the present study, which concurs with the findings of various authors, as shown in cadaveric studies in Table 9. Our study reported a larger average thickness of the radial artery at the wrist joint according to sex which differs from the findings reported by various authors in Table 9.

Table 9: Thickness of the radial artery at the wrist joint

Author (year)	Population	Sample size	Thickness of the radial artery (mm)		
			Body side	Sex	
				Male	Female
Al Talalwah et al. (2015)	British	68	Right: 0.15 (±0.10) Left: 0.16 (±0.13)	Right: 0.17 (±0.13) Left: 0.18 (±0.16)	Right: 0.12 (±0.05) Left: 0.12 (±0.09)
Getachew et al. (2018)	Ethiopian	78	Right: 0.25 (±0.22) Left: 0.28 (±0.24)	Right: 0.26 (±0.21) Left: 0.22 (±0.19)	Right: 0.25 (±0.23) Left: 0.35 (±0.28)
Tariq et al. (2020)	Pakistani	84	Right: 0.16 (±0.11) Left: 0.17 (±0.14)	Right: 0.13 (±0.06) Left: 0.19 (±0.17)	Right: 0.13 (±0.06) Left: 0.13 (±0.08)
Present study	South African	60	Right: 0.80 (±0.39) Left: 0.86 (±0.38)	Right: 0.75 (±0.32) Left: 0.82 (±0.44)	Right: 0.84 (±0.45) Left: 0.89 (±0.32)

The present study noted that the internal diameter of the radial artery was between 1.8mm and 2.6mm (which corresponds to a 5Fr sheath) in 32% of the sample at the wrist joint and in 38% of the sample in the anatomical snuffbox. Yilmaz et al. (2015) reported that a 5Fr sheath was safer for trans-radial catheterization based on their findings. Importantly, the sheath size suitability estimates presented in this study are derived from static and embalmed cadaveric measurements. While these findings provide useful anatomical baseline data, they must be interpreted cautiously when extrapolating to clinical practice. In vivo, arterial dimensions may be influenced by vasomotor tone, arterial elasticity, blood pressure, and procedural factors such as vasospasm.

Consequently, the small differences in the arterial calibre may assume greater procedural significance when the vessels approach critical sheath-to-artery ratios. Therefore, sheath selection in clinical settings should be individualized and guided by patient-specific assessment. Future studies incorporating ultrasound or angiographic measurements in living patients would provide valuable insight into sheath suitability under physiological conditions.

The differences in the radial artery diameter and thickness can be attributed to the demographics of the study population and the geographical location. The sex-based differences in the external diameter of the right radial artery at the point of origin, external diameter of the radial artery at the wrist joint (bilaterally), as well as the thickness of the right radial artery in the anatomical snuffbox differed from the findings of previous studies. This can be attributed to the non-normal distribution of these variables in this cohort, which contrasted with the normally disturbed data, underlying the means and standard deviation, reported by previous studies.

Limitations

The donors used in this study all belonged to the same ethnic group. Therefore, ethnicity-based differences in the external and internal diameters as well as the thickness of the radial artery could not be documented. The body donors were predominantly elderly, with an advanced mean age. Therefore, age-related vascular changes may have influenced the morphometric measurements obtained in this study. Furthermore, detailed clinical histories of the body donors were not available; therefore, the potential impact of comorbidities on the radial artery morphometry could not be assessed.

The embalming process can cause varying levels of tissue shrinkage or swelling, and the absence of physiological intravascular pressure may lead to the collapse of vessel lumens. As a result, absolute measurements of both the external and internal diameters may differ from those observed in in-vivo conditions. Cadaveric measurements should be interpreted as indictors of anatomical feasibility rather than definitive predictors of procedural safety in living patients.

3.6 Conclusion

This study investigated the morphometric parameters of the radial artery in a select adult donor cohort at the University of KwaZulu-Natal. Measurements of the external and internal diameters, along with the wall thickness, were taken at three anatomical sites: at the point of origin, at the wrist joint, and in the anatomical snuffbox bilaterally. The findings demonstrated a progressive distal tapering pattern, with the radial artery decreasing in size from the point of origin to the anatomical snuffbox. Notably, no significant differences were observed between sexes or laterality. The internal diameter measurements indicated that a 5 French sheath may be suitable for trans-radial interventions in approximately one-third of the sample at the wrist joint and slightly more in the anatomical snuffbox. The findings of the present study can contribute to the existing knowledge in this field and may assist clinicians during cardiovascular and neurological interventions within this select adult donor cohort.

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Funding statement

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Ethical approval

Institutional ethical approval was obtained from the ethics committee (BREC/00006978/2024). The authors hereby confirm that every effort was made to comply with all local and international ethical guidelines and laws concerning the use of human cadaveric donors in anatomical research.

Informed consent

For the dissemination of this research, written informed consent was secured from the University of KwaZulu-Natal's Body Donor Programme.

Data Availability

All the data are available from the corresponding author upon reasonable request.

Competing interest

The authors declare that they have no conflicts of interest.

CRediT authorship contribution statement

Aleisha J. Singh: All persons listed as authors have contributed substantially to the conceptualization, writing - original draft, writing – review and editing.

Rohen Harrichandparsad: All persons listed as authors have contributed substantially to the conceptualization, writing - original draft, writing – review and editing.

Lelika Lazarus: All persons listed as authors have contributed substantially to the conceptualization, writing - original draft, writing – review and editing.

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BRIDGING TEXT

From Chapter 3 to Chapter 4

Chapter 3 comprised a morphometric analysis of the radial artery at its point of origin, wrist joint and in the anatomical snuffbox. The data obtained provided an understanding of the external and internal diameter and wall thickness of the radial artery at three measurement points within a select sample of adult body donor South African cadavers.

CHAPTER 4
SCIENTIFIC MANUSCRIPT 3

Contributions of this chapter

This chapter is comprised of a scientific manuscript that investigated the origin of the radial artery in thirty adult cadaveric specimens. The results were compared to previous literature. The following manuscript has been published in a scientific journal.

Title: A cadaveric investigation of the radial artery origin and its anatomical variations

Authors: A. J. Singh, R. Harrichandparsad, L. Lazarus

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A cadaveric investigation of the radial artery origin and its anatomical variations

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ABSTRACT

Introduction: According to standard anatomical description, the radial artery typically originates as one of two terminal branches of the brachial artery within the cubital fossa. Despite the common embryological process of the upper limb arteries, there are anatomical variations in the origin of the radial artery such as the radial artery originating from the axillary artery or from the brachial artery in the arm. The present study aimed to investigate the origin of the radial artery within a select adult cadaveric South African sample.

Methods: A total of thirty adult cadaveric specimens (n 60 upper limbs) were dissected at the University of KwaZulu-Natal (BREC/00006978/2024).

Results: The radial artery originated from the brachial artery in the cubital fossa as per standard anatomical description in 90 % of the upper limb specimens. In 10 % of the sample, the aberrant radial artery originated from the axillary artery (four unilaterally, and one bilaterally in an 80-year-old male cadaver). The aberrant radial arteries originated an average 172 $\pm$ 20.81 mm above the inter-epicondylar line of the humerus, with external and internal diameters of 5.45 $\pm$ 1.71 mm, and 3.10 $\pm$ 0.70 mm respectively.

Conclusion: This study reports an incidence of 10 % of the sample in which the radial artery originated from the axillary artery. Knowledge of the variations in the origin of the radial artery within this select South African population may assist the clinician during coronary and neuro-interventional procedures.

1. Introduction

The radial artery is one of the terminal branches of the brachial artery at the neck of the radius in the cubital fossa [1,2]. The radial artery courses laterally in the forearm from the cubital fossa to the palm, where it terminates by anastomosing with the ulnar artery to form the deep palmar arch [1,2]. This standard anatomical pathway is crucial for numerous clinical procedures such as coronary artery bypass grafting, surgical flaps, and radial artery catheterization [3–6].

The study of the arterial variations of the upper extremity has a rich historical lineage beginning with von Haller's pioneering 18th century documentation of the arterial variations in the upper limb [7–9]. By the early 19th century, Friedrich Tiedemann had systematically examined the arterial configurations in his seminal work, "*Tabulae arteriarum corporis humani*", which included cases of high origin radial arteries [10].

Later in the 19th century, Richard Quain further refined the classifications of arterial variations, many of which remain crucial in modern anatomical literature [11]. In the mid-20th century, McCormack et al. [12] conducted one of the most comprehensive studies examining 750 upper extremities, which refined the classification of brachial and antebrachial arterial variations.

While the radial artery typically originates in the cubital fossa, it may exhibit high-origin deviations, arising from the axillary artery or the proximal part of the brachial artery [4,13–15]. To standardize the terminology for such variations, Rodriguez-Niedenfuhr et al. [16] proposed the term 'brachioradial artery,' a unified and precise nomenclature to describe the previously descriptive terminology for the following: radial artery originating from the brachial artery; high bifurcation of the brachial artery; radial artery originating from the axillary artery; double brachial artery; and continuance of the superficial brachial artery as the radial artery [2,17].

Hence, the term 'brachioradial artery' refers to the high origin of the radial artery [2,16,17]. However, the radial artery can exhibit a more

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distal origin which is under the pronator teres muscle [18,19]. The radial artery can even be absent [20–25]. The radial artery can even originate from the thoraco-acromial trunk [26,27]. The anatomical variations in the origin of the radial artery are caused during the embryological development of the upper limb arteries [2].

The incidence of high origin of the radial artery differs across study modalities and population demographics. Weathersby et al. [28] documented a 15.6 % variation in the origin of the radial artery in cadaveric (n = 249) and embryonic (n = 159) specimens. In contrast, Janevski et al. [29] reported a higher incidence (24.4 %) in angiographic studies. Knowledge of the variant origin of the radial artery is crucial during reconstructive surgeries, coronary and neurological interventions to prevent complications. This study aimed to investigate the origin of the radial artery within a select adult cadaveric South African sample.

