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CRITICAL ANALYSIS OF THE MACRO- AND
SONOGRAPHIC ANATOMY OF THE BRACHIAL
PLEXUS

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2017

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List of abbreviations

m	Muscle
BP	Brachial plexus
AS	Anterior scalene
MS	Middle scalene
SCM	Sternocleidomastoid
SCA	Subclavian artery
SCV	Subclavian vein
AA	Axillary artery
EJV	External jugular vein
T	Trapezius
ISG	Interscalene groove
SCF	Supraclavicular fossa
ICF	Infraclavicular fossa
Lsmin	Supraclavicular approach: left side minimum distance to the hypothetical injection site
Rsmin	Supraclavicular approach: right side minimum distance to the hypothetical injection site
Tifmin	Total infraclavicular minimum distance to the hypothetical site
Tifsbpp	Total infraclavicular skin to posterior cord of BP

Executive summary

Various institutions and government hospitals in South Africa, still perform nerve blocks using anatomical landmarks to approximate the precise position of the targeted nerve(s). Although this technique has been reported to be successful, variation does occur within the South African population therefore increasing the risk of complications. Thus causing surgeons and anaesthesiologist's to employ sonography-guided techniques. Sonography allows the visualisation of structures in real time. This technique provides adequate coverage of the needle insertion site and its surrounding structures, to allow for readjustment in order to obtain a successful block in the event of a variation.

The aim of this study was to investigate the sonographic anatomy of the brachial plexus at the three common areas in which brachial plexus nerve blocks are performed, i.e. the interscalene groove, supraclavicular fossa and the infraclavicular space. The anatomy of the brachial plexus was also studied on 60 cadavers and then further compared to the anatomy seen on the sonographic screen.

Bilateral dissections were done on 60 embalmed cadavers, comprising of 43 males and 17 females, from the Department of Anatomy in the School of Medicine at the Faculty of Health Sciences of the University of Pretoria, South Africa. The use of these cadavers was in accordance with the South African National Health Act 61 of 2003. Dissection was done to expose the brachial plexus in situ. The various segments of the brachial plexus were evaluated. The root contributions, branching patterns and relationships were noted. Upper limb sonographic scans were done bilaterally for the 3 approaches to measure the distance of surrounding structures to the brachial plexus, the skin to structure distances and to determine the ideal placement of the probe for each approach. A full step-by-step guideline was recorded.

Variations found in the cadaveric component of the study include the following: a direct branching of the C5 cord into the suprascapular nerve; the direct branching of the medial cutaneous nerve of the arm distinctly as a larger single branch; a communicating branch forming between the musculocutaneous and median nerve; abnormal formation of the median nerve from two lateral roots from the lateral cord and one medial root from the medial cord and; a post fixed brachial plexus.

In the interscalene approach, the roots of the brachial plexus were found lying in a horizontal plane between the anterior and middle scalene muscles or the roots were found lying anterior to the anterior scalene muscle yet posterior to the sternocleidomastoid muscle. In the supraclavicular approach the brachial plexus was situated between the subclavian artery and vein and in the infraclavicular approach, the cords of the brachial plexus were found at variable angles to the subclavian artery/axillary artery.

This study focused on variations that may be present, each of which are important to note if any clinical or surgical procedures are to be performed in the area. The most prevalent variation found was the direct braching of the suprascapular nerve from the C5 root instead of the superior trunk. The study aimed to improve “blind”, as well as sonographic-guided, nerve blocks that may be performed in a South African population.

Keywords: brachial plexus, subclavian artery, roots, cords, variation, sonography, interscalene, supraclavicular, infraclavicular, nerve blocks.

1. Introduction

Modern medicine is evolving at a rapid rate, with new medical procedures and advanced peri- and postoperative patient care treatments becoming more readily available. With the priority being the patients' well-being and prompt recovery, the role of the anaesthesiologist is of growing importance. Brachial plexus (BP) blocks have been reported to be safer and more efficient than general anaesthesia, when used to provide regional anaesthesia for a multitude of upper extremity procedures (Yang *et al.*, 1998). Benefits of using regional anaesthesia include: a decrease in the stress response; reduced tumour recurrence; improved glucose control; easier participation in physiotherapy and; a reduction in the use and necessity of opiates (Brown, 1993; Fischer, 2011; Kettner *et al.*, 2011).

Primary care institutions and government hospitals in South Africa, as well as other developing countries, still perform nerve blocks using anatomical landmarks to approximate the precise position of the target nerve(s). Here, nerve stimulation is the gold-standard to test and confirm the proximity of the needle tip to the targeted nerve(s) (Urmey, 2006). Although there are various approaches that can be used to perform a BP block, each has its own advantages, disadvantages and contraindications. It is also important to note that individual anatomical variations occur, which in turn increases the risk of complications if the normal – or potential variable – anatomy of the region is not properly known or understood. Another disadvantage of the “blind” technique is not knowing the extent that the local anaesthetic has spread, specifically whether it spread consistently around the nerve(s) after it was administered (Jung Kim *et al.*, 2014; Nowakowasi, 2015).

Literature suggests that the failure rate of “blind” blocks can be decreased if the anatomical variation of every individual can be visualised while performing the nerve block. The concept has employed sonographic guidance to assist and improve the accuracy of regional nerve blocks (Jung Kim *et al.*, 2014). Sonography is used to visualise anatomical structures in real-time during the performance of many clinical procedures,

including when performing regional nerve blocks (Nowakowasi and Bierylo, 2015). The real-time visualisation of the needle tip makes it easier, quicker and safer to position it close to the target nerve(s). An accurate knowledge of the macro-anatomy, as well as the “visible” anatomical structures displayed on the screen, is crucial in order to perform a successful sonographic guided nerve block. This is best achieved by comparing the anatomy seen on the sonograph images to observations made on human formalin-fixed cadavers, but also to provide detailed descriptions of the sonographic anatomy visible on the screen. This is because of the fact that it is widely accepted that no technique can truly be called simple, safe and consistent until the anatomy has been closely examined (Winnie *et al.*, 1973).

2. Literature review

2.1. Brachial plexus anatomy

The BP is formed by the union of the ventral rami of the fifth to eighth cervical spinal nerves (C5 - C8) as well as the first thoracic spinal nerve (T1). It may also receive variable contributions from spinal nerves C4 and T2 (pre- or postfixed) (Moore *et al.*, 2016). From proximal to distal, the BP consists of these five roots (C5 - T1) that will eventually unite into three trunks (superior, middle and inferior), six divisions (three anterior and three posterior), three cords (medial, lateral and posterior) and finally, the five terminal branches of the BP. Nerves from the BP provide sensory innervation to the upper limb and most of the axilla (Table 1 below), except for the upper half of the medial and posterior arm. These areas receive their sensory innervation from the intercostobrachial nerve, a branch of the second thoracic spinal nerve (T2). The terminal branches of the BP supply motor innervation to the muscles of the upper limb as well as the shoulder girdle (Table1 below), with the exception of the trapezius muscle that is innervated by the spinal accessory nerve, the twelfth cranial nerve (CNXII).

As the spinal nerve roots of the BP pass through the intervertebral foramina, they travel between the anterior (AS) and middle (MS) scalene muscles. They pass on the medial margin of the MS muscle and the lateral margin of the AS muscle, to reorganise into the superior (formed by the union of C5 & C6), middle (continuing from C7) and inferior (formed by the union of C8 & T1) trunks. The trunks course across the superior surface of the first rib to its lateral border, where they each divide into three anterior (ventral) and three posterior (dorsal) divisions. The anterior divisions will supply the muscles that bring about flexion in the arm, forearm, hand and fingers, whereas the posterior divisions will supply the muscles responsible for extension. As the divisions enter the axilla, they are rearranged into the lateral, posterior and medial cords inferior to the clavicle (Figure 1) (Yang *et al.*, 1998; De Andres and Sala-Blanch, 2002; Haddad and Coventry, 2002).

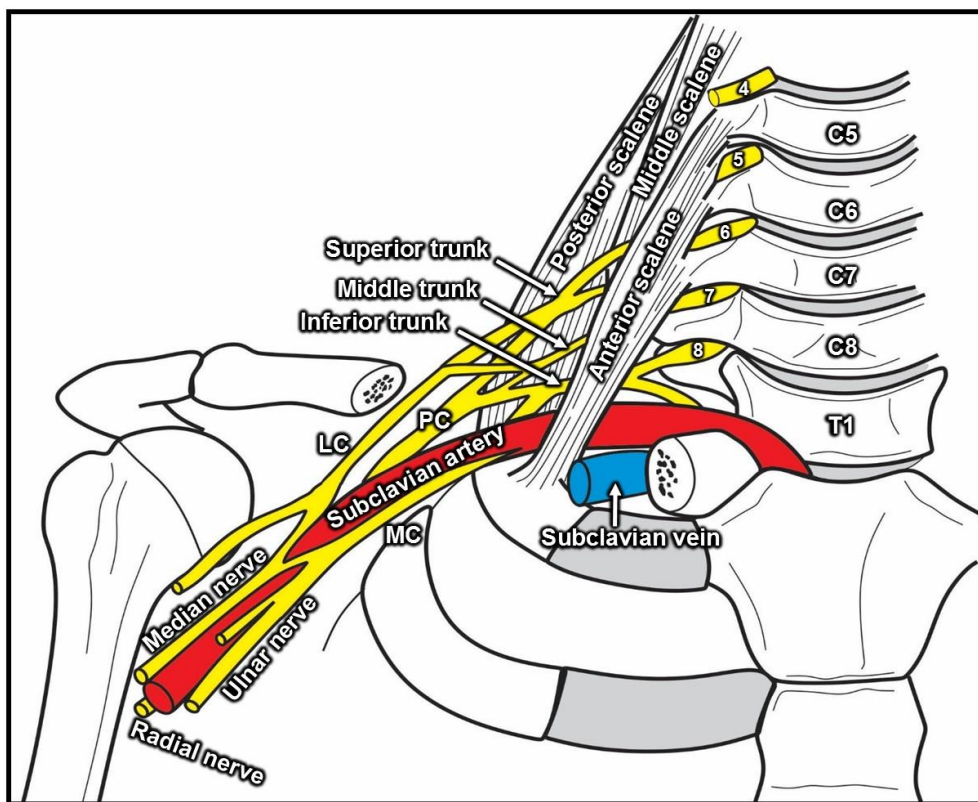


Figure 1: Diagram showing the BP course and its branches in situ. LC - lateral cord, PC - posterior cord, MC - medial cord.

As the cords approach the coracoid process, the lateral cord remains on the lateral side while the posterior and medial cords migrate behind the subclavian artery (SCA) (Moore *et al.*, 2016), adopting the characteristic position around the vessel, from which they get their names. At this level, the pectoralis minor and major muscles can be found anterior (superficial) to the BP.

The union of the anterior divisions of the superior and middle trunks forms the lateral cord of the BP. Before the lateral cord terminates as the musculocutaneous nerve and the lateral contribution (root) of the median nerve, it gives off the lateral pectoral nerve. The posterior cord is formed from the fusion of the posterior divisions of all the trunks. Along its course, several nerves originate from it. These include the superior (upper) subscapular nerve, thoracodorsal nerve and the inferior (lower) subscapular nerve. The posterior cord will eventually terminate as the axillary and radial nerves. The anterior division of the inferior trunk continues as the medial cord. The medial pectoral nerve, the medial cutaneous nerve of the arm and the medial cutaneous nerve of the forearm are branches of the medial cord before it terminates into the ulnar nerve and the medial contribution (root) of the median nerve on the medial side. In the neck region, the proximal parts of the BP lie posterior to the SCA, whereas the distal parts of the plexus can be found surrounding the axillary artery (AA) within the axilla (Moore *et al.*, 2016).

Table 1: Motor and sensory supply of the BP (Moore *et al.*, 2016).

Level	Nerve	Motor	Sensory
Roots	• Long thoracic	• Serratus anterior m.	
	• Dorsal scapular	• Levator scapulae & rhomboid mm.	
	• Branch of phrenic	• Diaphragm	
Trunks	• Suprascapular	• Supra- & infraspinatus m.	
	• Nerve to subclavius	• Subclavius m.	
Cords	• Lateral pectoral	• Pectoralis major & minor m.	
	• Medial pectoral	• Pectoralis minor m.	
	• Medial cutaneous nerve of arm		• Skin of medial side of arm
	• Medial cutaneous nerve of forearm		• Skin of medial side of forearm, as far distal as wrist
	• Thoracodorsal	• Latissimus dorsi m.	
	• Superior subscapular	• Superior portion of subscapularis m.	
	• Inferior subscapular	• Inferior portion of subscapularis & teres major m.	
Branches	• Axillary	• Deltoid and teres minor m.	• Deltoid & superior-posterior arm
	• Musculocutaneous	• Muscles - anterior arm (flexors)	• Lateral forearm
	• Radial	• Muscles - posterior arm & forearm (extensors)	• Posterior arm & forearm • Lateral 2/3 of dorsal hand & fingers
	• Median	• Anterior forearm (flexors)	• Lateral 2/3 of palm & fingers
	• Ulnar	• Intrinsic hand m. & flexor carpi ulnaris, flexor digitorum profundus	• Medial surface of dorsum and palm of hand

2.2. Axillary sheath of the BP

The different segments of the BP and its terminal branches are surrounded by a sheath. This is referred to as the axillary sheath and is the distal continuation of the prevertebral layer of deep cervical fascia. Partridge *et al.*, (1987), described it as a sheath consisting of multiple layers of thin connective tissue surrounding the various elements of the neurovascular bundle. This sheath forms a fascial compartment around each nerve, further defining the anatomical boundaries of the individual nerves. The axillary sheath serves functionally to limit the circumferential spread of the injected local anaesthetic either proximally or distally within the sheath. These compartments have clinical importance and potential implications in the various techniques for BP nerve blocks (Thompson and Rorie, 1983; Partridge *et al.*, 1987; Oldman and Nicholls, 2004).

2.3. Peripheral nerve blocks

A peripheral nerve block is the employment of regional anaesthesia to an area in order to block a targeted nerve or multiple nerves. Peripheral nerve blocks date as far back as the 19th century with the first few recorded cases of anaesthetic injection agents in the mid to late 19th century. In these cases, cocaine was used as the anaesthetic agent of choice. Earlier experimenting included using cocaine for eye surgery and, although it did not involve the administering of the substance, it remained a breakthrough. Since then, peripheral nerve blocks have become more advanced, with new drugs that cause less side effects and yield more positive results (Urmey, 2006). Some of the main benefits of peripheral nerve blocks can be associated with improved postoperative pain management and the reduced use of opioids. A study done by Joshi *et al.*, (2016), reported that reduced opioids influenced public health implications, since opioids are usually prescribed at hospital discharge and, are often in excess of the amount necessary for postoperative pain management. Other benefits of peripheral nerve blocks include; reduced length of stay in hospitals (Lenart *et al.*, 2012; Liu *et al.*, 2014), earlier participation in physical therapy leading to quicker recovery, prevention of hospital readmissions and; improved patient satisfaction as a result (Williams *et al.*, 2004).

2.4. Sonography

Sonography is a non-invasive method for visualisation of tissue structures within the body. It utilises sound waves at a frequency greater than 20000Hz (Hertz), which is not audible to humans (De Andres and Sala-Blanch, 2002; Helayel *et al.*, 2007). These sound waves have different wavelengths that diffract and produce an overall image. Electrical impulses are sent from the probe through a medium. When the probe is pressed firmly against the skin, small inaudible pulses are directed into the body. As the sound waves encounter the different internal organs, tissues or structures, it is reflected and transformed into electrical energy (parts of the wave). The probe which has a sensitive receiver, records the tiny changes in the sound waves' pitch and direction, thereby creating an image (Helayel *et al.*, 2007). These waves are safe and harmless to the human body. The depth of a structure is calculated by the time it takes a sound wave to reflect back to the probe. Higher frequency probes ranging from 10 to 15MHz (Megahertz) are used to visualise more superficial structures up to a depth of 3cm. Whereas lower frequency probes, ranging from 4 to 7MHz, are ideal for structures at a greater depth of 3 - 5 cm (De Andres and Sala-Blanch, 2002; Arcand *et al.*, 2005). In clinical application, any amount of air between the probe placement and skin contact will result in reflection of the sound wave and thus impede penetration of tissue structures. Hence, a small amount of sterile gel (such as KY gel) is applied to the skin and probe. Hyperechoic structures such as bone, tendons or fat do not allow sound waves to pass through them and will therefore reflect more of the sound waves back to the probe. These appear white on a sonographic screen. Other structures, such as blood or tissues rich in water, allow sound waves to travel through, appearing grey or darker on a sonographic screen. These are called hypoechoic structures (Arcand *et al.*, 2005).

The type of probe used will also influence the image produced and displayed on the screen. For regional anaesthesia there are two types of probes to consider, a linear array probe and a curvilinear probe (Figure 2). A linear array probe will produce a parallel scan displaying as a rectangular image, whereas the curvilinear probes provides a wider arc-shaped image scan (Hadzic, 2012). Linear probes are generally high in frequency,

providing better imaging for superficial structures and vessels. The higher the frequency the better the spatial resolution of the image produced, however, to the detriment of reduced depth perception (Butterworth *et al.*, 2013).

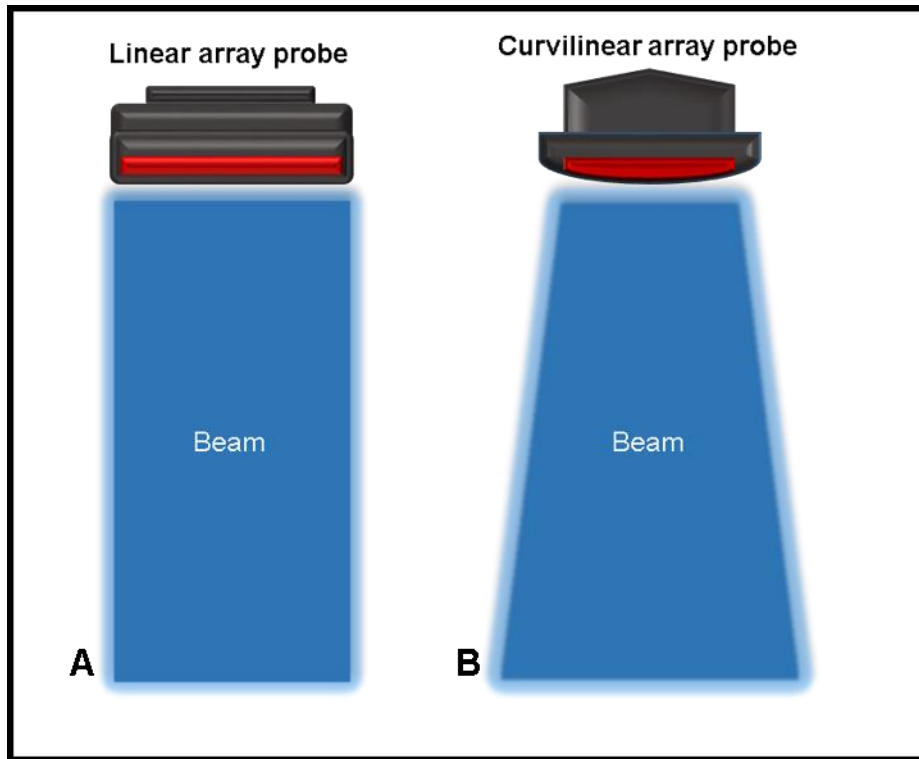


Figure 2: Sonographic probe types, A - Linear array probe. B - Curvilinear probe.

Any needle-based procedure requires guidance in order to achieve contact with the targeted nerve(s) or area. In the case of sonography-guided BP nerve blocks, the success of these image guided procedures greatly depend on the ability to locate the needle (especially its tip) in relation to the surrounding anatomical structures visible on the screen. As the needle is inserted, it may be deflected due to interaction of the needle to its surrounding structures, which may deviate the needle from its original inserted direction (Sandhu and Capan, 2002). Moreover, certain targeted points may be inaccessible due to anatomical obstructions. Two needle approaches can be used for sonography-guided nerve blocks, i.e. In-Plane approach and Out-of-Plane approach. In the In-Plane approach, the needle is inserted at the side (the short-axis) of the probe, transecting the plane of the sound waves projected from the sonographic probe. This

approach allows for complete visualisation of the needle along its entire course. An advantage of this approach is that the needle tip is easily identifiable. However, a disadvantage is that the needle course is only seen in relation to the targeted nerve(s) and not in relation to the adjacent structures. With the Out-of-Plane approach, the needle can be inserted some distance away from the probe - usually in relation to the long-axis of the probe. The needle is inserted parallel to the plane of the sound waves, therefore only the needle tip is visualised - and only once it moves "in line with" the sound waves generated by the probe. A disadvantage to this approach is that only a small portion of the inserted needle is observed, therefore what is thought to be the tip of the needle might actually be the needle shaft (Meiser *et al.*, 2015).

2.4.1. Advantages and disadvantages of sonography-guided nerve blocks

An advantage of sonography-guided nerve blocks is that, if the targeted nerve(s) can be visualised, anaesthesiologists do not have to rely on anatomical landmarks to approximate needle insertion sites. Furthermore, needle depth can be determined without having to feel or listen for described "clicks" or "pops" through areas of resistance (Retzl *et al.*, 2001; Williams *et al.*, 2003; Longnecker *et al.*, 2012). The spread of anaesthetic solution can also be visualised, giving the anaesthesiologist an indication of the area of spread of the solution. Any anatomical variations can be visualised, allowing the surgeon to change his/her technique for optimal results. Visualisation of the internal anatomy, and any variations that may be present, decreases the risk of complications such as intraneural or intravascular injections and pleural puncture. It also assists in determining the amount of local anaesthetic required, reducing the chances of local anaesthetic toxicity (Marhofer *et al.*, 2004; Hadzic, 2012, Longnecker *et al.*, 2012). Studies have also shown a general improved quality of the block as reported by patients who underwent surgical procedures (Marhofer *et al.*, 1997; Sandhu and Capal, 2002). A disadvantage of employing sonography-guided techniques is the additional costs that may be incurred to purchase the required equipment and, very importantly, obtaining the knowledge and technical proficiency required to effectively use sonography and be able to accurately interpret the image visible on the screen (Greher and Kapral, 2003).

2.5. Brachial plexus blocks

A BP block is performed using a local anaesthetic injected in very close proximity to the BP, as opposed to using general anaesthesia for surgery of the upper extremities and shoulder (Oldman and Nicholls, 2004). There are several approaches that can be used to perform a BP block, these include the interscalene, supraclavicular and infraclavicular approaches (Figure 3).

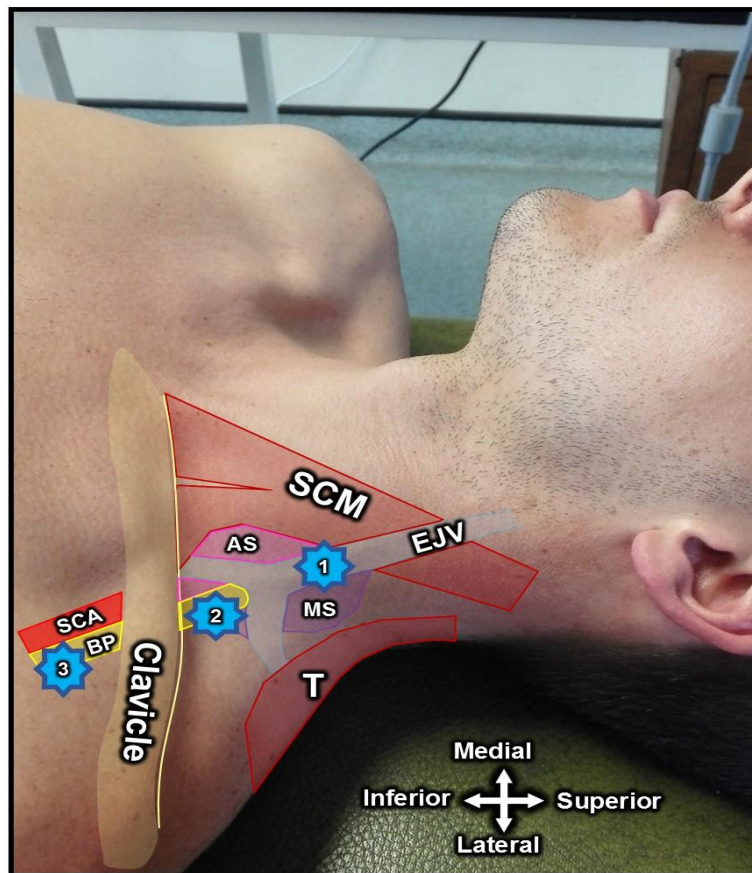


Figure 3: Photograph showing the three approaches when performing a BP nerve block. 1 - interscalene approach. 2 - supraclavicular approach. 3 - infraclavicular approach. SCM - sternocleidomastoid muscle. AS - anterior scalene muscle. MS - middle scalene muscle. T - trapezius muscle, SCA - subclavian artery, EJV - external jugular vein, BP - brachial plexus.

2.5.1. Interscalene block

The interscalene block is performed within the interscalene groove (ISG) or tissue space, situated between the MS and AS muscles. The ISG is located at the level of the cricoid cartilage, forming a shallow groove that is easily identifiable on the lateral surface of the neck. Injecting anaesthetic into the ISG will provide adequate spread around the BP. The external jugular vein (EJV) usually crosses the area of the ISG as it drains to the root of the neck. Indications for this particular approach include surgery of the shoulder/shoulder joint, lateral two thirds of the clavicle, proximal humerus and the elbow joint (Oldman and Nicholls, 2004; Mariano *et al.*, 2009).

Easily palpable landmarks for this approach are the clavicular head of the sternocleidomastoid muscle (SCM), EJV and the clavicle (Haddad and Coventry, 2002). The AS emerges deep to the SCM to form the floor of the posterior triangle of the neck. The muscle runs inferolaterally to then attach to the scalene tubercle on the superior surface of the first rib (Mariano *et al.*, 2009). If the anaesthesiologist finds it difficult to identify the ISG, the patient can be requested to take in a deep breath or to lift their head (extend their head) against pressure. This will help highlight the anatomical structures and landmarks, as well as the groove.

A sonography-guided interscalene block does not make use of distinct, palpable bony landmarks to obtain a correct needle insertion site. Instead, the aim is to visualise the correct “pattern” on the screen before proceeding. This so-called pattern refers to the two scalene muscles with the roots of the BP lying between them (Lapegue *et al.*, 2014).

An advantage of this approach is that, unlike the supraclavicular approach, it anaesthetises the supraclavicular nerve, thereby providing a block that anaesthetises structures deep to both the upper extremity and shoulder (Haddad and Coventry, 2002; Mariano *et al.*, 2009). The supraclavicular nerve supplies the skin over the shoulder, so blocking this nerve will allow for pain-free surgery of the shoulder region. However, a disadvantage of this approach is that the anaesthetic solution may not spread to the

inferior trunk of the BP (C8, T1) and is therefore not recommended for surgery of the forearm or hand.

Complications that may occur include damage or anaesthesia of the ipsilateral phrenic nerve leading to diaphragmatic paresis (most common injury found with this approach) and a reduction in pulmonary function. It may also cause Horner's syndrome, a paralysis of the ipsilateral sympathetic cervical chain caused by drugs, surgery or local compression. But in the case of an interscalene block, it can be caused by the large accumulation of local anaesthetic solutions or the atypical proximal migration of the solution above the clavicle toward the BP area. Patients with Horner's syndrome may present with: miosis, a condition where there is excessive constriction of the pupil of the eye; anhidrosis absence of perspiration; ptosis or drooping of the upper eyelid; and vasodilation, which is the dilatation of blood vessels, decreasing blood pressure (Mariano *et al.*, 2009; Lapegue *et al.*, 2014). Vascular puncture can lead to haematoma formation, while injury to the recurrent laryngeal nerve could result in hoarseness. Life-threatening, yet rare, complications include common carotid artery puncture, pneumothorax and subdural injection (De Andres and Sala-Blanch, 2002; Helayel *et al.*, 2007; Mariano *et al.*, 2009; Russon *et al.*, 2009)

2.5.2. Supraclavicular block

The supraclavicular approach is performed lateral to the insertion of the clavicular head of the SCM on the clavicle, in the supraclavicular fossa (SCF). It is performed where the BP runs between the clavicle and the first rib, together with the SCA. At this location, the superficial nerves innervate the proximal part of arm, while the deeper nerves, closer to the first rib, innervate the distal part of the arm (Hanumanthaiah *et al.*, 2015). Indications for this approach are surgery of the upper extremity (shoulder, arm, elbow joint, forearm, and the hand) (Oldman and Nicholls, 2004).