2. Materials and methods

The present study consisted of thirty adult cadaveric specimens (n = sixty upper limbs) that were obtained from the Department of Clinical Anatomy at the University of KwaZulu-Natal, Durban, South Africa. Institutional ethical approval was granted (Reference number: BREC/00006978/2024). Embalmed adult cadaveric specimens of both sexes and White population group with no damage to the radial artery were included in this study. The method of dissection of the upper limb specimens was adapted from Detton and Tank [30].

The inter-epicondylar line of the humerus was defined as the transverse line connecting the medial and lateral epicondyles of the humerus. The axillary artery was defined as a vessel extending from the lateral border of the first rib to the inferior margin of the teres major muscle. The brachial artery was considered to begin distal to the teres major muscle. The transition point between the axillary and brachial arteries were demarcated by the lower border of the teres major muscle.

A radial artery was classified as arising from the axillary artery it its origin was proximal to the lower border of the teres major muscle. The relation between the vessel and the pectoralis minor muscle was noted. A brachial artery origin was classified when the radial artery emerged distal to the lower border of the teres major muscle.

The origin of the radial artery was classified relative to the inter-epicondylar line of the humerus as.

- Above the inter-epicondylar line: For these cases, the distance from the point of origin of the radial artery to the inter-epicondylar line of the humerus was measured using suture string. The external and internal diameters of the radial artery was measured at the point of origin.
- Below the inter-epicondylar line: For these cases, the level of origin of the radial artery was recorded relative to the anatomical landmarks on the radius bone.
- Along the inter-epicondylar line

All measurements were taken in triplicate using a digital vernier caliper. The course of the aberrant radial artery was noted.

2.1. Statistical analysis

Descriptive statistics were used to summarize the data. Numerical measurements were expressed using means and standard deviations (SD). The data was examined using Levene's test, and T-test. An intraclass correlation coefficient test was also conducted. A significant *p*-value of 0.05 was set. IBM SPSS Statistics V. 30 was used for the analysis.

3. Results

A total of sixty upper limb specimens (30 right and 30 left) from thirty embalmed adult cadaveric specimens were dissected and used in this study. The sample consisted of 53.3 % females, and 46.7 % males. Measurements showed excellent consistency across attempts, with a high inter-item correlation. The intraclass correlation coefficient confirmed strong agreement.

The radial artery originated below the inter-epicondylar line of the humerus in 54 upper limb specimens (27 right and 27 left upper limb specimens) (Table 1). In six upper limb specimens, the radial artery originated above the inter-epicondylar line of the humerus (3 right and 3 left upper limb specimens). The radial artery did not originate along the inter-epicondylar line of the humerus.

In the specimens (54 upper limbs) where the radial artery originated below the inter-epicondylar line of the humerus, the radial artery precisely originated from the lateral aspect of the arterial circumference of the brachial artery in the cubital fossa at the neck of the radius (Fig. 1) (Table 2).

In six upper limb specimens (3 right and 3 left upper limbs), where the radial artery originated above the inter-epicondylar line, the radial artery originated from the 3rd part of the axillary artery (i.e., the aberrant radial artery) in the axillary region (below the pectoralis minor muscle) (Fig. 2) (Table 2). In all six upper limb specimens, the aberrant radial artery originated from the medial aspect of the arterial circumference of the 3rd part of the axillary artery. As shown in Fig. 3 and 90 % of radial arteries originated in the cubital fossa, while 10 % originated from the axillary artery.

The median nerve crossed anteriorly to the point of origin of the aberrant radial arteries from the axillary artery. The aberrant radial arteries traversed laterally after its medial point of origin crossing the median nerve in the middle third of the arm (Fig. 4).

The aberrant radial arteries traversed deep to the biceps brachii muscle in the arm, and the bicipital aponeurosis as well as passed through the cubital fossa on the lateral side. There was no cubital crossover or arterio-arterial anastomoses in the cubital fossa. The main trunk also passed through the cubital fossa. The course of the aberrant radial artery followed standard anatomical descriptions as well as its relationship to other structures in the forearm (Fig. 5). The aberrant radial artery was observed in four (two male and two female) upper limbs unilaterally and bilaterally in one male cadaver with an average age of 78 $\pm$ 3 years.

The average distance between the point of origin of the aberrant radial artery and the inter-epicondylar line was 172 $\pm$ 20.81 mm. The average external diameter of the aberrant radial artery at the point of origin was 5.45 $\pm$ 1.71 mm, while the average internal diameter of the aberrant radial artery at the point of origin was 3.10 $\pm$ 0.70 mm.

4. Discussion

In this study, the radial artery originated in the cubital fossa in 90 % of the sample. This finding is similar to the findings reported by Nasr [31]; Agarwal et al. [32]; and Kadel et al. [33]. In 10 % of the sample, the radial artery originated from the axillary artery. This finding coincides with the findings of Karlsson and Niechajev [13]; Uglietta and Kadir [34]; Gonzalez-Compta [35]; Sargon and Celik [36]; Konarik et al. [37]; Waghmare et al. [38]; Daimi et al. [39]; Balachandra et al. [40]; Bidarkotimath et al. [31,41]; Yagain et al. [42]; Shiny et al. [43]; Haładaj et al. [17]; Kadel et al. [33]; Syed et al. [44]; Elizabeth and

Table 1
Origin of the radial artery in relation to the inter-epicondylar line of the humerus.

Relation to the inter-epicondylar line of the humerus	Body side		Total
	Right	Left	
Above the inter-epicondylar line	3 (5.00 %)	3 (5.00 %)	6 (10.0 %)
Below the inter-epicondylar line	27 (45.0 %)	27 (45.0 %)	54 (90.0 %)
Along the inter-epicondylar line	0 (0.00 %)	0 (0.00 %)	0 (0.00 %)
Total	30 (50.0 %)	30 (50.0 %)	60 (100 %)

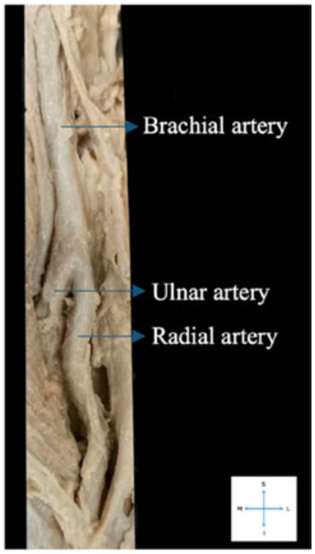

Fig. 1. Cadaveric dissection showing the origin of the radial artery in the cubital fossa. Key: S: Superior; I: Inferior; L: Lateral; and M: Medial.

Table 2
Site of origin of the radial artery.

Site of origin of the radial artery	Body side		Total
	Right	Left	
In the cubital fossa at the neck of the radius	27 (45.0 %)	27 (45.0 %)	54 (90.0 %)
From the axillary artery in the axillary region	3 (5.00 %)	3 (5.00 %)	6 (10.0 %)
Total	30 (50.0 %)	30 (50.0 %)	60 (100 %)

Vishwakarma [15]; Bundi et al. [4]; Barry et al. [45]; and Shilpa et al. [46] in which they reported high origin of the radial artery from the axillary artery as shown in Table 3.

Rodriguez-Niedenfuhr et al. [52] reported that the brachioradial artery was noted in 14 % of 112 human embryos. Brachial artery trifurcation was reported by Malcic-Gürbüz et al. [80]; Vollala et al. [81]; and Gupta et al. [82]; Clarke et al. [83]. In four cadavers, the radial artery originated from the axillary artery unilaterally which coincides with the findings of Konarik et al. [37]; Waghmare et al. [38]; Daimi et al. [39]; Balachandra et al. [40]; Yagain et al. [42]; Das et al. [67]; Kadel et al. [33]; Syed et al. [44]; Elizabeth and Vishwakarma [15]; Bundi et al. [4]; Barry et al. [45], and Shilpa et al. [46] in which the radial artery originated from the axillary artery unilaterally (Table 3).

In an 80-year-old male cadaver, the radial artery originated from the axillary artery bilaterally. Okoro and Jiburum [53] reported that the radial artery originated bilaterally from the medial side of the axillary artery in a Nigerian male cadaver. Whilst, Ghosh et al. [63] reported bilateral high origin of the radial artery (10.5 cm below the lower border of the teres major muscle on the medial side of the brachial artery) in a 60-year-old male cadaver.

In this study, the aberrant radial arteries originated 172 $\pm$ 20.81 mm from the point of origin to the inter-epicondylar line of the humerus. Mudiraj and Dhobale [3]; Reddy et al. [69]; Sucharitha et al. [71]; Gandhi and Lakshmi [72]; Clarke et al. [77]; Sophia et al. [78]; Rathi [79] reported shorter distances of the high origin radial artery from the point of origin to the inter-epicondylar line. Whilst Gandhi and Lakshmi [72]; Haładaj et al. [17]; Alves et al. [75] reported longer distances from the point of origin to the inter-epicondylar line.

Embryologically, the definitive right subclavian artery is derived from three structures viz., the right fourth arch (the aortic sac connected to this arch is modified to form the brachiocephalic artery – which is also known as the innominate artery), right dorsal aorta (a short segment), and the right seventh intersegmental artery [84,85]. The left subclavian artery is derived from the left seventh intersegmental artery [84]. When the subclavian artery passes the lateral border of the first rib, it becomes known as the axillary artery [85].

As described by Schoenwolf et al. [84], the radial, ulnar, and median arteries develop moderately as sprouts from the axis or axial artery which develops along the central axis of the limb bud. Similarly, Singh [86] indicates that the radial and ulnar arteries develop as sprouts from the axis or axial artery. Wacker et al. [87] states that the axial artery is a continuation of the sixth cervical segmental artery. The axial artery forms the axillary, brachial, and the anterior interosseous arteries as well as the deep palmar arch [75,84,86–88].