Landmarks for this approach are the clavicular head of the SCM and the superior surface of the clavicle. The ISG is first palpated and followed distally. The needle insertion point is at the most inferior part of the ISG, where the neck “flattens out”. The needle is directed posterior to the pulsating SCA where the cords of the BP are located (Leonard and Papper, 1961; Hempel *et al.*, 1981; Koscielniak *et al.*, 2009; Hanumanthaiah *et al.*, 2015).

Advantages of this block include the rapid onset of anaesthesia, high success rate and blocking of most of the upper extremity (Haddad and Coventry, 2002; Coventry, 2010). Complications that can occur include: pneumothorax; vascular puncture; Horner’s syndrome; hemidiaphragmatic paresis; hoarseness of the voice (due to anaesthesia of or damage to the recurrent laryngeal nerve) and intravascular or intraneural injection (Hempel *et al.*, 1961; Haddad and Coventry, 2002).

2.5.3. Infraclavicular block

The infraclavicular nerve block is performed in the infraclavicular fossa (ICF), inferior to the clavicle, in close proximity to the coracoid process (Figure 3). This is an area where the axillary vessels and BP cords lie deep to the pectoral muscles (Carty and Nicholl, 2007). Indications for this approach are surgery of the distal arm, elbow, forearm and the hand (Raj *et al.*, 1973; Oldman and Nicholis, 2004).

Landmarks for this approach include the coracoid process and the clavicle (Haddad and Coventry, 2002). The coracoid process can be identified as a bony prominence just medial to the shoulder joint. The needle will be inserted at a point medial to the coracoid process and inferior to the clavicle, approximately 1 cm caudal to the mid-clavicular point.

An advantage to this approach is ease of arm positioning. With the other two approaches, the arm may have to be abducted at a 90-degree angle or flexed at the elbow joint - which might be impossible in patients with serious trauma to the upper extremities. The disadvantage is that the landmarks for this approach may not always be easily visible or palpable (Coventry, 2010). At this point, the cords of the BP is surrounding the AA and

therefore the needle might have to be repositioned - close to each cord - in order to ensure the local anaesthetic adequately spreads around each cord. This could increase the risk of needle related complications/injuries.

Complications are rare, but the most prevalent is a pneumothorax, as well as vascular puncture along the upper limb and neck (Conventry, 2010). Clear knowledge of both the anatomical and sonographic appearance of the anatomy of the BP would assist in reducing these complications and increase procedural success.

3. Aim

The aim of this MSc study was to investigate the macroscopic and sonographic anatomy of the BP at three points where BP blocks are commonly performed.

4. Research objectives

1. To accurately describe the complete anatomy and the course of the BP by dissection of formalin-fixed cadavers.
2. To use sonographic imaging to describe the anatomy of three locations used for blocking the BP. The anatomy will be described, for each location by:
 - a. Reporting any variations seen on the sonographic image
 - b. Measuring the distance from the skin to the most superficial point of the BP.
 - c. Measuring the distance from the skin to the musculoskeletal and/or vascular structures within the interscalene, infraclavicular and supraclavicular approaches.
 - d. Measuring the distance from the closest point of the BP to the surrounding musculoskeletal and vascular structures.
 - e. Determining the minimum distance to an ideal hypothetical needle point location for the injection of local anaesthetic solution.
3. To provide an accurate anatomical guideline (a step-by-step sonography-guided block procedure) for successfully performing the three BP blocks.

5. Materials and Methods

5.1. Cadaveric study

Bilateral dissection of the root of the neck was performed on 60 human formalin fixed adult cadavers, comprising of 43 males and 17 females, and ages ranging from 29 - 91 years. The mean height and weight of the sample were 1.65 meters and 63 kilograms respectively. The BMI of cadavers ranged from 12 – 38 kg/m². The cadavers were obtained from the Department of Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria in South Africa. The use of these cadavers was in accordance with the South African National Health Act 61 of 2003 and permission to conduct the dissections were obtained from the Head of the Department of Anatomy as well as Faculty of Health Science Research Ethics Committee.

The cadavers were placed in a supine position with the arms abducted to allow for better access to the BP. To expose the BP, dissection was performed from superficial to deep to remove and reflect structures that obscure visualisation of the BP. In the neck, the platysma muscle was exposed below the skin and reflected towards its insertion at the base of the mandible to reveal the SCM deep to it. The SCM was carefully dissected from its origins at the sternum and clavicle and its insertion at the mastoid process, together with the underlying neurovascular structures. Deep to the SCM, the superior and inferior bellies of the omohyoid muscles were exposed and reflected towards their origin at the scapula. Deep to the bellies of the omohyoid muscle, the BP was observed running between the AS and MS (Figure 4). The phrenic nerve, which courses towards the thoracic inlet anterior to the AS, was dissected and removed together with the AS muscle to directly expose the roots of the BP. Vascular structures in the area - the SCA and SCV - was observed to course inferior to the BP and the vertebral artery located anterior to the AS and medial to the phrenic nerve.

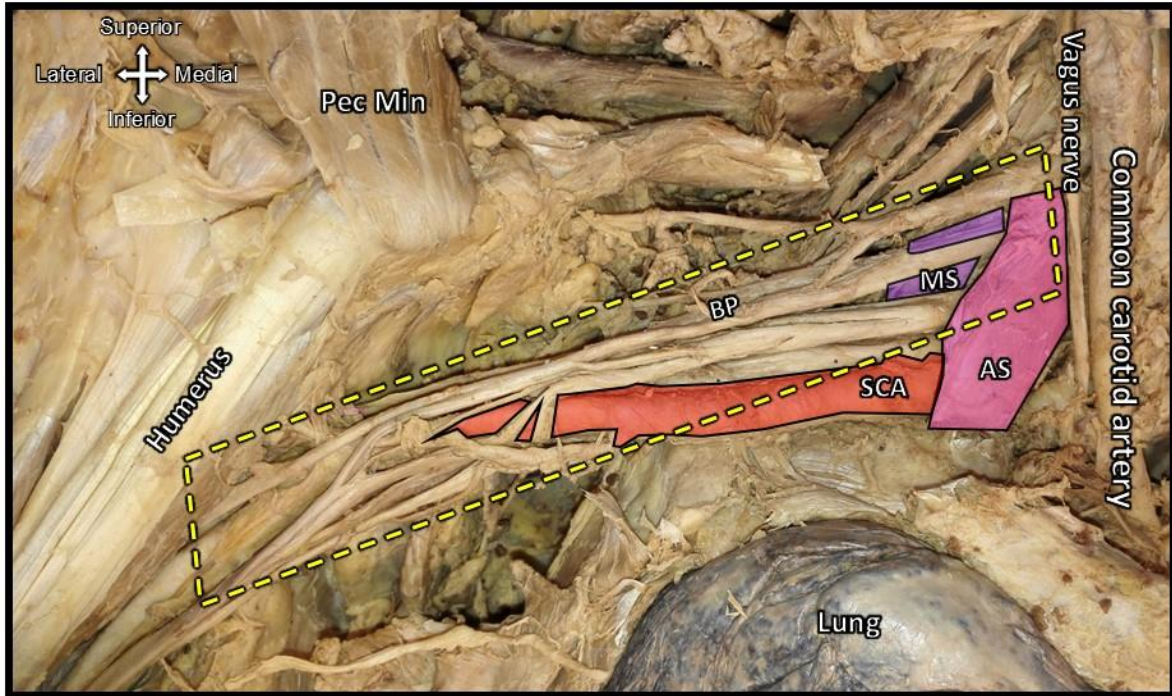


Figure 4: Cadaveric photograph showing the BP in situ. The pectoralis minor (Pec Min) was reflected to expose the brachial plexus (BP) - passing between the anterior scalene (AS) and middle scalene (MS) muscles in relation to the subclavian artery (SCA) proximally and axillary artery (AA) distally.

To access the axilla and the arm, an incision was made through the deltopectoral groove, removing skin and subcutaneous tissue. The deltoid, pectoralis minor and major muscles were transected at their origins and reflected towards their insertions (Figure 4). Thereafter, the medial and lateral pectoral nerves - branches from the medial and lateral cords of the BP, respectively - were identified. The lateral pectoral nerve was located superomedial to the pectoralis minor muscle, whereas, the medial pectoral nerve pierced the pectoralis minor muscle. Once the above-mentioned structures were removed, the axillary vessels were located in the axillary sheath, together with the cords and terminal branches of the BP.

Once the BP and its related structures were clearly exposed, it was observed from its roots at the vertebrae to the terminal branches within the axilla. Each nerve was followed along its course, noting all surrounding structures and variations from the normal described anatomy. Cadavers were excluded from the study when the area of interest or key muscular or neurovascular structures were damaged.

5.2. Sonographic study

Sixty medical and medical science students of the University of Pretoria, 30 males and 30 females, were asked to participate in this study. All volunteers were above the age of 18 and had a BMI (Body Mass Index) ranging between 20 - 34kg/m². Written informed consent was obtained from each participant, conveying the aim of this study and all essential information. The primary investigator assisted a qualified anaesthesiologist to operate the sonographic machine and obtain the scans of the BP. Scans of all three locations were performed bilaterally on each participant, giving a total sample of 120 BPs scanned and analysed.

Sonographs were performed using an Edge™ Ultrasound system machine, ref: P15000-11, SN-03P55Z, with a frequency ranging from 6 - 13MHz. It was decided to use a linear probe with a footprint size of 2.5cm. All scans taken were of horizontal/transverse sections of the related arteries (either the SCA or the AA) as they are the main landmarks when identifying the BP. Structures identified were either defined as hyperechoic (appear white on the screen) or hypoechoic (appear black or grey on the screen). Arteries were differentiated from the veins as having more of an outward pulse and confirmed using the Doppler function to detect reflected sound waves of blood flowing through the arteries. Veins, on the other hand, had an inward pulse.

Volunteers were asked to lie in a supine position at the head of the bed, with their head turned to the contralateral side to where the sonographic probe was to be placed. They were requested to expose their neck and upper thoracic area (to expose the entire clavicle). A small amount of KY sterile gel was applied to the skin, followed by placement of the probe angled parallel or perpendicular to the clavicle. The sonographic probe was placed to visualise the BP at the levels of the ISG, SCF and the ICF. At each of these three locations, the probe was positioned to replicate its placement in a clinical setting.

Once an image exposing the relevant structures was obtained, a screen shot was taken to allow for on-screen editing. Several measurements were made from the frozen image on the screen. These were: (A) the shortest distance from the skin to the BP, (B) the minimum distance from the corner footprint of the probe to the hypothetical minimum injection site and the distance between the hypothetical tip of the needle to its surrounding vascular and musculoskeletal structures related to each of the three approaches, which was taken as the shortest distance between the two structures. For the interscalene approach, measurements were made from the (C) skin to AS, (D) skin to MS, (E) skin to SCM, (F) BP to AS, (G) BP to MS, (H) BP to SCM (Figure 5A & B). Images 5 to 7 below is referred to the norm for each approach

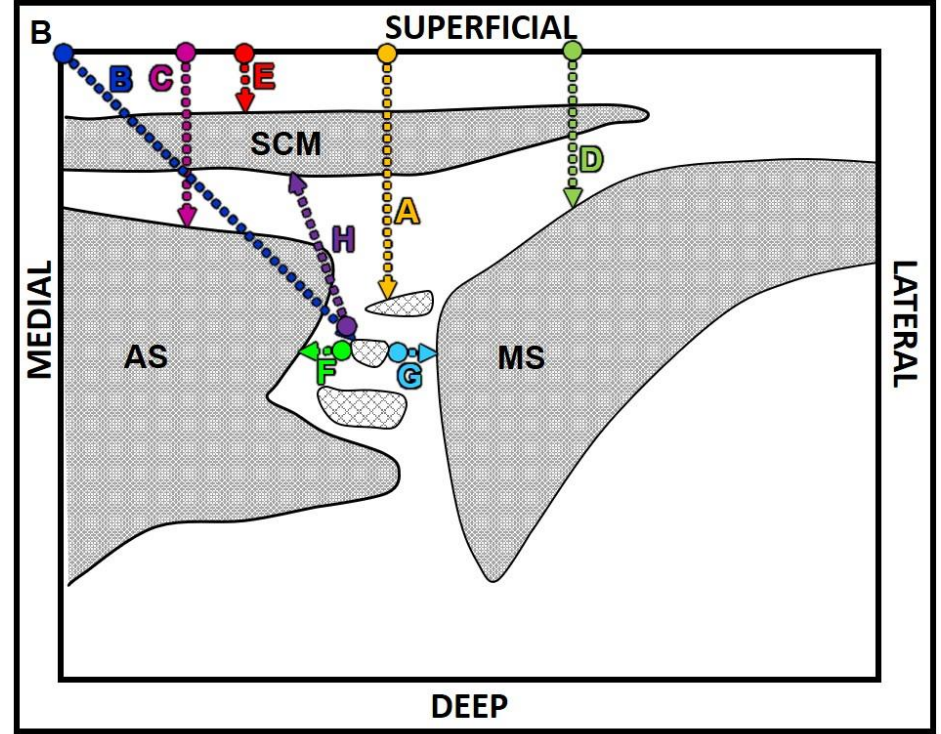
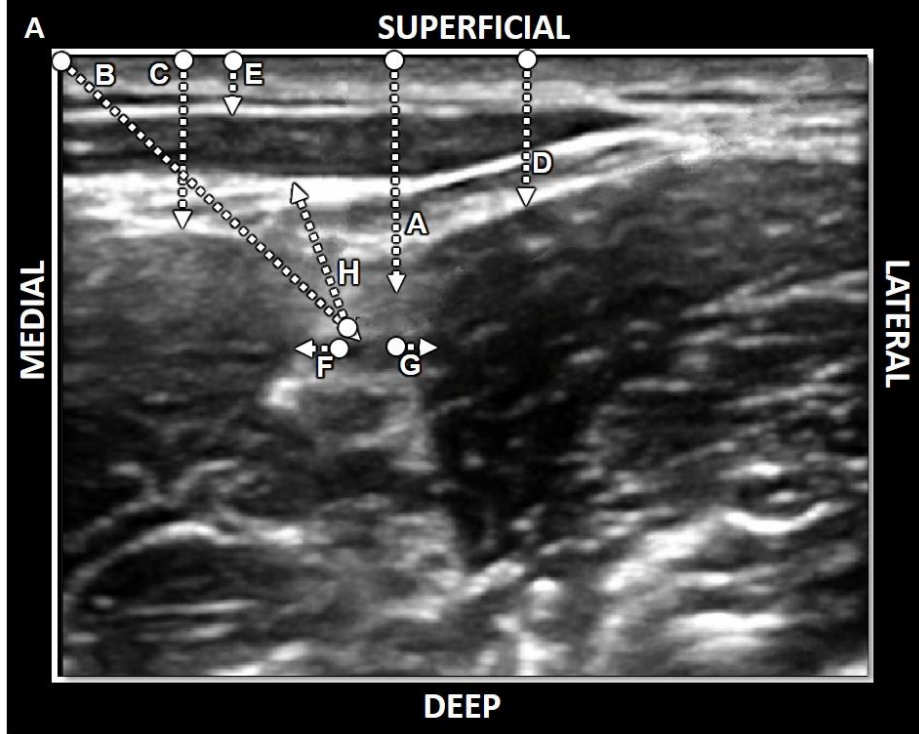


Figure 5A & B: Interscalene approach showing the various measurements that were taken. A - skin to superficial point of BP, B - the corner footprint of the probe to hypothetical minimum needle injections site, C - skin to AS, D - skin to MS, E -skin to SCM, F - BP to AS, G - BP to MS, H - BP to SCM.