The radial artery initially has a more proximal origin (as the superficial brachial artery which arises from the axillary artery) than the ulnar artery as it crosses the median nerve anteriorly and supplies the biceps brachii muscle which is located in the anterior compartment of the arm [59,87,88]. Subsequently, a new connection is established between the radial artery (i.e., the superficial brachial artery) and the main trunk at or near the origin of the ulnar artery [75,88]. As a result, the upper portion of the radial artery's original stem (the superficial brachial artery) normally disappears and the radial artery remains [75,87,88].

If the original stem (i.e., the superficial brachial artery) or the

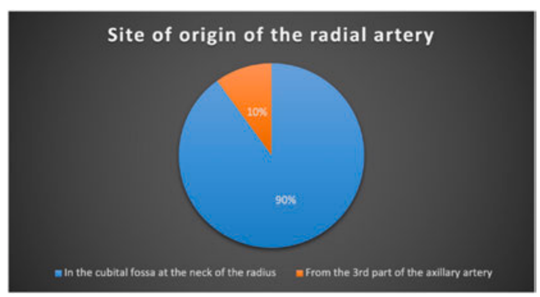

Fig. 3. Distribution of site of origin of radial artery.

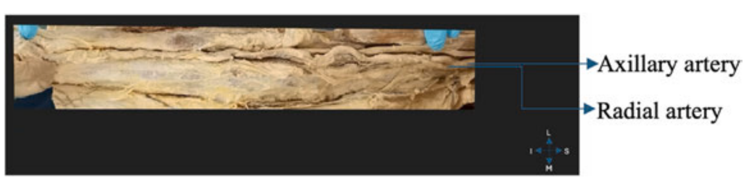

Fig. 2. Cadaveric dissection of high origin of the radial artery in the axilla. Key: S: Superior; I: Inferior; L: Lateral; and M: Medial.

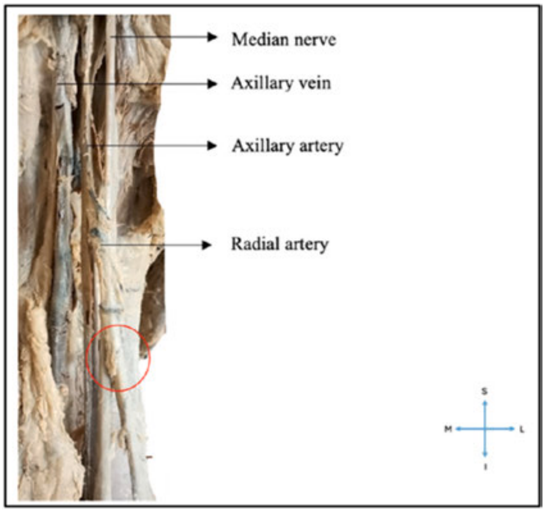

Fig. 4. Cadaveric dissection of aberrant radial artery crossing the median nerve (indicated by the red circle). Key: S: Superior; I: Inferior; L: Lateral; and M: Medial.

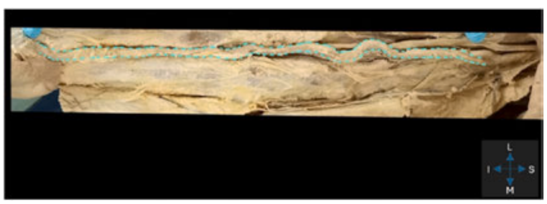

Fig. 5. Cadaveric dissection of the course of the aberrant radial artery (indicated by the turquoise dotted line). Key: S: Superior; I: Inferior; L: Lateral; and M: Medial.

proximal part of the radial artery fails to disappear, or if remodeling of the arterial system is incomplete then this can result in the radial artery arising from the axillary artery or higher up from the brachial artery in the arm [84]. Similarly, if the radial artery (initially known as the superficial brachial artery) fails to establish a connection with the brachial artery, then the connection between superficial brachial artery and the axillary artery will be retained – causing the radial artery to arise from the axillary artery.

Thus, the occurrence of variations in the origin of the radial artery can mainly be attributed to the embryological development of the upper limb arteries. The variations in the origin of the radial artery can also be attributed to smooth muscle-endothelial interactions, foetal position in the uterus, nutritional demands, hemodynamics, chemical factors, and genetics [4,32,67,63,75,64,73].

There was a high incidence of the radial artery originating from the axillary artery (high origin of the radial artery) in this select South African sample as compared to previous reports in which one case was report or it accounted for 1.11–6.7 % of the sample [4,15,33,42,44–46,67]. Clinicians, radiologists, and surgeons need to be aware of the possibility of variations in the origin and course of the radial artery before planning invasive procedures to prevent radiological misdiagnosis and mistaken anesthetic applications as the radial artery is closely related to the cephalic vein when its arises from the axillary artery [35,44,67,63,75,64,68,89].

Knowledge of the variations in the origin of the radial artery is crucial while planning vascular and reconstructive surgeries, coronary interventions, orthopedic surgeries, neuro-interventional procedures, during radiological and angiographic diagnostic procedures, and therapeutic procedures [9,32,37,38,40,44,67,63,69,71,72,75,49,54,64,68,73,76,89,90]. The variant anatomy of the radial artery may compress the median nerve, potentially mimicking radiculopathy or neuropathy symptoms [73,57].

For surgeons, clinicians, and radiologists recognizing the common arterial patterns and incidence of arterial variations in the upper limb is crucial, as precise vascular knowledge is fundamental when conducting invasive interventions in specific anatomical regions [16]. Aberrant arterial anatomy in the cubital fossa may lead to challenges during surgeries such as biceps brachii repair [90,91]. The high origin variants of the radial artery create challenges for radial forearm free flaps due to their proximity to common intravenous insertion points [32].

When the radial artery originates higher in the mid-arm, it can create difficulties and increase the risk of complications during certain medical procedures as well as make cannulation and arterial line placement more challenging due to the atypical anatomical position [17,79]. The elongated course associated with a high origin radial artery raises the risk of complications, including thrombosis, occlusion, or vasospasm [79]. The superficial anatomical position of the radial artery makes it susceptible to trauma-related injuries [68].

According to Bondage et al. [64], an angiogram before catheter advancement is mandatory to identify anatomical variants so there is no resistance to the catheter or guide wire. The superficial course of the radial artery can be mistaken for a vein and lead to accidental injection of drugs which results in amputation and tissue gangrene [38–40,67,64,68,49,54,90]. The variant position of the bifurcation of the brachial artery can make identifying the artery and catheterization difficult [75,90].

4.1. *Study limitations*

The number and distribution patterns of the radial recurrent branches were not recorded, and classification of the superficial and deep palmar arches were not documented as these parameters fell outside the scope of this study.

5. Conclusion

The authors reported that the radial artery originated from the brachial artery in the cubital fossa in 90 % of the sample. In 10 % of the sample (five cadavers), the radial artery originated from the axillary artery. In four cadavers, the radial artery originated unilaterally from the axillary artery, while in one cadaver it was a bilaterally occurrence. Knowledge of the variations in the origin of the radial artery within this select South African sample may assist the clinician during coronary and neuro-interventional procedures.

CRediT authorship contribution statement

Aleisha J. Singh: Writing – review & editing, Writing – original draft, Conceptualization. **Rohen Harrichandparsad:** Writing – review & editing, Writing – original draft, Conceptualization. **Lelika Lazarus:** Writing – review & editing, Writing – original draft, Conceptualization.

Informed consent statement

Written informed consent was obtained from the University of KwaZulu-Natal's Body Donor Programme to report this study. A copy of the written consent is available for review by the Editor-in-Chief of this journal on request. The authors state that every effort was made to follow all local and international ethical guidelines and laws that pertain to the use of human cadaveric donors in anatomical research.

Table 3
Variations in the origin of the radial artery.

Author (year)	Population	Modality	Sample size	Variations in the origin of the radial artery
McComarck et al. [12]	–	Cadaveric	750	• High origin of the radial artery was noted in 2.13 % of cases (16 limbs). • The radial artery originated in the proximal fourth of the arm in 6.8 % of the sample. • The radial artery originated from the mid of the forearm in 4.13 % of the sample. • The radial artery originated from the third quarter of the forearm in 0.67 % of the sample. • The radial artery originated from the distal fourth of the forearm in 0.54 % of the sample.
Karlsson and Niechajev [13]	–	Imaging (angiography)	231	• High origin of the radial artery was reported in eight patients. • In one out of the eight cases, the radial artery originated from the axillary artery. • In five out of the eight cases, the radial artery originated from the proximal third of the brachial artery. • In two out of the eight cases, the radial artery originated from the middle third of the brachial artery.
Uglietta and Kadir [34]	–	Imaging (arteriograms)	100	• In 2 % of the sample, the radial artery originated from the axillary artery.
Gonzalez-Compta [35]	–	Cadaveric	1	• High origin of the radial artery from the axillary artery bilaterally in a 65-year-old male cadaver.
Golan et al. [47]	–	Cadaveric	4	• High division of the brachial artery was noted in 4 cadavers that gave rise to the radial and ulnar arteries in the medial bicipital sulcus.
Sargon and Celik [36]	–	Cadaveric	1	• The radial artery originated from the axillary artery proximal to the humeral intercondylar line.
Içten et al. [48]	–	Cadaveric	1	• High origin of the radial artery was noted. • The radial artery branched 2 cm superior to the confluence point of the median nerve's two roots on the right side. • On the left side, the radial artery branches from the brachial artery 3 cm distal to the profunda brachii artery's origin.
Sargon et al. [49]	–	Cadaveric	1	• The radial artery originated from the brachial artery on the medial side 16.7 cm below the coracoid process in the right upper extremity.
Sachin and Seelig [50]	–	Cadaveric	1	• The superficial radial artery originated from the brachial artery in the left upper limb and from the axillary artery in the right upper limb.
Celik et al. [51]	–	Imaging (arteriogram)	81	• High origin of the radial artery from the brachial artery was noted in 87.5 % of all variations.
Rodriguez-Niedenfuhr et al. [52]	–	–	224 (embryos)	• The brachioradial artery was noted in 14 % of the sample.
Rodriguez-Niedenfuhr et al. [16]	–	Cadaveric	384	• The brachioradial artery was noted in 13.8 % of the sample (53 specimens). • The brachioradial artery originated from the axillary artery in 23 % of cases (12 out of 53 specimens). • The brachioradial artery originated from the upper one-third of the brachial artery in 65.4 % of cases (34 out of 53 specimens). • The brachioradial artery originated from the middle one-third of the brachial artery in 7.7 % of cases (4 out of 53 specimens). • The brachioradial artery originated from the inferior one-third of the brachial artery in 3.9 % of cases (2 out of 53 specimens). • The origin of the brachioradial artery could not have been determined in 1 specimen.
Okoro and Jiburum [53]	Nigerian	Cadaveric	1	• The radial artery originated bilaterally from the anterior part of the axillary artery on the medial side in a male cadaver.
Rodriguez-Niedenfuhr et al. [7]	–	–	480	• The brachioradial artery was noted in 14.2 % (62 upper limbs) of the sample.
Sarikcioglu and Yildirim [54]	Turkish	Cadaveric	1	• The radial artery originated from the brachial artery near the middle third of the humerus on the right upper extremity of a male cadaver.
Coskun et al. [55]	–	Cadaveric	1	• The superficial brachial artery originated from the third part of the axillary artery in a 50-year-old male cadaver on the left side.
Loukas et al. [26]	–	Cadaveric	1	• The radial artery originated from the thoraco-acromial trunk.
Yoo et al. [56]	Korean	Imaging (angiogram)	1103	• High origin of the radial artery was reported in 2.4 % of the sample. • Double radial artery was reported in 0.2 % of the sample.
Pelin et al. [57]	–	Cadaveric	1	• On the right side of a male cadaver, the radial artery originated from the medial side of the brachial artery.
Valsecchi et al. [58]	–	Imaging (angiography)	505	• Abnormal origin of the radial artery was noted in 8.3 % of 505 patients.
Yang et al. [59]	Korean	Cadaveric	304	• The superficial brachial artery had an axillary origin in 12.2 % of the sample. • In 8.9 % of the 12.2 %, the superficial brachial artery gave rise to the radial and ulnar arteries in the cubital fossa. • In 2.3 % of the 12.2 %, the superficial brachial artery continued as the radial artery in the forearm. • In 1.0 % of the 12.2 %, the superficial brachial artery ended in the upper arm.
Konarik et al. [37]	Czech	Cadaveric	80	• The radial artery originated from the 3rd part of the axillary artery in a left upper limb of a male cadaver.
Lo et al. [60]	British	Imaging (arteriography)	1540	• High bifurcating radial origin was reported in 7.0 % of the sample. • A radial artery loop was reported in 2.3 % of the sample.
Madhyastha et al. [61]	Indian	Cadaveric	1	• The radial artery originated in the upper third of the arm in a right female upper limb.
Waghmare et al. [38]	Indian	Cadaveric	1	• The radial artery originated from the 2nd part of the axillary artery in a left upper limb of a male cadaver.
Bhanu et al. [62]	Indian	Cadaveric	1	• The brachioradial artery originated from the brachial artery in the middle of the arm in a right upper extremity of a 52-year-old male cadaver.
Daimi et al. [39]	–	Cadaveric	1	• The radial artery originated from the second part of the axillary artery in the right upper limb of a male cadaver.

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Table 3 (*continued*)

Author (year)	Population	Modality	Sample size	Variations in the origin of the radial artery
Zhan et al. [14]	Singaporean Chinese	Cadaveric	1200	• The brachioradial artery originated from the medial side of the upper 1/3rd of the brachial artery in a male right upper limb. • The brachioradial artery was present in both the right and left upper limbs of a female cadaver and originated from the upper 1/3rd of the brachial artery.
Balachandra et al. [40]	–	Cadaveric	1	• The radial artery originated from the third part of the axillary artery in a left upper limb of a male cadaver.
Bidarkotimath et al. [41]	–	Cadaveric	100	• In one case, the radial artery originated from the axillary artery.
Bidarkotimath et al. [8]	–	Cadaveric	100	• The radial artery originated from the 2nd part of the axillary artery in a 30-year-old male cadaver. • In two cases, the radial artery originated from the brachial artery in the middle of the arm.
Nasr [31]	Saudi Arbian	Cadaveric	100	• High origin of the radial artery was noted in 8 % of the sample (8 limbs). • In four limbs, the radial artery originated from the medial side of the upper third of the brachial artery. • In three limbs, the radial artery originated from the lateral side of the upper part of the brachial artery. • In one limb, the radial artery originated from the anterior aspect of the second part of the axillary artery.
Yagain et al. [42]	–	Cadaveric	1	• The radial artery originated from the 3rd part of the axillary artery in a right upper limb of a female cadaver.
Ghosh et al. [63]	–	Cadaveric	1	• The radial artery originated 10.5 cm below the lower border of the teres major muscle from the medial side of the brachial artery. This was a bilateral occurrence.
Shiny et al. [43]	–	Cadaveric	1	• The superficial brachioradial artery originated from the 3rd part of the axillary artery in a right upper limb of a female cadaver.
Bondage et al. [64]	Indian	Cadaveric	1	• The radial artery originated from the brachial artery in the proximal 1/3rd of the right upper limb of a male cadaver.
Hassan et al. [65]	Egyptian	Imaging (arteriography)	650	• High bifurcating radial origin was reported in 6.2 % of the sample. • A full radial loop was reported in 1.2 % of the sample.
Mudiraj and Dhobale [3]	–	Cadaveric	90	• High origin of the radial artery was noted in 3 specimens. • High origin of the radial artery from the brachial artery was noted in 12 specimens.
Ostojić et al. [66]	–	Imaging (angiography)	602	• High origin of the radial artery was noted in 5.1 % of the sample.
Agarwal et al. [32]	Indian	Cadaveric	16	• The radial artery originated from the third part of the axillary artery in 3.12 % of the sample.
Das et al. [67]	Indian	Cadaveric	1	• The radial artery originated from the 3rd part of the axillary artery in a left upper limb of a male cadaver.
Deepa and Martin [68]	–	Cadaveric	102	• The radial artery originated from the brachial artery in the mid-arm on the right side in a 65-year-old male cadaver. • The radial artery originated from the trifurcation of the brachial artery at mid-arm level on the left side in a 65-year-old male cadaver.
Lee et al. [27]	Korean	Cadaveric	1	• The radial artery originated from the thoraco-acromial artery in the right upper limb of a 73-year-old male cadaver.
Reddy et al. [69]	–	Cadaveric	32	• The radial artery originated from the brachial artery in the middle of the arm 6.5 cm above the intercondylar line of the humerus in the left upper extremity of two male cadavers. • The radial artery originated from the brachial artery 7.2 cm above the intercondylar line of the humerus in the right upper extremity of a female cadaver.
Rao and Rao [70]	–	Cadaveric	1	• The radial artery originated from the brachial artery in the middle third of the right arm in a middle-aged male cadaver.
Sucharitha et al. [71]	Indian	Cadaveric	1	• The radial artery originated from the brachial artery 60 mm above the inter-epicondylar line of the humerus in a right upper extremity of a female cadaver.
Wysiadecki et al. [19]	–	Cadaveric	1	• The radial artery in right upper limb, originated deep to the pronator teres muscle.
Gandhi and Lakshmi [72]	Indian	Cadaveric	18	• High origin of the radial artery was noted in two right upper extremities. • The radial artery originated from the right brachial artery on the anteromedial surface 13.5 cm above the intercondylar line. • The radial artery originated from the right brachial artery on the anteromedial surface 19.0 cm above the intercondylar line
Haładaj et al.[17]	–	Cadaveric	120	• High origin of the radial artery was reported in 9.2 % of the sample (11 upper limb specimens). • In two cases, the radial artery originated from the axillary artery. • In nine cases, the radial artery originated from the brachial artery.
Lalitha and Devi [73]	–	Cadaveric	96	The radial artery originated from: • the 3rd part of the axillary artery in two upper limb specimens • from the medial side of the brachial artery in the middle of the arm bilaterally in one cadaver • from the lateral side of the brachial artery in the middle of the arm in one upper limb specimen
Polfer et al. [74]	–	Imaging (angiograms)	26	• The radial artery originated from the axillary artery in three patients. • The radial artery originated from the proximal part of the brachial artery in two patients. • The radial artery originated at the mid-brachium in five patients.
Kadel et al. [33]	Nepali	Cadaveric	53	The radial artery originated from: • the axillary artery in 1.88 % of the sample (one upper limb specimen), • the upper 1/3rd of the arm in 5.66 % of the sample (three upper limb specimens), • from the middle third of the arm (as the brachioradial artery) in 3.77 % of the sample (two specimens), and • the lower part of the arm in 1.88 % of the sample (one specimen).