For the supraclavicular approach, the measurements were from the: (C) skin to SCA, (D) skin to SVC, (E) BP to SCA, (H) BP to SCV (Figure 6A & B).

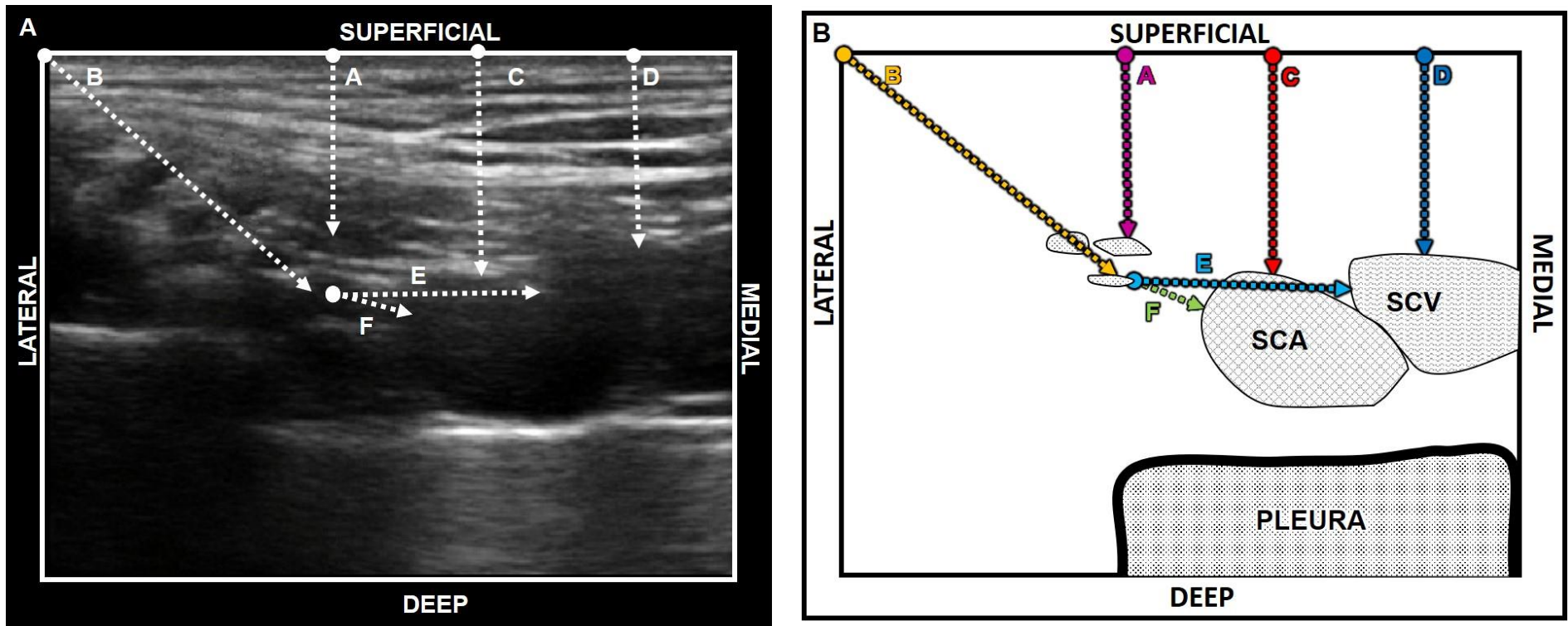


Figure 6A & B: Supraclavicular approach showing the various measurements that were taken. A - skin to superficial point of BP, B - the corner footprint of the probe to minimum distance to an ideal hypothetical needle site, C - skin to SCA, D - skin to SCV, E - BP to SCV, F - BP to SCA.

For the infraclavicular approach, measurements were from the: (C) skin to superficial point of the pectoralis minor, (D) skin to superficial point of the pectoralis major, (E) skin to SCV, (A) the skin to each cord of the BP (Figure 7A & B).

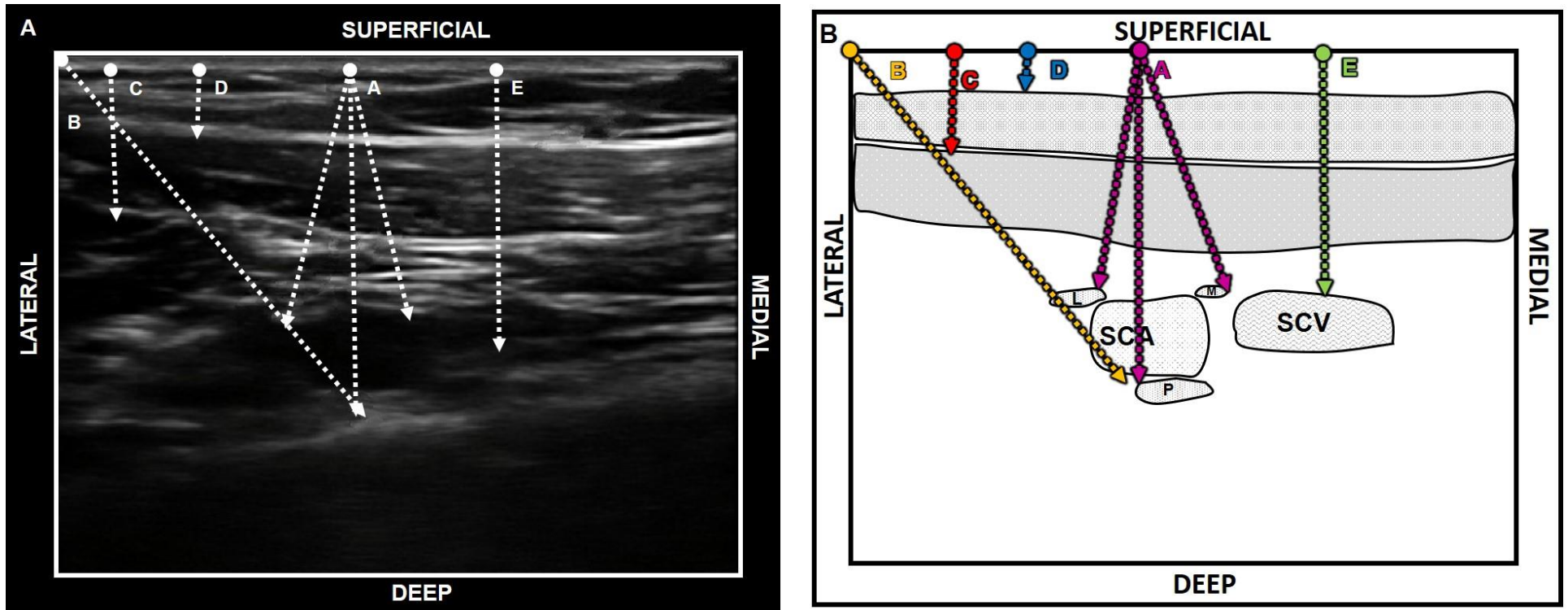


Figure 7A & B: Infraclavicular approach showing the various measurements that were taken. A - skin to superficial point of BP (each cord), B - the corner footprint of the probe to minimum distance to an ideal hypothetical needle site, C - skin to superficial point of pectoralis minor, D - skin to superficial point of pectoralis major, E - skin to SCV.

A Shapiro-Wilks test was then done to test for normality. The purpose of this test was to determine normal distribution from a random sample. This test generates a W-value. Smaller W-values indicate that the sample was not normally distributed. This test will reject the hypothesis of normality if the p-value is less than or equal to 0.05. If the hypothesis is rejected, it allows you to state with 95% confidence the data does not fit normal distribution. However, if there is normal distribution, we can confidently state no significant difference from normality was found. The results obtained from this study was for left and right hand side measurements, due to this the Shapiro-Wilks test for each side was done to obtain all relevant values and then subtracted from each other to obtain a difference. The difference was used to determine normality. If the measurement pair was normally distributed a further paired t-test was done to determine significance, however, if the measurement pair was not normally distributed, a Wilcoxon sign rank test was done, again to determine significance

The Wilcoxon sign-ranked test created z-scores. These z-scores determined the p-value and therefore, the significance. The standard score, which is referred to as a z-score, allows us to calculate the probability of a score occurring within our normal distribution and further enable us to compare two scores that are from different normal distributions. In other words, the standard score does this by converting or standardising scores in a normal distribution to z-scores in what becomes a standard normal distribution.

5.3. Anatomical guidelines

In order to formulate an accurate guideline, the steps of the procedure were recorded under the following headings; patient positioning, patient preparation, probe placement, anatomical structures seen on the sonographic scan, as well as the needle insertion when performing a nerve block. Information regarding each of these headings was obtained from verbal descriptions of Dr Möhr as he was obtaining the ideal image for each of the three approaches, as well as from published scientific articles on the subject of sonography-guided BP blocks (Mistry *et al.*, 2006, Helayel *et al.*, 2007, Hadzic 2012, Hanumanthaiah *et al.*, 2015).

6. Results

6.1. Cadaveric study

A total of a 120 BPs were dissected and examined. However, taking the exclusion criteria into consideration, twelve sides were excluded, leaving a total sample of 114 BPs examined. Three BPs on the right and three on the left were excluded from the study due to damage caused by previous dissections.

Of the 60 dissected cadavers, 52 (86%) displayed the normal BP anatomy as described in several anatomical texts. The remaining 8 (13%) presented with abnormal variants. The most common variant was the direct branching of the suprascapular nerve from the C5 root instead of the superior trunk (Figure 8) which was recorded in three cases (5%). In these cases, the superior trunk was solely formed from the root of the C6 spinal nerve.

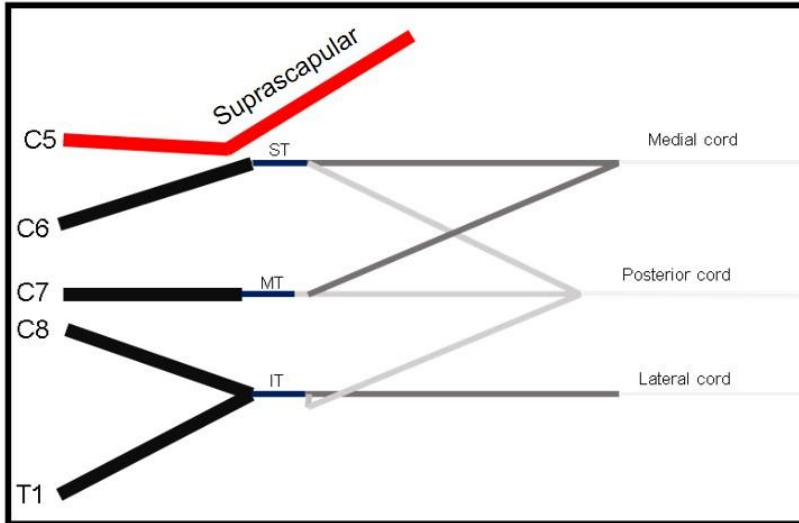


Figure 8: Variation found in the BP: the C5 spinal root forming the suprascapular nerve travelling posteriorly. ST- superior trunk, MT- middle trunk, IT- inferior trunk.

In one case (1.67%), the long thoracic nerve pierced the MS muscle before continuing on its normal course along the mid-axillary line (Figure 9).

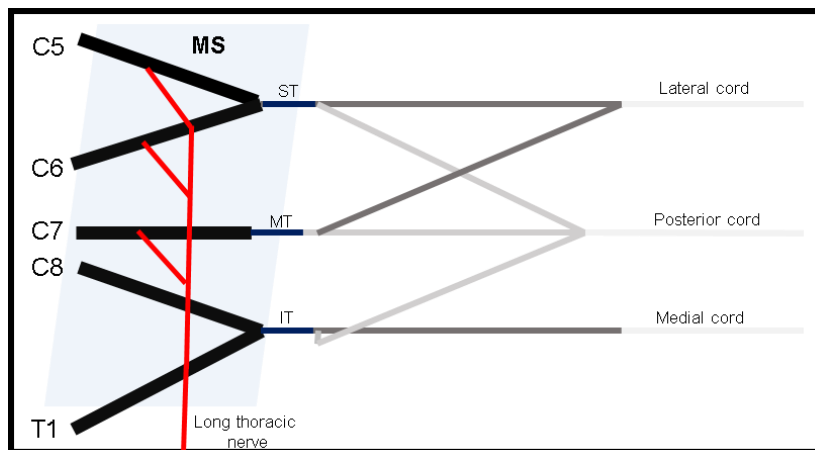


Figure 9: Variations in the BP: the long thoracic nerve which receive contributions from C5, C6 and C7 spinal nerves, pierce the middle scalene (MS) muscle on its course towards the serratus anterior muscle. ST- superior trunk, MT- middle trunk, IT- inferior trunk.

The medial cutaneous nerve of the arm branched separately as a single larger branch, rather than branching directly from the medial cord (Figure 10) in one case (1.67%).