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Table 3 (*continued*)

Author (year)	Population	Modality	Sample size	Variations in the origin of the radial artery
Sharma et al. [9]	–	Cadaveric	12	• The radial artery originated from the brachial artery in the middle third of the arm in one right upper extremity. • The radial artery originated from the brachial artery in the upper third of the arm in one right upper extremity.
Syed et al. [44]	–	Cadaveric	1	• The radial artery originated from the 3rd part of the axillary artery on the right side of a cadaver.
Alves et al. [75]	–	Cadaveric	1	• The radial artery originated from the brachial artery in the upper 1/3rd of the right arm in a male cadaver.
Chauhan and Yadav [76]	–	Cadaveric	1	• The radial artery originated from the brachial artery in the proximal 1/3rd of the left arm in a male cadaver.
Clarke et al. [77]	–	Cadaveric	1	• The brachioradial artery originated in the distal 16 % of the arm's length in a right upper limb.
Elizabeth and Vishwakarma [15]	–	Cadaveric	51	The radial artery originated from: • the axillary artery (left side) in one upper limb, • the brachial artery at the midarm level (left side) in one upper limb, and • the brachial artery in the proximal part of the arm (right side) in two upper limbs.
Sophia et al. [78]	Indian	Cadaveric	48	• The radial artery originated from the brachial artery above the intercondylar line of the humerus in three upper extremities. • In one upper limb, the radial artery originated from the pentafurcation of the brachial artery.
Bundi et al. [4]	Kenyan	Cadaveric	62	• High origin of the radial artery was reported in eight upper limbs. • The radial artery originated from the middle third of the brachial artery in four upper extremities. • In one upper extremity, the radial artery originated from the brachial artery below the lower border of the teres major muscle. • In one upper extremity, the radial artery originated from the brachial artery at the same level as the profunda brachii artery. • Two out of the eight (one left and right side), originated from the 3rd part of the axillary trunk.
Barry et al. [45]	–	Cadaveric	90	• High origin of the right radial artery (arising from the axillary artery) was reported in 1.11 % of the sample. • This was found in a female.
Rathi [79]	Indian	Cadaveric	1	• High origin of the radial artery in the mid-arm was noted in one specimen approximately 70 mm proximal to the elbow crease.
Shilpa et al. [46]	Kerala	Cadaveric	60	• High origin of the radial artery (from the axillary artery) was reported in 6.70 % of the sample. • Found in two female (one left and right side) and two male (two right sides) upper limbs.

Editor-conflict-of-interest statement

Given their role as editor/editorial board member, Prof Lazarus had no involvement in the peer-review of this article and has no access to information regarding its peer-review.

Ethical statement

Ethical approval was obtained from the institutional ethics committee (BREC/00006978/2024).

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Declaration of competing interest

The authors declare that they have no conflicts of interest to report.

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BRIDGING TEXT

From Chapter 4 to Chapter 5

Chapter 4 outlined an analysis of the origin of the radial artery and its anatomical variations in 30 cadavers. The data obtained provided an understanding of the origin of the radial artery and the embryological basis of the anatomical variations in the origin of the radial artery.

CHAPTER 5
SYNTHESIS

Contributions of this chapter

This chapter elaborates on and discusses the main findings of Chapters 2, 3 and 4, along with their potential impact. It also compares the present study with relevant literature. Additionally, it outlines the limitations encountered during the research and suggests areas for future investigation.

5.1 Synthesis

The radial artery has become more frequently utilised in neuro-interventional procedures due to its association with lower complication rates and cost-effectiveness (Brunet, Chen, Sur, McCarthy, Snelling et al., 2019). Although the distal radial artery is smaller, there is no need to downsize the sheath intended for use to accommodate the size of the distal radial artery (Narsinh, Mirza, Caton, Baker, Winkler et al., 2021). The use of ultrasound guidance during transradial access for neurointerventional procedures leads to a higher success rate, shorter duration, reduced attempts, reduced crossover rates, efficiency of radial artery cannulation and reduced occurrence of complications (such as radial artery occlusion) (Seto, Roberts, Abu-Fadel, Czak, Latif et al., 2015; Pitta and Prasad, 2020; Bhatia, Kumar and Arafath, 2023). Despite extensive documentation of the variations in the origin of the radial artery, there is sparse literature regarding the origin of the radial artery within the South African population. Similarly, morphometric data about the radial artery and its distal segment in the African population are scarce. This study, therefore, aimed to document the anatomical characteristics of the radial artery and its distal segment within a select South African population.

This study comprises three manuscripts. The first manuscript analysed the diameter of the distal forearm and snuffbox radial arteries in 128 adult and 128 paediatric patients, as well as the factors that affect the diameter, such as occupational environment, smoking, hypertension, diabetes mellitus, BMI, BSA, weight, height, wrist circumference and shoe size. The sheath size was recorded based on the diameter of the distal forearm and snuffbox radial arteries. The second manuscript analysed the morphometry of the radial artery along three points, namely at the point of origin, at the wrist joint and in the anatomical snuffbox, in 30 adult cadavers. The sheath size was also recorded based on the diameter of the radial artery at the wrist joint and in the anatomical snuffbox. The third manuscript analysed the origin of the radial artery in 30 adult cadavers.

5.1.1 Manuscript 1 – An anatomical investigation of the distal forearm and snuffbox radial arteries in a select South African population

Within subset A, the average DFRA and SRA were smaller compared to the literature reviewed. The range of the average diameter of the DFRA reported in subset A aligned with the range reported in the consulted literature. Females exhibited a smaller diameter of the DFRA compared to males, which aligned with the findings of the literature reviewed. Previous studies reported larger average diameters of the DFRA bilaterally compared to the findings of the present study; however, Domagała, Grzelak, Pospiech, Hunter, Klakowski et al. (2021) reported a smaller bilateral diameter of the DFRA compared to the present study.

The average diameter of the SRA bilaterally in the present study diverged from the findings of the literature reviewed. The average diameter of the DFRA and SRA bilaterally according to sex in the present study was smaller than the findings reported by Deora, Sharma, Choudhary, Kaushik, Garg et al. (2022) and Lee, Son, Go, Kang, Lee et al. (2022) in an Indian and Korean population, respectively. The present study noted that the average diameter of the DFRA was statistically larger in males bilaterally, which agreed with the findings of Kotowycz, Johnston, Ivanov, Asif, Almoghairi et al. (2014) in a Canadian population. Similarly, the average diameter of the SRA was statistically larger in males bilaterally, which coincided with the findings reported by Deora et al. (2022) and Lee et al. (2022).

While sex-based differences were consistently observed, with males demonstrating larger DFRA and SRA diameters, the overall calibre of the vessels in this South African cohort remained comparatively smaller. These findings may be attributed to the differences in the anthropometric characteristics, genetic diversity, and the prevalence of comorbidities within the present cohort relative to the populations described in international studies. Notably, the absence of significant ethnic variation within the present cohort contrasts with some international studies that report inter-ethnic differences in the diameter of the radial artery. This may be attributed to the unequal distribution of the participants across ethnic groups in the present study. The geographical and socioeconomic factors influencing cardiovascular health and early vascular ageing may also contribute to the differences when compared to high-income country cohorts.

The average diameter of the DFRA was larger than the average diameter of the SRA and concurred with the findings of Norimatsu, Kusumoto, Yoshimoto, Tsukamoto, Kuwano et al. (2019) and Hadjivassiliou, Cardarelli-Leite, Jalal, Chung, Liu, Ho and Klass (2020) while contradicting the findings reported by Naito, Sawaoka, Sasaki, Iida, Sakuraba et al. (2019) and Hammami, Zouari, Ben Abdessalem, Sassi, Ellouze et al. (2021). The average diameter of the DFRA was larger bilaterally in patients who described their occupational environment as a quiet environment, as opposed to the findings of Aykan, Hatem, Kalaycıoğlu, Altıntaş Aykan, Gökdeniz et al. (2015). The average diameter of the DFRA was larger in non-hypertensive patients on the right side and in hypertensive patients on the left side. The findings of Ashraf, Panhwar, Habib, Memon, Shamsi and Arif (2010) and Deora et al. (2022) partly coincide with the findings of the present study, as non-hypertensive patients had a larger average diameter of the DFRA on the right side only. However, the findings of this study partially contradict the findings of Beniwal, Bhargava and Kausik (2014) and Shlimon, Lindenberger, Welander, Dangardt and Bjarnegård (2022), who reported that hypertensive patients had a larger diameter of the radial artery compared to non-hypertensive patients.

The average diameter of the DFRA was larger in diabetic patients than in non-diabetic patients in this study, which differed from the findings reported by Ashraf et al. (2010), Beniwal et al. (2014), Yilmaztepe and Yilmaz (2018) and Deora et al. (2022), who reported that non-diabetic patients had a larger average diameter of the radial artery compared to diabetic patients. The average diameter of the SRA was larger in diabetic patients than in non-diabetic patients, which contradicted the findings of Deora et al. (2022). The average diameter of the SRA was larger in smokers than in non-smokers, which concurred with the findings of Deora et al. (2022). The average diameter of the DFRA was larger in smokers than in non-smokers, which concurred with the findings of Ashraf et al. (2010) and Deora et al. (2022), but differed from the findings of Shlimon et al. (2022).

Although statistically significant differences in the diameter were not consistently observed between hypertensive and non-hypertensive patients, diabetic and non-diabetic patients, and smokers and non-smokers in this study, the potential structural impact on the arterial wall of these conditions should be taken into consideration. Chronic hypertension has been associated with medial hypertrophy, increased collagen deposition, and reduced arterial compliance, while diabetes mellitus has been associated with endothelial dysfunction, intimal hyperplasia, and accelerated atherosclerosis (Hadi and Suwaidi, 2007; Kim, 2023; Cheraghi, Karimi, Sedighi, and Jabarzare, 2025). Similarly, smoking has been associated with endothelial injury, inflammatory changes and increased arterial stiffness (Messner and Bernhard, 2014). These pathological changes may not always result in measurable changes in the diameter of the DFRA and SRA by ultrasound imaging; however, they may influence the mechanical properties of the arterial wall.