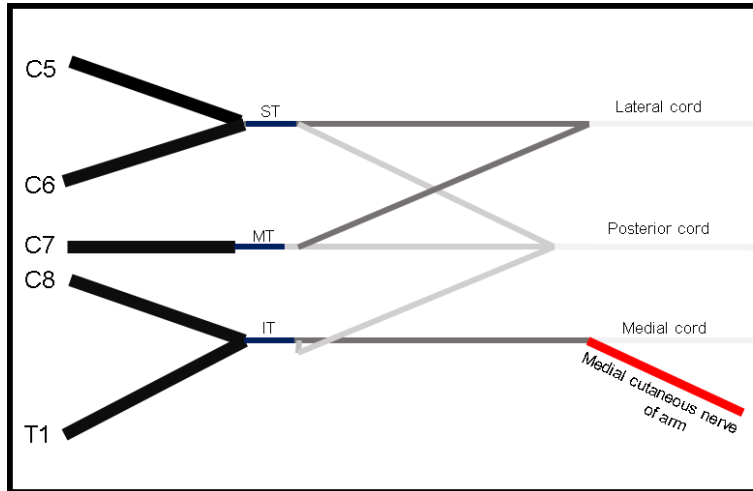


Figure 10: Variation found in the BP: the medial cutaneous nerve branches as a distinct larger nerve, rather than a branch from the medial cord itself. ST- superior trunk, MT- middle trunk, IT- inferior trunk.

In another case (1.67%), the musculocutaneous nerve gave rise to a communicating branch to the median nerve (Figure 11).

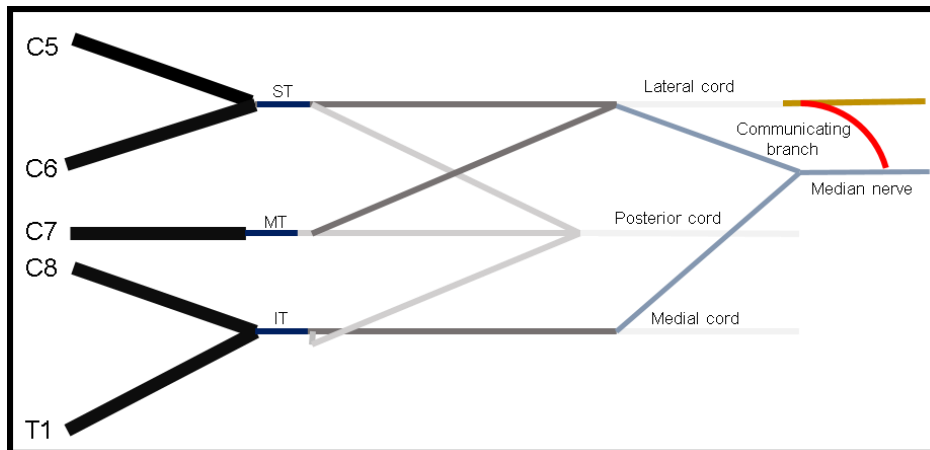


Figure 11: Variation in the BP: the musculocutaneous nerve (gold line) giving off a communication branch travelling to the median nerve. ST- superior trunk, MT- middle trunk, IT- inferior trunk.

Normal variation was also present in the median nerve, where in one case (1.67%) it was formed by two lateral roots from the lateral cord and one medial root from the medial cord (Figure 12).

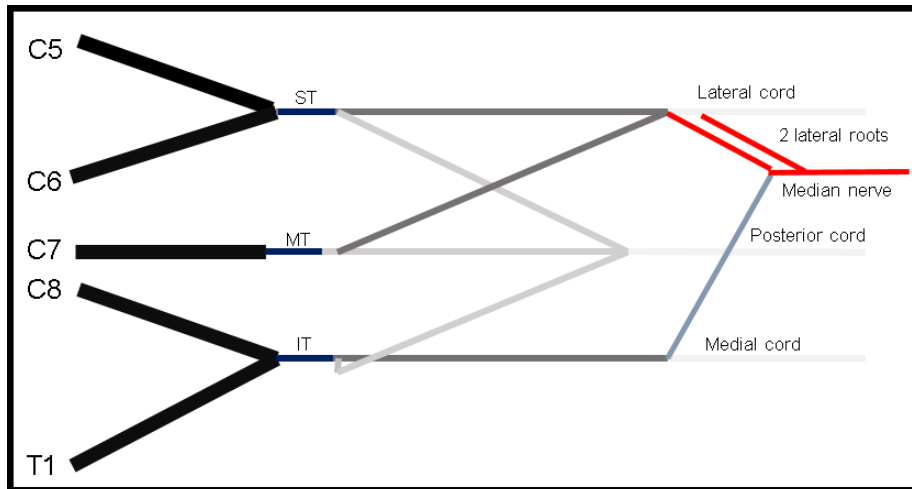


Figure 12: Variation in the BP: the lateral cord contributing 2 lateral roots to the formation of the median nerve. ST- superior trunk, MT- middle trunk, IT- inferior trunk

In another case (1.67%), the inferior trunk was formed from the T1 and T2 spinal nerves (Figure 13). There was also observed variation in the level at which the segments of the BP and its terminal branches divided and branched off.

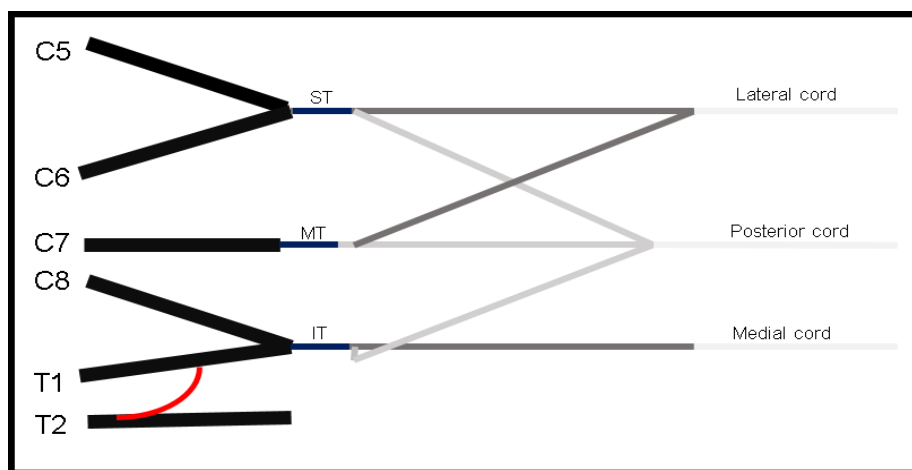


Figure 13: A post-fix BP: Spinal root T2 contributes to the formations of the Inferior trunk. ST- superior trunk, MT- middle trunk, IT- inferior trunk

The normal BP pattern was observed in the remaining dissections. Further vascular and musculoskeletal structures were recognised and found in close proximity to the BP. These structures were used as landmarks to determine the location of the BP. The phrenic nerve, which is formed from the anterior rami of C3 to C5, was found at the lateral border of the AS, which continues inferiorly over the anterior surface of the AS and was found deep to the prevertebral layer of the deep cervical fascia. The vertebral artery, which ascends in the transverse foramina of C6 to C2 vertebrae, was visible anterior to the roots of the BP as they exit the vertebral canal through the intervertebral foramina. Inferior to the clavicle – within the axilla – both pectoralis major and minor muscles lie in direct contact to the BP, anterior or superficial to the BP. The pectoralis major muscle is a large fan shaped muscle forming the anterior wall of the axilla and overlies the pectoralis minor muscle, which consequently covers the second part of the AA, including the cords and branches of the BP.

6.2. Sonographic study

About 79% of volunteers presented with a normal anatomy of the BP, whereas the remaining 21% display noteworthy variations. Further results of each approach were recorded and presented in the tables below. The results were pooled (sexes, age and BMI) together and averages were calculated for each measurement. All measurements were taken on the sonographic scans using the edit function of the sonographic machine. The various measurements for each approach are summarised in Tables 2 - 4. Distances between structures are shown for both left and right sides of the sample.

Table 2: Mean measurements taken in the interscalene approach

	Distance in cm		Interquartile range	
	Left	Right	Left	Right
Minimum distance to hypothetical injection site	1.72	1.76	1.50 ; 1.88	1.48 ; 1.92
Skin – BP	0.63	0.65	0.54 ; 0.76	0.49 ; 0.90
Skin – AS	0.73	0.76	0.63 ; 0.90	0.58 ; 0.89
Skin – MS	0.78	0.76	0.63 ; 0.86	0.60 ; 0.94
Skin – SCM	0.26	0.28	0.22 ; 0.31	0.23 ; 0.35
BP – AS	0.77	0.81	0.61 ; 0.99	0.64 ; 0.99
BP – MS	0.90	0.90	0.69 ; 1.11	0.73 ; 1.07
BP – SCM	0.80	0.79	0.59 ; 1.11	0.58 ; 1.11

Note the mean skin to BP depth for this approach is 0.64 with a standard deviation of 0.3

Table 3: Mean measurements taken in the supraclavicular approach

	Distance in cm		Interquartile range	
	Left	Right	Left	Right
Minimum distance to hypothetical injection site	1.95	2.08	1.76 ; 2.22	1.86 ; 2.33
Skin – Superficial BP point	0.89	0.90	0.75 ; 1.04	0.75 ; 1.20
Skin – SCV	1.13	1.10	0.91 ; 1.39	0.98 ; 1.40
Skin – SCA	1.00	1.00	0.78 ; 1.25	0.76 ; 1.31
BP – SCA	0.61	0.59	0.51 ; 0.74	0.49 ; 0.69
BP – SVC	1.11	0.89	0.87 ; 1.30	0.78 ; 1.11

Note the mean skin to BP depth for this approach is 0.89 with a standard deviation of 0.3

Table 4: Mean measurements taken in the infraclavicular approach

	Distance in cm		Interquartile range	
	Left	Right	Left	Right
Minimum distance to hypothetical injection site	2.63	2.72	2.31 ; 3.15	2.33 ; 3.36
Skin – Posterior cord of BP	2.60	2.59	2.17 ; 3.05	2.32 ; 3.10
Skin – Medial cord of BP	2.03	2.05	1.66 ; 2.33	1.70 ; 2.50
Skin – Lateral cord of BP	2.16	2.15	1.72 ; 2.59	1.68 ; 2.62
Skin – Pec Min	1.14	1.16	1.00 ; 1.43	1.01 ; 1.34
Skin – Pec Maj	0.53	0.54	0.44 ; 0.66	0.44 ; 0.68

Note the mean skin to BP depth for this approach is 2.6 with a standard deviation of 0.7

Note for the infraclavicular approach (Table 4), the anaesthesiologist’s recommended technique was to first block the posterior cord, followed by the medial and lateral cord if necessary, therefore the minimum distance to hypothetical injection site is similar to that of the distance from the probe to the posterior cord.

All measurements were directly done from the scans taken using the edit function on the sonographic machine. Measurements were re-calculated at a later stage manually from each scans - using a ruler to obtain values that were further covered to a measurement according to the scale present in the scan - in order to ensure accuracy. A pearson’s correlation test was done between sonographic scan measurements and manual scan measurements to obtain an r-value of 0.94. This meant that values of both data sets were similar, further proving precision of measurements taken.

The parametric (continuous) and non-parametric (categorical) data were analysed. A normal paired t-test was used for the parametric data, whereas, a Wilcoxon sign ranked test was used for non-parametric data. From the parametric data types: age, weight and BMI - all had a p-value of less than 0.05 - therefore indicating that the data was not normally distributed (Table 5). Height, however, had a p-value greater than 0.05, was the only normally distributed parametric data type.

Table 5: A summary of the parametric data types

Data type	Sample size	Median	Interquartile range
Age	60	21	20 ; 22
Height (cm)	60	172	164 ; 178
Weight (kg)	60	70	62 ; 80
BMI	60	24	21 ; 26

The non-parametric data types consisted of sex and hand dominance. Both these groups had two categories. For sex, males were assigned the number 0, and females 1. The same applied to hand dominance, 1 was given for right hand dominance and 0 for left hand dominance.

All measurements were then tested for normality and significance. Results from the Shapiro-Wilk test revealed normal distribution amongst the data if a p-value of greater than 0.05 was obtained in the sample of 60 volunteers. Table 6 below shows the measurements that were normally distributed, followed by table 7 which shows the remaining measurements that were not normally distributed.

Table 6: Measurements that were normally distributed

Approach	Measurement	P values
Interscalene approach	Left side BP to SCM muscle - right side BP to SCM muscle	0.43
	Left side BP to MS muscle - right side BP to MS muscle	0.10
Supraclavicular approach	Left side minimum distance to the hypothetical site - right side minimum distance to the hypothetical injection site	0.29
	Left side skin to SCV - right side skin to SCV	0.62
	Left side skin to SCA - right side skin to SCA	0.99
	Left side BP to SCV - right side BP to SCV	0.32
Infraclavicular approach	Left side minimum distance to the hypothetical site - right side minimum distance to the hypothetical site	0.21
	Left side skin to the posterior cord of the BP - right side skin to the posterior cord of the BP	0.17
	Left side skin to the lateral cord of the BP - right side skin to the lateral cord of the	0.19

Table 7: Measurements that were not normally distributed

Approach	Measurement	P values
Interscalene approach	Left side minimum distance to the hypothetical site -	
	Left side skin to superficial point of BP - right side skin to superficial point of BP	
	Left side skin to AS muscle - right side skin to AS muscle	< 0.001
	Left side skin to MS muscle - right side skin to MS muscle	
	Left side BP to AS muscle - right side BP to AS muscle	
	Left side skin to SCM muscle - right side skin to SCM muscle	0.01
	Left side skin to superficial point of BP - right side skin to superficial point of BP	0.02
Supraclavicular approach	Left side BP to SCA - right side BP to SCA,	
	Left side minimum distance to the hypothetical site - right side minimum distance to the hypothetical site	< 0.001
Infraclavicular approach	Left side skin to the medial cord of the BP - right side skin to the medial cord of the BP	
	Left side skin to pectoralis minor - right side skin to pectoralis minor	

Following the test for normality, measurements were then tested for statistical significance. Overall there were a total of 21 comparisons, due to which the Bonferroni correction method was adopted. The Bonferroni method is used to adjust the p-value when numerous dependent or independent statistical tests are being performed simultaneously on a single data set. The Bonferroni correction method, reduces the chances of obtaining false-positive results (type I errors) when multiple paired tests are performed on a single set of data. This test is done by dividing the critical p-value (α/α) by the number of comparisons being made. For this study it was $0.05/21 = 0.0023$, Therefore, a p-value less than 0.0023 was considered significant.

As we can see, when comparing left side minimum distance (lsmín) and right side minimum distance (rsmín) (Table 8), the distance varies between the left and right hands. However, for the remaining results there is no difference. Due to this, lsmín and rsmín cannot be combined and separate data tests must be done to confirm these data sets.

If the measurements were normally distributed a paired T-test was done to test for significance. Table 8 below reveals the only significant measurement to be that of the supraclavicular approach: left side minimum distance to the hypothetical site - right side minimum distance to the hypothetical site with a p-value of 0.0019. Equally if the measurements were not normally distributed a Wilcoxon sign-ranked test was done to test for significance. In the supraclavicular approach the left side skin to superficial point of BP - right side skin to superficial point of BP and left side BP to SCA - right side BP to SCA were the only significant measures with a p-value of 0.04 and less than 0.001 respectively (Table 9).

Table 8: Results of left and right side comparisons

Paired T-test					
Variable	Sample size (n)	Mean	95% confidence interval		P value
Interscalene approach: left side BP to MS muscle - right side BP to MS muscle	60	0.11	-0.08	0.10	0.81
Interscalene approach: left side BP to SCM muscle - right side BP to SCM muscle	60	0.04	-0.06	0.14	0.39
Supraclavicular approach: left side minimum distance to the hypothetical site (lsmin) - right side minimum distance to the hypothetical site	60	-0.16	-0.26	0.60	0.0019*
Supraclavicular approach: left side skin to SCV - right side skin to SCV	60	-0.30	-0.09	0.04	0.37
Supraclavicular approach: left side skin to SCA - right side skin to SCA	60	0.75	-1.38	0.29	0.46
Infraclavicular approach: left side minimum distance to the hypothetical site - right side minimum distance to the hypothetical site	60	-0.03	-0.14	0.08	0.58
Infraclavicular approach: left side skin to the posterior cord of the BP – right side skin to the posterior cord of the BP	60	-0.01	-0.12	0.10	0.86
Infraclavicular approach: left side skin to the lateral cord of the BP - right side skin to the lateral cord of the BP	60	-0.02	-0.15	0.10	0.72
* = Significant					

Table 9: Results showing significance**Wilcoxon sign-ranked test**

Variable	Sample(n)	P value
Interscalene approach: left side minimum distance to the hypothetical site - right side minimum distance to the hypothetical site	60	0.86
Interscalene approach: left side skin to superficial point of BP - right side skin to superficial point of BP	60	0.95
Interscalene approach: left side skin to AS muscle - right side skin to AS muscle	60	0.68
Interscalene approach: left side skin to MS muscle - right side skin to MS muscle	60	0.28
Interscalene approach: left side skin to SCM muscle - right side skin to SCM muscle	60	0.42
Interscalene approach: left side BP to AS muscle - right side BP to AS muscle	60	0.66
Supraclavicular approach: left side skin to superficial point of BP - right side skin to superficial point of BP	60	0.04*
Supraclavicular approach: left side BP to SCA - right side BP to SCA	60	P < 0.001*
Infraclavicular approach: left side skin to the medial cord of the BP - right side skin to the medial cord of the BP	60	0.49
Infraclavicular approach: left side skin to pectoralis minor - right side skin to pectoralis minor	60	0.71
Infraclavicular approach: left side skin to pec major muscles – right side skin to pec major muscle	60	0.93

*** = Significant**

If no significant difference was found, each measurement (dependant variable) was then added to obtain total values, and further tested for correlation against fixed factors: height, weight, BMI and age (independent variables) using regression models. (Tables 10, 11 and 12)

Table 10: Regression models showing the R values for the total measurement values of the interscalene approach

	Minimum distance to the hypothetical site	Skin to BP	Skin to AS	Skin to MS	Skin to SCM	BP to AS	BP to MS	BP to SCM
Weight	0.11	0.04	0.14	0.23	0.22	0.15	0.14	0.04
Height	-0.16	0.43	0.44	0.01	-0.05	-0.01	-0.03	-0.11
BMI	0.22	0.44	0.42	0.23	0.28	0.17	0.23	0.08
Age	0.02	0.18	0.18	0.05	0.07	0.13	0.10	0.03

Table 11: Regression models showing the R values for the total measurement values of the supraclavicular approach

	Skin to BP	Skin to SCV	Skin to SCA	BP to SCV	BP to SCA
Weight	0.28	0.52	0.58	0.02	0.04
Height	-0.07	0.08	0.22	0.23	0.003
BMI	0.33	0.37	0.53	-0.04	-0.02
Age	0.003	-0.05	0.25	0.02	0.36

Table 12: Regression models showing the R values for the total measurement values of the infraclavicular approach

	Hypothetical minimum distance to the hypothetical site (Tifmin)	Skin to posterior cord of BP (Tisbpp)	Skin to lateral cord of BP	Skin to medial cord of BP	Skin to pectoralis minor	Skin to pectoralis major
Weight	0.67	0.72	0.33	0.24	0.23	0.10
Height	0.27	0.32	0.05	-0.09	0.04	0.09
BMI	0.59	0.63	0.29	0.37	0.20	0.06
Age	0.27	0.30	0.08	0.04	0.17	0.02

If an R-value greater than or equal to 0.75 was obtained, there was a perceptible correlation between the dependant and independent variables. This was again done for all three approaches. No correlation between factors and the measurement were found in both the interscalene and supraclavicular approaches. In the Infraclavicular approach specific correlation was found between total infraclavicular minimum distance to the hypothetical site (Tifmin) in centimetres (dependant variable) and weight in kilograms (independent variable). Tifmin had an R value of 0.67 (Figure 14A). Correlation was also found between total infraclavicular skin to posterior cord of BP (Tifsbpp) in centimetres (dependant variable) and weight in kilograms (independent variable). Tifsbpp had a R value of 0.72 (Figure 14B). Although both R values were less than 0.75, compared to the remaining factors or independent variables these were the only two values that displayed a moderate correlation.

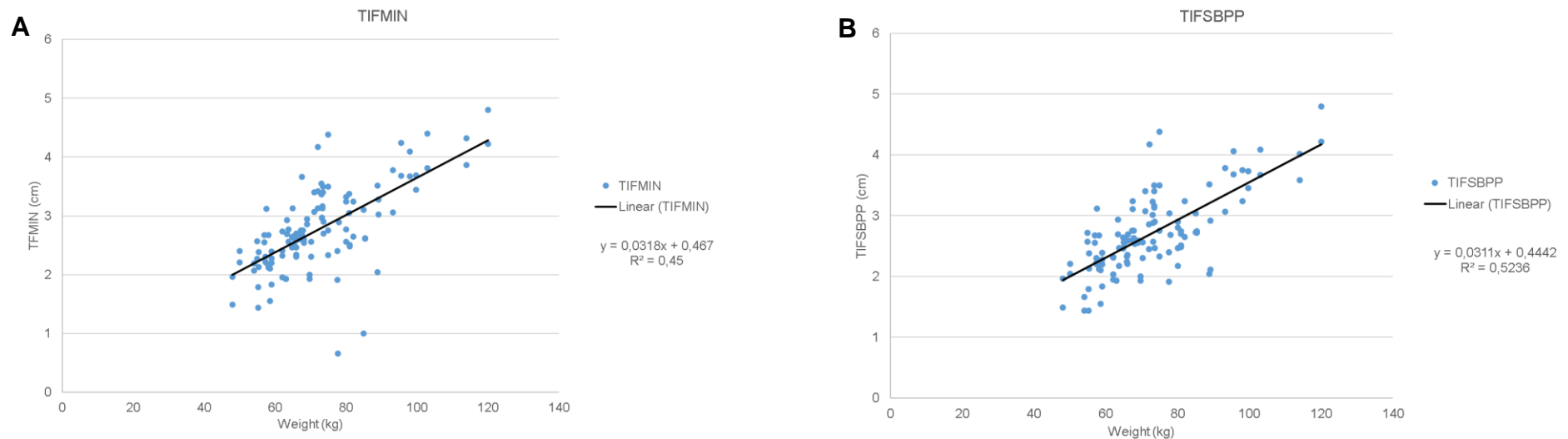


Figure 14A & B: Scatter plots showing the correlation between: A - total Infraclavicular minimum distance to the hypothetical site (Tifmin), B - total infraclavicular skin to posterior cord of BP (Tifsbpp) and weight

From the scatter plots above the R square values indicate how much of the attribution is caused by weight. In other words, 45% of variation in Tifmin can be explained by weight or is caused by weight. Likewise, 52% of variation in Tifsbpp can be explained due to weight.

Lastly, a paired t-test was done to test significant difference between males and females for each measurement in all three approaches. P-values less than 0.05 displayed significant difference. In the interscalene approach, significant difference was found between male and female skin to MS muscle ($p = 0.01$). Supraclavicular approach, significant difference was found between male and female minimum distance to the hypothetical site ($p < 0.001$), skin to SCA ($p < 0.001$) and BP to SCV ($p = 0.01$). In the infraclavicular approach, significant difference was found between male and female minimum distance to the hypothetical site ($p < 0.001$), skin to posterior cord of BP ($p < 0.001$), skin to pectoralis major muscle ($p < 0.001$) and skin to medial cord of BP ($p = 0.02$).

Observations regarding the anatomy of the BP were made from the sonographic scans taken. For each approach the the course of the BP, as well as it's surrounding structures were noted (Table 13).

Table 13: Variations seen on the sonographic scans of each approach

Approach	Percentages
Interscalene approach	
BP roots were found in a horizontal plane between the scalene muscles	3%
Variable distances found between each cord	5%
BP roots were found lying anterior to the AS muscle	3%
Supraclavicular approach	
BP found between the SCV and SCA	6%
Infraclavicular approach	
Medial cord of BP found superior to SCA	5%
Lateral cord of BP found adjacent to the posterior cord of BP	1%

7. Discussion

7.1. Cadaveric study

Variations in the branching patterns of the BP can be due to numerous factors, some of which can be explained by studying the embryological development of the upper extremity. Development starts at the 34th and 35th day of intrauterine life, and by the 46th to 48th day a definite adult BP pattern is present (Chaware *et al.*, 2012; Sinha *et al.*, 2012). Although these variations are often asymptomatic, it is very important to be aware of the possibility of these being present, especially during invasive procedures in the area. The SCA/AA, which has an important association with the divisions of the cords of the BP, influence the branching pattern. Any variation in the SCA/AA will cause the BP to readjust their position around the artery affecting the branching levels/patterns of the divisions and cords of the BP.

Upon analysis, the BP was found to be post-fixed (variable contribution from spinal root T2) in 1.67% of the cases examined. All variation found was unilateral. The most prevalent variation found was the direct branching of the C5 cord into the suprascapular nerve, which then proceeded to travel posterior to the scapula. This meant that the superior trunk was solely formed from spinal root C6. This was evident in 5% of the cases examined. Studies by Pattanshetti *et al.*, (2012) and Emamhadi *et al.*, (2016) and their colleagues reported similar findings for this variant with an incidence of 3.3% and 9% respectively. In 1.67%, the long thoracic nerve was seen piercing the MS muscle before descending down the mid-axillary line to lie superficially on the serratus anterior muscle, which it supplies with motor innervation. Similarly, Fazan *et al.*, (2003) and Emamhadi *et al.*, (2016) and their colleagues reported a much higher incidence of this variation – they reported this variation in 63% and 18% of their samples, respectively.

A communicating branch was seen between the musculocutaneous nerve and the median nerve in 1.67% of the sample. Gopal *et al.*, (2016) reported a communication between the musculocutaneous and the median nerve before piercing the

coracobrachialis muscle in 2.25% of their sample. They also reported an additional variation in which the musculocutaneous and median nerve joined after piercing the coracobrachialis muscle in 5% of cases. A study done by Pattanshetti *et al.*, (2012), described the musculocutaneous nerve to be absent altogether in 5% of the cases that they examined. In this situation, the median nerve will provide motor innervation to muscles of the anterior compartment of the arm, except for the coracobrachialis, which will receive motor innervation from a direct branch of the lateral cord of the BP.

Lastly, normal variation was also present in the median nerve, the median nerve was formed by two lateral roots from the lateral cord and one medial root from the medial cord in 1.67% of cases. The highest lateral root was noted to be at the level of the inferior part of the coracobrachialis muscle and the second lateral root was immediately distal to the first. These two roots pass obliquely to join the medial root of the median nerve (Sinha *et al.*, 2012). As can be seen in Table 14, various authors have previously reported a similar variation.

Table 14: Authors that reported a variation in the formation of the median nerve

Author	Findings
Fazan <i>et al.</i> , 2003	52%
Pattanshetti <i>et al.</i> , 2012	11.67%
Sinha <i>et al.</i> , 2012	2.5%
Emamhadi <i>et al.</i> , 2016	18.75%

Other popular findings found in previous studies, but not in the current population, include: an abnormal communication between the medial root of the medial cord and the ulnar nerve (Emamhadi *et al.*, 2016; Gopal *et al.*, 2016); two superior/upper subscapular nerves arising from the posterior cord instead of one nerve; the superior/upper subscapular and axillary nerves arising from the posterior division of the superior trunk instead of the posterior cord; the musculocutaneous nerve giving rise to a communicating branch to the formation of the median nerve (Chaware *et al.*, 2012; Sinha *et al.*, 2012); instead of branching from the posterior cord between the superior/upper and inferior/lower

subscapular nerves, the thoracodorsal nerve branching directly from spinal root C6; and the radial nerve formed from the union of the posterior divisions of the middle and inferior trunks rather than the posterior cord (Fazan *et al.*, 2003; Singhal *et al.*, 2007; Emamhadi *et al.*, 2016).

Due to the variability of the branches of the BP, the individual levels of each nerve was not documented, but the major nerve innervation of the upper arm compartments was. In all cases, the median nerve and radial nerve was found at the upper third of the arm, whereas the ulnar nerve formed at the middle third of the arm.

Furthermore, the anatomical course was viewed on cadavers and then compared to the structures seen on the sonographic view. Apart from a few cases of variations (13%), the cadaver anatomy correlated with the anatomy seen on the scans. However, a limitation, due to the visualisation of the “sectional” anatomy seen on the scan taken for each approach, was that we were unable to view the branches and terminal branches as you would on a cadaver - from proximal to distal in its entirety. Therefore, dissection plays an integral role in the continued studies of anatomical variation, as well as the development of novel dissection techniques and forming the platform from which clinically relevant anatomy can be taught.

7.2. Sonographic study

Knowledge of anatomy is vital for any clinical procedure or technique being performed. Even though one may be thoroughly primed with the normal anatomy of the human body, certain observations cannot be presumed. In certain cases we found structures lying outside of the norm (Figures 5, 6 and 7 represent the norm for each approach), which may be a concern since many countries today are still performing “blind” BP blocks without sonographic guidance and with only the anatomical landmarks to guide the procedure.