From a procedural perspective, these microstructural changes may make a patient more susceptible to spasm of the radial artery, intimal injury, thrombosis, and post-procedural radial artery occlusion during transradial access. Moreover, medial calcification and subclinical atherosclerotic changes may also contribute to the reduced elasticity of the artery, which may increase the resistance to sheath insertion and catheter manipulation. Therefore, even in the absence of statistically significant morphometric differences in this cohort, clinicians should remain cognizant of the potential impact of these comorbidities on procedural planning and risk stratification.

There was a statistically significant positive correlation between BSA and the average diameter of the DFRA, which agreed with the findings of Kotowycz et al. (2014) and Lee, Kim, Kim, Lee, Lee and Kwak (2016). There was no significant correlation between BMI and the average diameter of the DFRA, which agreed with the findings of Ashraf et al. (2010), Beniwal et al. (2014), Aykan et al. (2015), Dharma, Kedev, Patel, Rao, Bertrand and Gilchrist (2017) and Yilmaztepe and Yilmaz (2018), while contradicting the findings of Kotowycz et al. (2014) and Domagała et al. (2021).

This study reported no significant correlation between BMI and the average diameter of the SRA, which contradicts the findings of Norimatsu et al. (2019). There was no significant correlation between weight and the average diameter of the DFRA in this study, which concurred with the findings of Ashraf et al. (2010) and Beniwal, Bhargava and Kausik (2014). However, Li, Zeng, Zhong, Wu, Zeng et al. (2013), Kotowycz et al. (2014), Aykan et al. (2015), Yilmaztepe and Yilmaz (2018) and Domagała et al. (2021) reported a correlation between the radial artery and weight. This study reported no correlation between weight and the average diameter of the SRA, which contradicts the findings of Norimatsu et al. (2019) and Deora et al. (2022). This study reported a moderately significant correlation between height and the average diameter of the DFRA bilaterally, which differed from the literature reviewed.

The correlation between the wrist circumference and the average diameters of the DFRA and SRA reported in the present study compared favourably with the literature reviewed. Similarly, the correlation between shoe size and the average diameter of the DFRA in the present study concurred with the literature reviewed. The present study noted no difference between the different ethnic groups and the average diameter of the DFRA, which contradicts the findings of Kotowycz et al. (2014), which can be attributed to the unequal distribution of patients in each ethnic group. The diameters of the DFRA and SRA in relation to the sheath size in this study contradicted the incidence reported in the literature reviewed.

From a clinical perspective, the relationship between the arterial diameter and sheath size warrants careful consideration. Sheath size is expressed using the French (Fr) scale, where 1 Fr equals to one-third of the circumference in millimetres (Mathis, Romans and Divekar, 2020). Although the sheath size denotes the inner diameter, the outer diameter (typically 1 Fr larger) determines the risk of arterial injury (Mathis, Romans and Divekar, 2020). Critically, the outer diameter of sheaths with identical Fr sizes can vary substantially among different manufacturers and product lines, making manufacturer-specific specifications more clinically relevant than the Fr number alone.

In the present study, 55% of adults had DFRA diameters below 2.0mm (which is the outer diameter of a 4 Fr sheath) and 97% had SRA diameters below this threshold. These findings carry direct clinical implications. Saito, Ikei, Hosokawa and Tanaka (1999) reported an increased incidence of severe radial artery flow reduction where the ratio between the inner diameter of the radial artery and the outer diameter of the sheath was less than 1.0. A sheath-to-artery mismatch may contribute to the development of radial artery spasm, intimal injury, thrombosis, and post-procedural radial artery occlusion.

While the present study observed statistically smaller or larger diameters of the DFRA and SRA compared to other populations, the magnitude of these inter-population variations was within tenths of a millimetre. Although statistically significant, these differences may fall within normal anatomical variation and may not independently necessitate alternation in sheath selection. However, the clinical relevance of the small differences in the diameter becomes more pronounced when the arterial measurements approach critical thresholds for sheath compatibility. For example, when the SRA measures approximately 1.8 – 2.0mm, even a reduction of 0.2mm may increase the sheath-to-artery ratio beyond optimal limits, thereby predisposing the patient to vasospasm, intimal trauma, or radial artery occlusion. Thus, the interpretation of smaller or larger arterial diameters should not be purely viewed in statistical terms, but rather in relation to the outer diameter of the sheath and procedural risk.

In subset B, the average diameters of the DFRA and SRA were smaller compared to the literature reviewed. The average diameter of the SRA according to sex was smaller than the findings reported by Alehaideb, Ha, Beckford, Dmytriw, Bhatia et al. (2020) in a paediatric sample. There was no significant correlation between BMI and the average diameters of the DFRA and SRA, which contradicted the findings of Babuccu, Ozdemir, Hosnuter, Kargi, Söğüt and Ayoglu (2006). There was a correlation between weight and height and the average diameters of the DFRA and SRA, which supported the findings of Babuccu et al. (2006). The differences between the findings of the present cohort compared to previous studies may be attributed to the anthropometric characteristics, genetic diversity, and the geographical location.

5.1.2 Manuscript 2 – Morphometric analysis of the radial artery in a select South African sample

The average external diameter of the radial artery at the point of origin diverged from the findings reported by Al Talalwah, Getachew and Soames (2015) in a British population and Mahajan, Shashank, Muthukrshnan, Verma and Razdan (2022) in an Indian population. The average external diameter of the radial artery at the point of origin was greater on the left side, which aligned with the findings reported by Getachew, Astatkie and Lemma (2018), but diverged from the findings reported by Nasr (2012), Al Talalwah, Getachew and Soames (2015), Tariq, Ahmad, Khan, Hakim, Usmanullah and Aman (2020) and Mahajan et al. (2022). The average external diameter of the radial artery at the wrist joint and in the anatomical snuffbox differed from the findings reported in the literature reviewed. The average external diameter of the radial artery decreased from the point of origin to the anatomical snuffbox, which compared favourably with the findings of Getachew, Astatkie and Lemma (2018).

Differences in the external diameter between the present study and previous studies may be attributed to the methodological variation, including differences in anatomical landmarks, measurement instruments, and whether the vessels were assessed under physiological or cadaveric conditions. Cadaveric vessels are measured in a non-pressurized state, which differs from in vivo imaging studies where arterial tone and intra-luminal pressure are preserved. In addition, demographic factors, anthropometric variability, and the advanced mean age of the present donor cohort may influence the arterial dimensions. These considerations highlight the relevance of contextual analysis when comparing morphometric data across different study paradigms and populations. The biological sex-based differences in the external diameter of the right radial artery at the point of origin, and external diameter of the radial artery at the wrist joint (bilaterally) between the present study and previous studies can be attributed to the non-normal distribution of these variables in this cohort, which contrasted with the normally disturbed data, underlying the means and standard deviation, reported by previous studies.

The average internal diameter of the radial artery at its point of origin, at the wrist joint and within the anatomical snuffbox differed from the values reported in the reviewed literature. However, the mean arterial wall thickness at the point of origin contradicted the findings of Al Talalwah, Getachew and Soames (2015), Getachew, Astatkie and Lemma (2018) and Tariq et al. (2020), who reported lower values in British, Ethiopian and Pakistani populations, respectively. The differences between the present findings and previous studies can be attributed to the methodology, study design, and demographics of the study population. The advanced mean age of the present donor cohort may have influenced the internal diameters due to age-related vascular remodeling.

Notably, the mean thickness of the radial artery at its point of origin was greater on the right side, consistent with the findings of Getachew, Astatkie and Lemma (2018). Males demonstrated a greater radial artery thickness at the point of origin, which contrasted with the findings of Al Talalwah, Getachew and Soames (2015). Similarly, the mean thickness of the radial artery at the wrist joint differed from the results reported by Al Talalwah, Getachew and Soames (2015), Getachew, Astatkie and Lemma (2018) and Tariq et al. (2020), who studied British, Ethiopian and Pakistani populations, respectively.

The wall thickness values reported in the present study were greater than those reported in previous cadaveric studies. However, wall thickness in this study was calculated using the formula: 0.50 × (average external diameter – average internal diameter), which may include adventitial tissue and connective tissue components. Additionally, the embalming process may result in vascular wall stiffening, luminal collapse, or tissue dehydration, which can potentially contribute to an increased measured wall thickness. Differences in methodology and embalming processes used in cadaveric dissections may therefore limit the direct comparability of wall thickness measurements. Additionally, the advanced mean age of the body donors may have contributed to age-related vascular remodeling.

The internal diameter of the radial artery at the wrist joint and within the anatomical snuffbox corresponded to the dimensions of a 5 Fr sheath in 32% and 38% of the sample, respectively. However, the sheath size suitability estimates presented in this study are derived from static and embalmed cadaveric measurements. While these findings provide useful anatomical baseline data, they must be interpreted cautiously when extrapolating to clinical practice. In vivo, arterial dimensions may be influenced by vasomotor tone, arterial elasticity, blood pressure, and procedural factors such as vasospasm. Therefore, sheath selection in clinical settings should be individualized and guided by patient-specific assessment.

5.1.3 Manuscript 3 – A cadaveric investigation of the radial artery origin and its anatomical variations

According to standard anatomical descriptions, the radial artery arises as one of the terminal branches of the brachial artery within the cubital fossa, at the level of the neck of the radius (Drake, Vogl, Mitchell and Gray, 2020; Narsinh et al., 2021). Although the arterial supply of the upper limb develops through well-established embryological processes, anatomical variations have been documented since the eighteenth century. In the present study, the radial artery originated within the cubital fossa in 90% of the sample, aligning with the observations of Nasr (2012), Agarwal, Lalwani and Babu (2016) and Kadel, Hada and Sedhain (2019). In the remaining 10% of cases, the artery exhibited a high origin, arising from the axillary artery. This variation aligns with the findings of several previous studies (Karlsson and Niechajev (1982); Uglietta and Kadir (1989); Gonzalez-Compta (1991); Sargon and Celik (1994); Konarik, Knize, Baca and Kachlik (2009); Waghmare, Tarnekar, Sonatakke, Bokariya and Ingole (2009); Daimi, Siddiqui and Wabale (2010); Balachandra, Prakash, Padmalatha and Ramesh (2011); Bidarkotimath, Avadhani and Kumar (2011); Nasr (2012); Yagain, Dave and Anadkat (2012); Shiny Vinila, Sangeeta, Sanikop and Venkateshu (2013); Haładaj, Wysiadecki, Dudkiewicz, Polguj and Topol (2018); Kadel, Hada and Sedhain (2019); Syed, Akram and Faruqi (2019); Kore and Vishwakarma (2021); Bundi, Mutua, Cheruiyot, Munguti, von Csefalvay et al. (2022); Barry, Gun, Chabry, Harmouche, Padurean et al. (2023); Shilpa, Rani Raphael, Rajad, Manju and Tejaswi (2024)).

Unilateral high origin was identified in four cadavers, consistent with the findings reported by Konarik et al. (2009), Waghmare et al. (2009), Daimi, Siddiqui and Wabale (2010), Balachandra et al. (2011), Yagain, Dave and Anadkat (2012), Das, Rai, Das and Mehrotra (2016), Kadel, Hada and Sedhain (2019), Syed, Akram and Faruqi (2019), Kore and Vishwakarma (2021), Bundi et al. (2022), Barry et al. (2023) and Shilpa et al. (2024), who reported unilateral origin from the axillary artery. In an 80-year-old male cadaver, bilateral high origin of the radial artery from the axillary artery was observed, which is consistent with the findings of Okoro and Jiburum (2003) and Ghosh, Roy, Kundu and Mukherjee (2013).

The aberrant radial arteries originated at a mean distance of 172 ± 20.81 mm from the point of origin to the inter-epicondylar line of the humerus. This measurement contrasts with the findings of Mudiraj and Dhobale (2015), Reddy, Gajbe, Fulzele and Singh (2016), Sucharitha, Hema and Phanindra (2016), Gandhi and Lakshmi (2018), Clarke, Skrzat, Shane Tubbs, Iwanaga, Mazurek and Wysiadeck (2021), Sophia, Singh, Xalxo, Yadav, Agarwal et al. (2021) and Rathi (2023), who reported shorter distances for high-origin radial arteries. Conversely, studies by Gandhi and Lakshmi (2018), Haładaj et al. (2018) and Alves, de Azevedo and Fazan (2020) documented longer distances. Notably, the incidence of radial arteries arising from the axillary artery (high-origin radial arteries) in the present study was higher than in previous reports, where such variations accounted for approximately 1.11% to 6.7% of cases (Yagain, Dave and Anadkat, 2012; Das et al., 2016; Kadel, Hada and Sedhain, 2019; Syed, Akram and Faruqi, 2019; Kore and Vishwakarma, 2021; Bundi et al., 2022; Barry et al., 2023; Shilpa et al., 2024).

Variations in the origin of the radial artery are primarily attributed to differences in embryological development of the upper limb vasculature, as well as to smooth muscle-endothelial interactions, foetal positioning, nutritional demands, hemodynamic factors, chemical influences and genetic determinants (Ghosh et al., 2013; Bondage, More and Gangane, 2014; Das et al., 2016; Agarwal, Lalwani and Babu, 2016; Lalitha and Lakshmi Devi, 2018; Alves, de Azevedo and Fazan, 2020; Bundi et al., 2022).

5.2 Limitations

In Manuscript 1, there was an uneven distribution of participants with respect to sex, ethnicity and baseline characteristics such as shoe size, occupational environment and medical history (including hypertension, diabetes mellitus and smoking). The study was conducted at a single centre and excluded patients with a history of surgery or procedures performed via the transradial approach; consequently, anatomical alterations of the radial artery before and after such interventions were not assessed.

In Manuscript 2, all cadavers were derived from a single ethnic group; therefore, potential ethnic variations in the radial artery at the point of origin, wrist joint and anatomical snuffbox could not be evaluated. The relatively small sample size further limited the ability to detect statistically significant differences related to laterality or sex. The body donors were predominantly elderly, with an advanced mean age. Therefore, age-related vascular changes may have influenced the morphometric measurements obtained in this study. The embalming process can cause varying levels of tissue shrinkage or swelling, and the absence of physiological intravascular pressure may lead to the collapse of vessel lumens. As a result, absolute measurements of both the external and internal diameters may differ from those observed in in-vivo conditions. Cadaveric measurements should be interpreted as indictors of anatomical feasibility rather than definitive predictors of procedural safety in living patients.

In Manuscript 3, the number and branching patterns of the radial recurrent arteries were not recorded, and the classification of the superficial and deep palmar arches was not documented, as these parameters were beyond the scope of the study.

5.3 Recommendations

A key consideration arising from the present findings is whether a single average Fr sheath size can reasonably be recommended for this population, or whether the observed inter-individual variability necessitates routine pre-procedural ultrasound assessment. Although this study provides valuable population-specific morphometric data for the DFRA and SRA, considerable variability was observed across sex, anthropometric or body parameters, and comorbidity profiles. Reliance solely on mean vessel diameters may therefore oversimply anatomical diversity and potentially increase the risk of radial artery spasm, intimal injury, or radial artery occlusion in individuals with smaller arterial calibres. While the population-level average may assist in procedural planning and device procurement within this select population, they should not replace patient-specific vascular assessment. Pre-procedural ultrasound evaluation allows for real-time measurement of the diameter of the radial artery and facilitates individualised sheath selection, thereby enhancing procedural safety and success. Consequently, the findings of this study support the use of population-based data as a foundational reference but advocate for ultrasound-guided sheath selection wherever feasible.

The apparent discrepancy between the ultrasound-based recommendation of a 4 Fr sheath and the cadaveric suggestion of a 5 Fr sheath further underscores the importance of contextual interpretation. Ultrasound measurements were obtained in living participants under physiological conditions, where arterial tone, blood pressure, and vasomotor reactivity influence luminal diameter. In contrast, cadaveric specimens lack vascular tone and are subject to post-mortem alternation, including potential shrinkage or distortion related to the embalming process. Furthermore, ultrasound reflects the functional luminal diameter in a dynamic clinical setting, whereas cadaveric measurements represent static anatomical dimensions.

Differences in the sample demographics, including the age distribution and comorbidities, may also contribute to the observed variations. Accordingly, the recommendation of a 4 Fr sheath in the ultrasound study reflects a conservative, patient-specific approach based on in vivo assessment, while the cadaveric findings demonstrate that a 5 Fr sheath may be anatomically feasible under ideal structural conditions. These findings are therefore complementary rather than contradictory and highlight the necessity of integrating anatomical reference data with real-time imaging in clinical practice. Individualised pre-procedural ultrasound assessment remains the preferred approach for sheath selection.

Further multi-centre studies (including both private and public institutions) on the anatomical characteristics of the distal forearm and snuffbox radial arteries are recommended, ensuring even distribution of patients across sex, ethnicity and baseline characteristics. Additionally, longitudinal studies should evaluate procedural outcomes and radial artery changes (such as occlusion or spasm) over time in patients undergoing transradial interventions, as these findings can improve procedural success and safety. Future studies should also investigate the changes in the radial artery diameter before and after various vasodilators in adult and paediatric patients, as this may minimise vascular complications and may optimise sheath compatibility during neurointerventional procedures.

Due to the paucity of data concerning the anatomical features of the distal forearm and snuffbox radial arteries in paediatric populations, future research should consider larger paediatric cohorts with age-specific stratification. This approach would advance the understanding of developmental variations and anatomy. For future cadaveric samples, a larger sample size with even distribution of cadavers based on sex and ethnicity is recommended.

5.4 Conclusion

This study aimed to document the anatomical characteristics of the radial artery and its distal segment in a select South African population, including both the participant adult and paediatric patients, as well as cadaveric specimens. The diameter of the DFRA was larger in living adult male patients compared to female patients, while paediatric patients exhibited smaller overall vessel sizes. Notably, 55% of adults and 99% of paediatric patients had a DFRA diameter less than 2.0 mm; similarly, the SRA was under 2 mm in 97% of adults and all paediatric patients.

Morphometric analysis of cadaveric specimens revealed a gradual tapering of the artery distally, with the diameter of the radial artery decreasing from its point of origin to the anatomical snuffbox. No significant differences were observed between sexes or laterality in the cadaveric cohort. The internal diameter measurements indicated that a 5 Fr sheath may be suitable for transradial procedures in approximately one-third of the sample at the wrist and slightly more at the snuffbox. Anatomical variations in the origin of the radial artery were also documented, with 90% originating from the brachial artery and 10% (five cadavers) originating anomalously from the axillary artery. The findings of the present study may assist clinicians during coronary, cardiovascular, neurological and neuro-interventional procedures within this select South African population.

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APPENDIX A
ETHICAL APPROVAL

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

30 September 2024

Miss Aleisha Jo Singh (220013401)
School of Laboratory Medicine & Medical Science
Westville

Dear Miss Singh,

Protocol reference number: BREC/00006978/2024
Project title: An anatomical investigation of the radial artery and its distal segment in a select South African population Degree: Masters

EXPEDITED APPLICATION: APPROVAL LETTER

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

The conditions have been met and the study is given full ethics approval and may begin as from 30 September 2024. Please ensure that any outstanding site permissions are obtained and forwarded to BREC for approval before commencing research at a site.

This approval is valid for one year from 30 September 2024. To ensure uninterrupted approval of this study beyond the approval expiry date, an application for recertification must be submitted to BREC on RIG on the appropriate BREC form 2-3 months before the expiry date.

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

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

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

The sub-committee's decision will be noted by a full Committee at its next meeting taking place on 12 November 2024.