All three approaches were reviewed and each approach presented with some form of variation. Although the percentage of variation compared to the total sample size was little, it is important that any and all variations should be noted, as even the slightest discrepancy can lead to complications or failed blocks.

At the interscalene level, approximately at the level of C6, the roots of the BP were identified. This approach must be carefully considered before being performed as it may not provide full spread – and thus anaesthesia – of the inferior trunk (important for forearm or hand surgery). In the interscalene approach, several variations were found upon sonographic visualisation. In 3%, the roots of the BP were found lying in a horizontal plane between the AS and MS. In a study done by Chin *et al.*, (2008), he reported variable distances between the roots of the BP in the ISG, but was unable to discover why this occurred. In the present study 5% of the cases revealed the roots to be positioned at variable distances from each other. In the majority of cases, the C5 roots were found further superior from the C6 and C7 roots. In 3% of cases, the roots were located lying anterior to the AS yet posterior to the SCM (Figure 15B), rather than the typical pattern of lying between the AS and MS (Figure 15A).

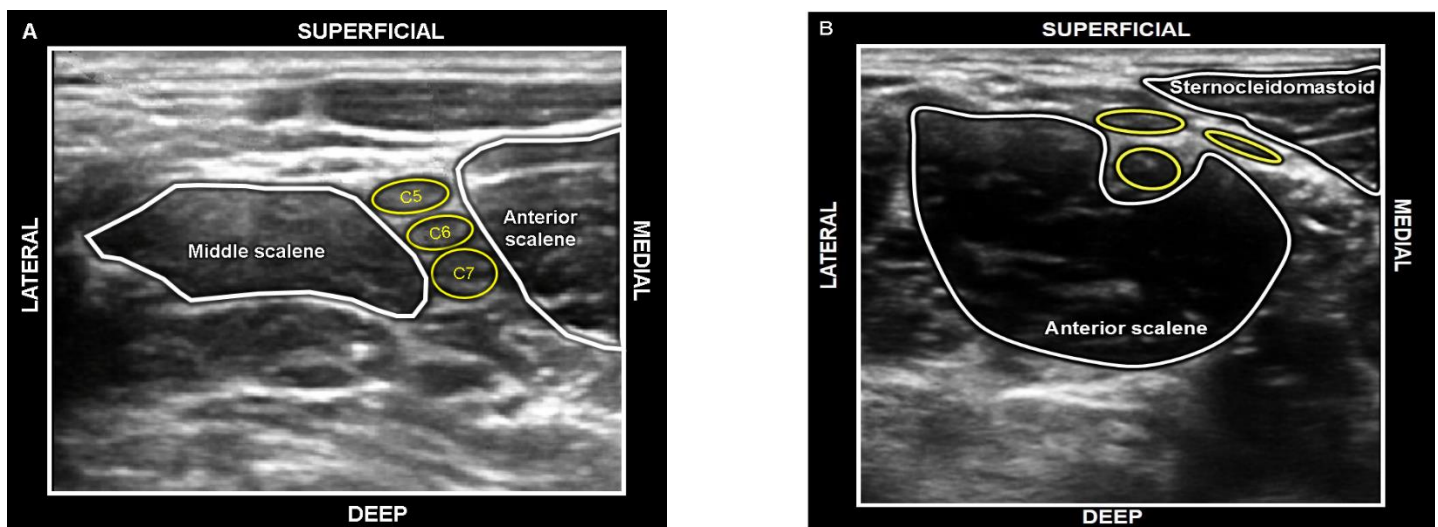


Figure 15A: The normal BP pattern between the scalene muscles. **B:** The roots of the BP located anterior/superior to the anterior scalene muscles, yet posterior to the sternocleidomastoid muscle.

Nambyiah *et al.*, (2011) conducted a sonographic analysis on the arteries present within the BP. It was concluded that in 90% of the cases vascular structures were present within the BP, while the remaining 10% presented either with inconsistent or absent vascular structures. The study advocated that preprocedural scans must be done when performing any BP nerve blocks in order to prevent vascular damage. Another study conducted by Muhly and Orebaugh (2011) who studied the sonographic anatomy of vasculature structures, specifically in the interscalene and supraclavicular approaches, found an arterial branch arising from the SCA to be in close proximity of the BP in a significant proportion of their sample. In the current study, an artery was located in the prevertebral fascia in the ISG together with the cords of the BP with its position directly related to spinal root C5. Initially it was noted as a cord but upon further observation and the Doppler function on the sonographic machine it was confirmed to be an artery due to its outward pulsation. This could be one of many branches, including the transverse cervical, the suprascapular, muscular branch to platysma or branch to the omohyoid muscle. In another 1%, the C5 root was found inside the MS muscle itself. This particular finding was also reported in a study done by Harry *et al.*, (1997).

In the supraclavicular approach the trunks/divisions are superficial and compacted and easy to visualise. From the total sample, 6% revealed the BP to be situated between the SCA and SCV, rather than posterolateral to just the SCA. Similar findings were reported in a study done by Carty and Nicholl (2007). In the infraclavicular approach, the cords were found at alternative positions around the SCA/AA. Observations made in this study indicate the lateral cord to be at 10-11 o'clock position, the medial cord at a 2-3 o'clock position and the posterior cord at a 6 o'clock position in relation to the SCA/AA. Similar findings were reported by Arcand *et al.*, (2005) and Carty and Nicholl (2007). In 5% of cases, the medial cord was lying superior to the SCA and in 1% the lateral cord was found lying adjacent to the posterior cord of the BP. Also, in the infraclavicular approach, one volunteer had a vessel overlapping the lateral cord. This was identified as the pectoral branch from the thoraco-acromial trunk, which was confirmed with the Doppler function on the sonographic machine.

All of the variations are important to identify as it may result in the anaesthesiologist not being aware of possible variations, which may impair their ability to adjust their technique accordingly. Any of the above mentioned discrepancies will require the needle to be re-inserted or redirected for a successful nerve block, or may call for the needle to be positioned at a different angle to the probe. This might mean that the needle be inserted at a lateral or inferior angle to the probe as opposed to the superior border of the probe. However, before any adjustments can be made to the technique, the anaesthesiologist needs to have a good understanding of the anatomy that is visible on the sonographic screen.

Various studies have been done to compare the efficiency between the supraclavicular and infraclavicular approaches. Arcand *et al.*, (2005) compared sonographic-guided supraclavicular and infraclavicular blocks and reported no significant difference between the performance of the blocks, onset times or block efficacy. However, Koscielniak *et al.*, (2009) reported different findings. In this study the infraclavicular approach had a faster onset, better surgical efficacy and fewer adverse events than the supraclavicular approach. Similar findings were also reported by Raj *et al.*, (2002) who had a total block success rate of 95% for the infraclavicular approach. Fredrickson *et al.*, (2009), reported that both approaches had some form of “corner pocket” and had similar onset times and blockade success rates. However, preference of the approach mainly depends on the anaesthesiologist.

Little research has been conducted into the measurement of the mean skin to BP depth amongst various population groups. For each approach, the BP depth differs according to the needle insertion site and angle. A study conducted on the British population recorded a mean skin to BP depth of 1 - 3 cm for the interscalene approach (Russon *et al.*, 2009). However, in the current study, the mean depth for a South African population was 0.64 cm with a standard deviation of 0.3 cm (Table 2). This is low when compared to the mean depth in the British population. In another study done by Mistry *et al.*, (2016), the depth of the BP was recorded and compared between two population groups. They recorded a mean skin to BP depth of 1 - 2 cm in the supraclavicular approach and stated

that this was only applicable to a Western population group but not to an Indian population. Similarly the mean skin to BP distance in a South African population for the supraclavicular approach was recorded to be 0.89 cm, with a standard deviation of 0.3 cm (Table 3). The low standard deviation for both approaches in our study is an indication of the accuracy of the measurement. Lastly, a mean skin to BP depth for the infraclavicular approach was reported to range from 2.5 - 4.5 cm among a British population (Macfarlane and Anderson, 2009). The current study reported a mean depth of 2.6 cm, with a standard deviation of 0.7 cm (Table 4). Overall the interscalene and supraclavicular approaches had a superficial BP, as opposed to the infraclavicular approach where, due to the presence of the pectoral muscles, the BP is slightly deeper.

Regression models were done for the measurements taken for each approach. A regression model can be best explained as a test performed to evaluate a particular variable in which you are interested – such as a measurement (dependant variable) – and to see if other variables (independent variables) affect it. The variables are thus modelled/tested against each other. For the regression models reported in Tables 10, 11 and 12 above, the independent variables were the weight, height, BMI and age.

Based on these regression models for all three approaches, the fixed factors influenced the R-squared values enough to suspect a correlation. Most models showed that, with an increase in height, the measurement significantly decreased in females while it increased in males. An increase in weight increased the measurements for both males and females. Simple comparisons showed that sex had an overall influence on the measurements where all measurements were smaller in females when compared to the male volunteers. Hand dominance had little influence on the measurement when comparing the measurements on the side of the dominant hand versus the non-dominant hand.

Since these measurements were taken from a South African population, it is safe to assume that if sonographic guidance is impossible and BP blocks need to be performed using surface anatomical landmarks, the measurements obtained in this study would be a good marker of depth of the key anatomical structures. Below is a step-by-step guideline

for each approach, developed based on the sonographic findings of the current study, verbal discussion with Dr Möhr and a review of the available literature.

7.3. Anatomical guideline

For each approach, both the probe and the needle may need to be manipulated to travel steep angles in order to gain access to the targeted nerve(s). Due to this, various obstructions may present itself, which can severely restrict needle visualisation. Various techniques can be adopted to overcome this restriction. One such technique includes adding pressure onto the pole of the probe further away from the needle as this will tilt extra sound waves more towards the needle, effectively increasing visualisation by reducing the probe angle.

Interscalene approach

Step 1: Position

The patient should be asked to lie in a supine position with their head turned to the contralateral side of the side where the block is to be performed. The patient could also be placed in a semi-lateral position where the patient lies on his/her side with the arm abducted or flexed at the elbow joint for sonographic-guided blocks. This could make needle and probe alignment easier. The position of the anaesthesiologist performing the block should be at the head of the bed, with the patient, the block area and the sonographic screen are all in line, ensuring a clear view during the procedure (Figure 16). The probe should ideally be held perpendicular or at a 90-degree angle to the skin at all times.



Figure 16: *The position of the sonographic screen throughout the procedure. This photo was included with the consent of Dr Mohr (consultant anaesthesiologist – taken at Eugene Marais Hospital, Pretoria, Gauteng).*

Step 2: Preparation

While the patient is in the supine position, a sterile sheet is placed over his/her thoracic area leaving only the area(s) of interest exposed. A small amount of KY sterile gel is placed on the skin at the ISG (found between the AS and MS muscles just posterior to the SCM and superior to clavicle) and a small amount of KY gel should also be placed on the probe. Normal aseptic techniques, prescribed for any invasive clinical procedure, should be adhered to.

Step 3: Probe placement

The landmarks for this approach are the clavicular head of the SCM, EJV and the clavicle. After palpating the clavicle, the probe is placed in the SCF, superior and parallel to the midpoint of the clavicle and posterior to the SCM (Figure 17). The placement of the probe should be in a coronal-oblique orientation. The probe is then moved superiorly along the EJV towards the ISG. Alternatively, the probe can be placed in the midline of the neck, at the level of the thyroid gland and neck vessels (common carotid artery and EJV), then moved laterally and inferiorly towards the SCA along the omohyoid muscle.

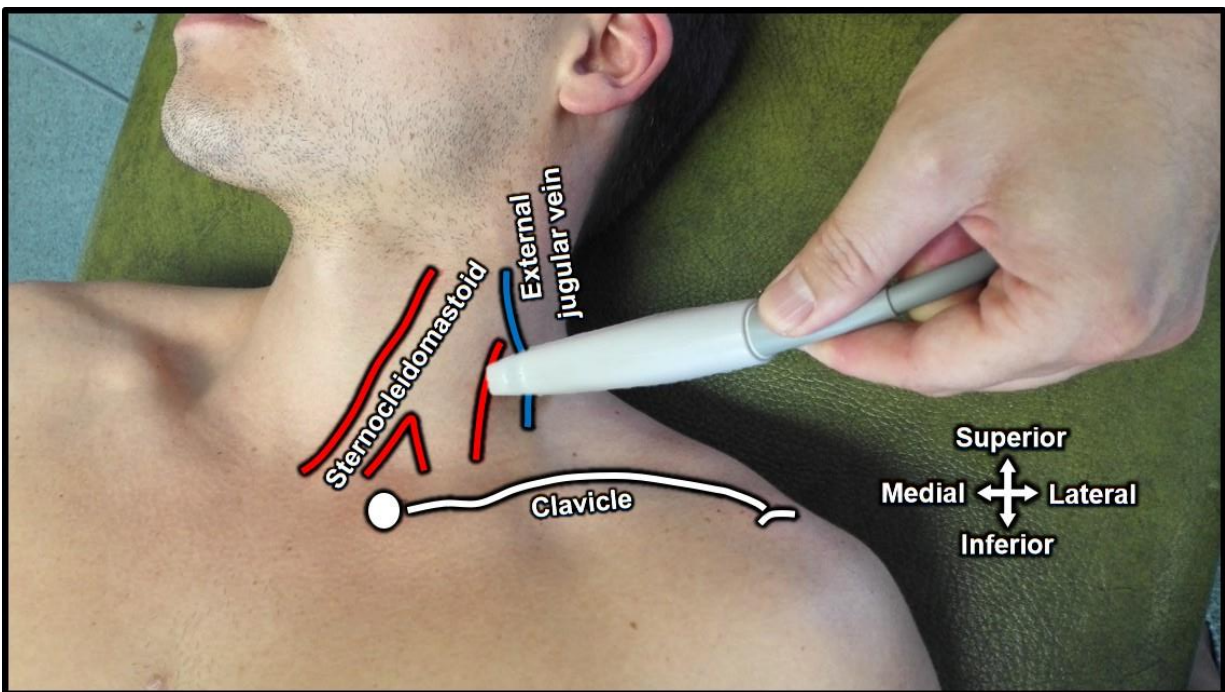


Figure 17: Probe placements during the interscalene approach

Step 4: Sonographic image

The SCA should first be identified, after which the BP can be found posterolateral to the SCA. The probe is then slowly moved superiorly (trace-back technique) (Lapegue *et al.*, 2014) to follow the BP proximally. The BP should be followed medially and cephalad along its course by keeping the nerves in the centre of the screen until the roots/trunks are located as hypoechoic round or oval structures in the ISG. If the transverse process of C6 can be seen, the probe has been traced too far cranial (Figure 18).