Yours sincerely,

[redacted]

Prof T Hardcastle
Deputy Chair: Biomedical Research Ethics Committee

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

APPENDIX B
DEPARTMENT OF HEALTH APPROVAL

KWAZULU-NATAL PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

DIRECTORATE:

Physical Address: 330 Langalibalele Street, Pietermaritzburg
Postal Address: Private Bag X9051
Tel: 033 395 2805/ 3189/ 3123 Fax: 033 394 3782
Email: hrkm@kznhealth.gov.za

Health Research & Knowledge Management

NHRD Ref: KZ_202408_014

Dear Ms Aleisha Jo Singh
(UKZN)

Approval of research

1. The research proposal titled **'An anatomical investigation of the radial artery and its distal segment in a select South African population'** was reviewed by the KwaZulu-Natal Department of Health (KZN-DoH).

   The proposal is hereby **approved** for research to be undertaken at Inkosi Albert Luthuli Central Hospital.

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

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

Yours Sincerely

[redacted]

Dr E Lutgé
Chairperson, Provincial Health Research Committee
Date: 21/08/2024

GROWING KWAZULU-NATAL TOGETHER

APPENDIX C
INFORMED CONSENT FORM

UKZN BIOMEDICAL RESEARCH ETHICS COMMITTEE

APPLICATION FOR ETHICS APPROVAL
For research with human participants (Biomedical)

INFORMED CONSENT FORM

Note to researchers: Notwithstanding the need for scientific and legal accuracy, every effort should be made to produce a consent document that is as linguistically clear and simple as possible, without omitting important details as outlined below. Certified translated versions (if applicable) will be required once the original version is approved.

There are specific circumstances where witnessed verbal consent might be acceptable, and circumstances where individual informed consent may be waived by BREC.

Information Sheet and Consent to Participate in Research

Date: 26 June 2024

Dear Patient/parent/guardian,

My name is Aleisha J. Singh, a Masters student, from the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Science, University of KwaZulu-Natal, Westville Campus, Private Bag X54001, Durban, South Africa. Email address: 220013401@stu.ukzn.ac.za/ [redacted]. Contact number: [redacted].

You are being invited to consider participating in a study that involves clinical research. The aim and purpose of this research is to investigation the radial artery and its distal segment in a select living and cadaveric South African population. The study is expected to enroll a total of 256 patients which is comprised of 128 adult (including mothers who accompany their children in the paediatric clinic/department) and 128 paediatric patients present in the neurosurgery adult and paediatric clinics/departments at the Inkosi Albert Luthuli Central Hospital, Durban. It will involve the following procedures viz., the use of ultrasound; determining your blood pressure, weight, height, wrist circumference; as well as recording your shoe size, occupation, and whether you smoke, have hypertension and/or diabetes mellitus. The duration of your participation if you choose to enroll and remain in the study is expected to be 20 to 25 minutes.

We hope that the study will contribute to existing literature regarding the anatomical characteristics of the radial artery and its distal segment.

This study has been ethically reviewed and approved by the UKZN Biomedical research Ethics Committee.

In the event of any problems or concerns/questions you may contact the researcher at: email: 220013401@stu.ukzn.ac.za/[redacted]; contact number: [redacted] or the UKZN Biomedical Research Ethics Committee, contact details as follows:

BIOMEDICAL RESEARCH ETHICS ADMINISTRATION
Research Office, Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA

1

Tel: 27 31 2602486 - Fax: 27 31 2604609
Email: BREC@ukzn.ac.za

Participation in this research is voluntary and participants may withdraw participation at any point, and in the event of refusal/withdrawal of participation the participants will not incur penalty or loss of treatment or other benefit to which they are normally entitled. There are no potential consequences to the participant for withdrawal from the study and the procedure/s required from the participants for orderly withdrawal.

There are no costs incurred by participants as a result of participation in the study. There are no incentives or reimbursements for participation in the study.

The participants personal and clinical information will be kept confidential. Neither the participants name nor identify will be disclosed in any form in the study. All information associated with the study will be kept in a password-protected file. Only the researchers involved, and the biostatistician will have access to this file. After a period of 5 years, the data will be destroyed.

DECLARATION OF CONSENT

I ________________________________ have been informed about the study entitled: An anatomical study of the radial artery and its distal segment in a select South African population by Miss Aleisha J. Singh.

I understand the purpose and procedures of the study.

I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.

I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without affecting any treatment or care that I would usually be entitled to.

I have been informed about any available compensation or medical treatment if injury occurs to me as a result of study-related procedures.

If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher at: email: 220013401@stu.ukzn.ac.za/[redacted] contact number: [redacted]

If I have any questions or concerns about my rights as a study participant, or if I am concerned about an aspect of the study or the researchers then I may contact:

BIOMEDICAL RESEARCH ETHICS ADMINISTRATION
Research Office, Westville Campus
Govan Mbeki Building
Private Bag X 54001
Durban
4000
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 2602486 - Fax: 27 31 2604609
Email: BREC@ukzn.ac.za

______________________	______________________
Signature of Participant	**Date**
______________________	______________________
Signature of Witness (Where applicable)	**Date**
______________________	______________________
Signature of Translator (Where applicable)	**Date**

APPENDIX D
DATA SHEET

Paediatric subset:

Table 1: Template used to record the body surface area and body mass index

Paediatric patient number	Sex	Age	Ethnicity	Height (cm)	Height (m)	Weight (kg)	Body surface area	Body mass index

Table 2: Template used to record the wrist circumference

Paediatric patient number	Sex	Age	Ethnicity	Body side	Wrist circumference			Average
					Attempt 1	Attempt 2	Attempt 3	

Table 3: Template used to record the inner diameter of the radial artery and its distal segment

Paediatric patient number	Sex	Age	Ethnicity	Body side	Inner diameter			Average
					Attempt 1	Attempt 2	Attempt 3	

Table 4: Template used to record the shoe size, hypertension and diabetes mellitus

Paediatric patient number	Sex	Age	Ethnicity	Shoe size	Hypertension	Diabetes mellitus	Smoking

Adult subset:

Table 5: Template used to record the body surface area and body mass index

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Height (cm)	Height (m)	Weight (kg)	Body surface area	Body mass index

Table 6: Template used to record the wrist circumference

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Body side	Wrist circumference			Average
						Attempt 1	Attempt 2	Attempt 3	

Table 7: Template used to record the inner diameter of the radial artery and its distal segment

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Body side	Inner/internal diameter			Average
						Attempt 1	Attempt 2	Attempt 3	

Table 8: Template used to record the outer diameter of the radial artery and its distal segment

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Body side	Outer/external diameter			Average
						Attempt 1	Attempt 2	Attempt 3	

Table 9: Template used to record the shoe size and occupation

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Shoe size	Occupation		
						Quiet environment	Physically active/ outdoors	Unemployed

Table 10: Template used to record smoking, hypertension and diabetes mellitus

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Smoking	Hypertension	Diabetes mellitus

Table 11: Template used to record the origin of the radial artery

Patient/ cadaveric number	Participant/ cadaveric	Sex	Age	Ethnicity	Body side	Origin of the radial artery

(Data is available on request)

APPENDIX E
SCIENTIFIC PRESENTATIONS EMANATING FROM THE STUDY

High origin of the radial artery in a select South African population: A case series

32nd Congress of the Society of Neurosurgeons of South Africa; 28–31 August 2025; Umhlanga, KwaZulu-Natal, South Africa

Aleisha J. Singh, Rohen Harrichandparsad, Lelika Lazarus

APPENDIX F
EDITING

Nicolene Barnard
Proofreading | Technical Editing | Metadata Specialist | Indexing
[redacted] | [redacted]

15 November 2025

CONFIRMATION OF EDITING AND PROOFREADING

I hereby confirm that I have verified all references, and have done the technical layout and language editing for the following dissertation:

Student:	Aleisha Jo Singh
Title:	An anatomical investigation of the radial artery and its distal segment in a select South African population
Department:	School of Medicine, College of Health Sciences, University of KwaZulu-Natal

My work for the student included the technical layout of the document, as well as proof reading and language editing for grammar, punctuation, spelling, and sentence structure. I tried to keep as much as possible of the student's own writing style while making sure that the student's intended meaning was not altered in the editing process. I also checked the list of references making sure that dates, spelling, and names used in the text are consistent with those listed in the reference list.

I have a B.Bibl. (Hons.) Degree and have worked as a cataloguer, metadata specialist and librarian for 33 years. I am an expert in the field of bibliographic information and resources. I have also completed a Copy-Editing course at the University of Cape Town.

Disclaimer: The ultimate responsibility for accepting or rejecting the changes and recommendations rests with the student and I cannot be held responsible for any layout or language issues that might have emerged as a result of subsequent amendments to the text.

Yours sincerely,

[redacted]

Nicolene Barnard

APPENDIX G
TURNITIN REPORT

An anatomical investigation of the radial artery

ORIGINALITY REPORT

5%	4%	5%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Shan Jiang, Shanlin Yu, Baodong Gu, Xin Li, Hui Xiao, Dandan Zhao, Xianjun Ma. "Distal versus proximal transradial access for diagnostic cerebral angiography: A single-center experience", Journal of Clinical Neuroscience, 2025 Publication	1%
2	Stelina Alkagiet, Dimitrios Petroglou, Dimitrios N. Nikas, Theofilos M. Kolettis. "Access-site Complications of the Transradial Approach: Rare But Still There", Current Cardiology Reviews, 2021 Publication	<1%
3	Mark R. Harrigan, John P. Deveikis. "Chapter 4 General Considerations for Neurointerventional Procedures", Springer Science and Business Media LLC, 2023 Publication	<1%
4	ouci.dntb.gov.ua Internet Source	<1%
5	www.rand.org Internet Source	<1%
6	Guglielmo Imbrìaco, Alessandro Monesi, Timothy R. Spencer. "Preventing radial arterial	<1%