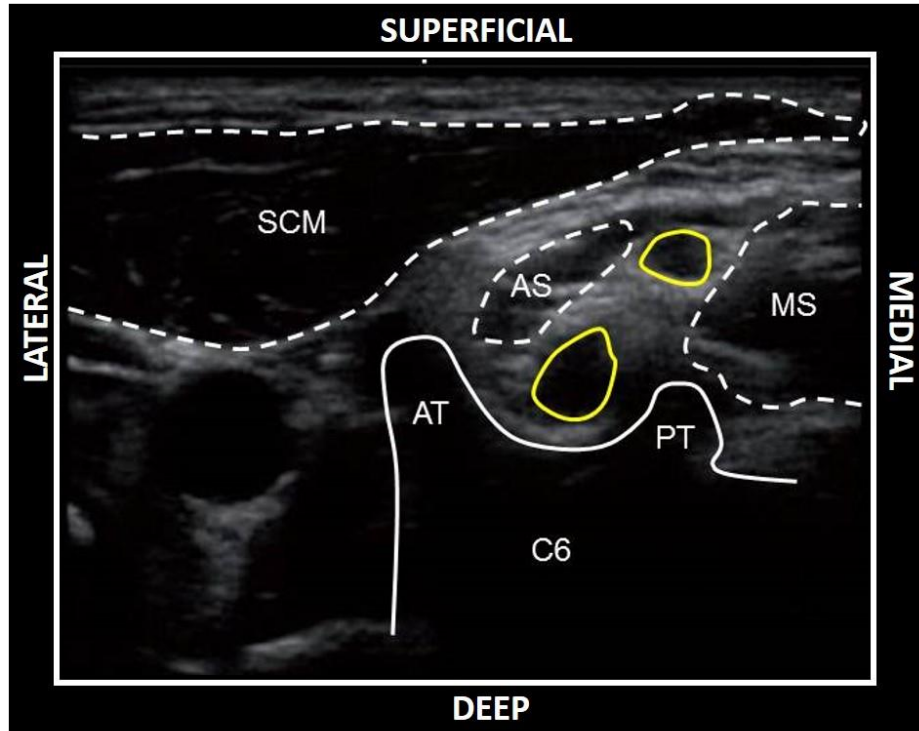


Figure 18: Sonographic scan showing the AT - anterior tubercle and the PT - posterior tubercle of the transverse process of the C6 vertebra. Yellow circles represents the cords of the BP.

The anaesthesiologist must try to visualise three round hypoechoic structures (on the screen from superior to inferior, the roots of spinal nerves C7, C6, C5) lying between the MS and AS muscles in a vertical plane (Figure 19). The spinal roots of C8 and T1 are posterior to the SCA and therefore difficult to visualise. Unlike the supraclavicular approach, the lung cannot be seen on the sonograph.

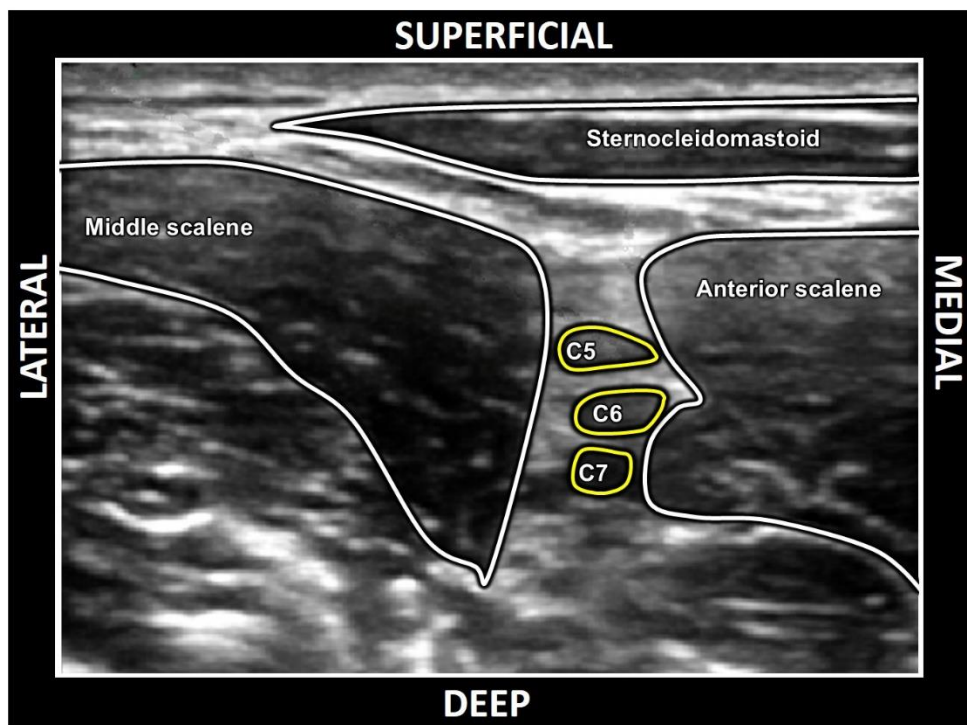


Figure 19: Sonographic scan showing the muscular and vascular structures in the ISG

Step 5: Needle insertion

The needle must be inserted in an in-plane approach from the posterolateral side of the probe at a 45-degree angle, travelling in a lateral to medial direction. As the needle advances, it will pass through the prevertebral fascia and a small amount of resistance will be felt. Passage through this fascia gives a characteristic “click” sensation. The needle then either advances through the AS muscle, or in-between the AS and MS muscles towards the BP. It is important to keep in mind that movement of the needle towards the BP could cause movement of the BP itself. The ideal position of the needle tip for this approach is between the C5 and C6 roots, or the superior and middle trunks of the BP (Figure 19). As the anaesthetic is injected, it spreads as hypoechoic fluid around the plexus. Once the required amount of anaesthetic is deposited the needle should be withdrawn while still injecting the last of the anaesthetic as it is removed.

Supraclavicular approach

Step 1: Positioning

See step 1 above of the interscalene approach

Step 2: Preparation

While the patient is in supine position, a sterile sheet is placed over their thoracic area keeping only the area(s) of interest exposed. A small amount of KY sterile gel is then placed on the skin at the area of interest (the SCF found superior to the clavicle and at the posterior border of the SCM) and also on the probe. Normal aseptic techniques should be adhered to.

Step 3: Probe placement

Landmarks for this approach are the clavicular head of the SCM and the clavicle. However, needle insertion does not rely directly on distance from certain bony landmarks. After palpating the clavicle and the clavicular head of the SCM (if possible), the linear probe is placed in the SCF, superior and parallel to the midpoint of the clavicle, adjacent to the posterior border of the SCM. The placement of the probe is in a parasagittal or coronal-oblique plane (Figure 20) to obtain an optimal short-axis view of the SCA, first rib, pleura, lungs and the trunks/divisions of the BP. The probe is aimed inferiorly in the direction of the chest or mediastinum.

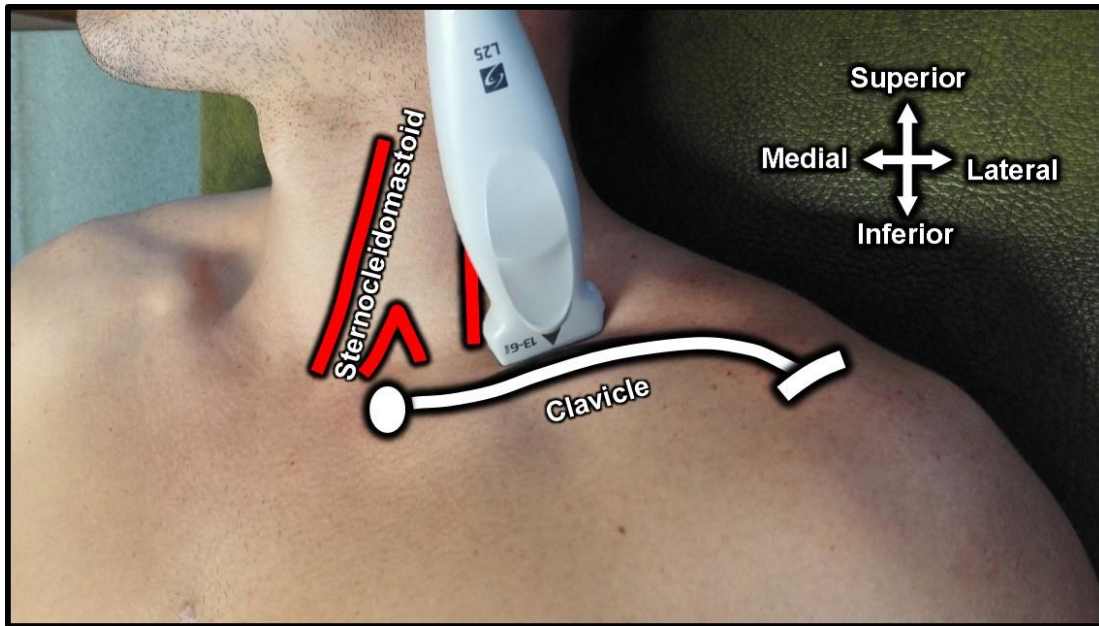


Figure 20: Probe placement during the supraclavicular approach

Step 4: Sonographic image

The first rib should be identified as a hyperechoic structure at the bottom of the sonographic screen (Figure 21), its reflective properties make the rib appear as a white horizontal/oblique line. Thereafter, the SCA is identified as a hypoechoic, or a dark, round pulsating circle superficial to the rib. The BP can be found posterolateral to the SCA. The BP has a grape like appearance of hypoechoic bundles embedded in a hyperechoic supporting connecting tissue surrounded by a connective tissue framework or sheath (hyper-epineurium) (Figure 21). The MS muscle is identified posterolaterally and the AS muscle anteromedially. Inferior to the first rib the lung can be viewed as a greyish mass. The area below the rib is referred to as the danger area. If the needle is advanced below this point, there will be a high risk of penetrating the parietal pleura, resulting in a pneumothorax.

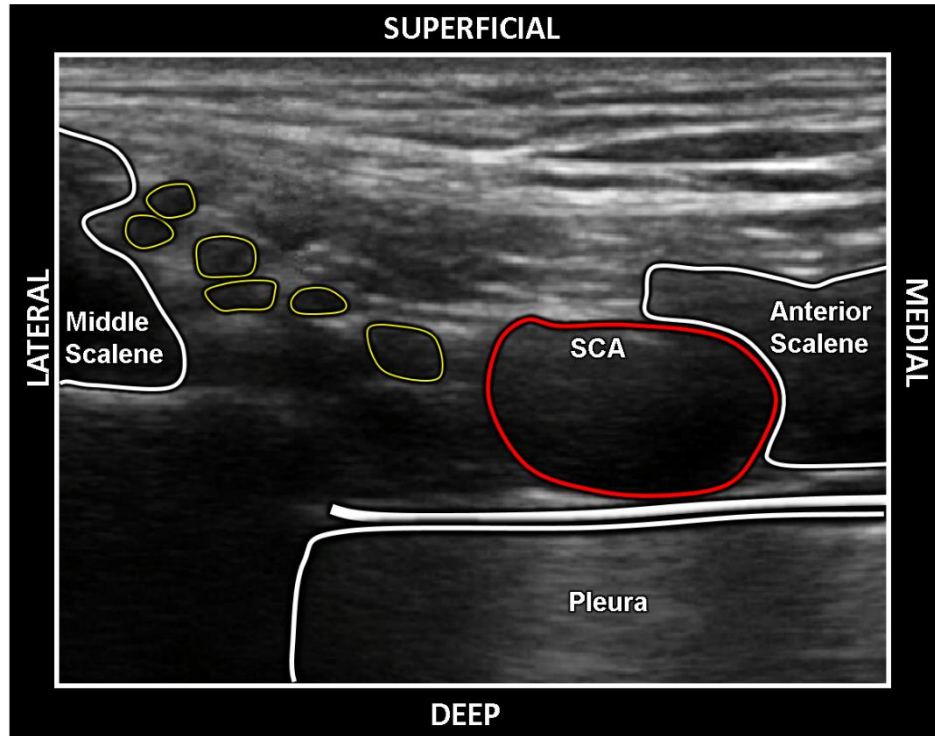


Figure 21: Sonographic scan showing the muscular- and vascular structures in the SCF.

Step 5: Needle insertion

The needle should be inserted using the in-plane approach at the lateral border of the probe, traveling in a lateral to medial direction. The needle tip will travel towards the BP located posterolateral to the SCA. The needle will have to pierce the axillary sheath, which offers a small amount of resistance and characteristic ‘click’ sensation. As with the previous approach, movement of the needle might result in movement of the BP as well. The needle tip should carefully be advanced as close to the BP (appearing as a grape-like structure) as possible. The ideal location is at the junction of the BP and posterolateral border of the SCA, superior to the first rib. This area is referred to as the “corner pocket” or common injection site for this approach (Hanumanthaiah *et al.*, 2015). Therefore, irrespective of original needle insertion site, if the anaesthetic is injected into this area, an efficient block will be provided. The spread of anaesthetic will cause slight movements of the BP away from the SCA. Once the anaesthetic is injected it appears as a hypoechoic spread of fluid and appears black on the screen. It should be limited to the axillary sheath

and the BP should be visible, surrounded by the hypoechoic local anaesthetic within the confines of the axillary sheath.

Infraclavicular approach

Step 1: Positioning

See step 1 above of the interscalene approach

Step 2: Preparation

While the patient is in a supine position, a sterile sheet is placed over their thoracic area keeping only the area(s) of interest exposed. A small amount of KY sterile gel is placed on the skin at the area of interest (the ICF, inferior to the clavicle near to the coracoid process) and also on the probe. Normal aseptic techniques should be adhered to.

Step 3: Probe placement

Landmarks for this approach are the coracoid process and the clavicle. After palpating the clavicle, the probe is placed inferior and perpendicular/sagittal to the lateral third of the clavicle, inferior to the coracoid process (Figure 22). Alternatively, the probe placement can be estimated by placing the probe two finger breadths inferior and one finger breadth medial to the coracoid process. This will provide a vertical/sagittal “slice” through the axilla at that specific point. The cranial end of the probe is found immediately inferior to the clavicle. The probe can then be rotated counter clockwise until a transverse image of the axillary artery can be seen on the screen.

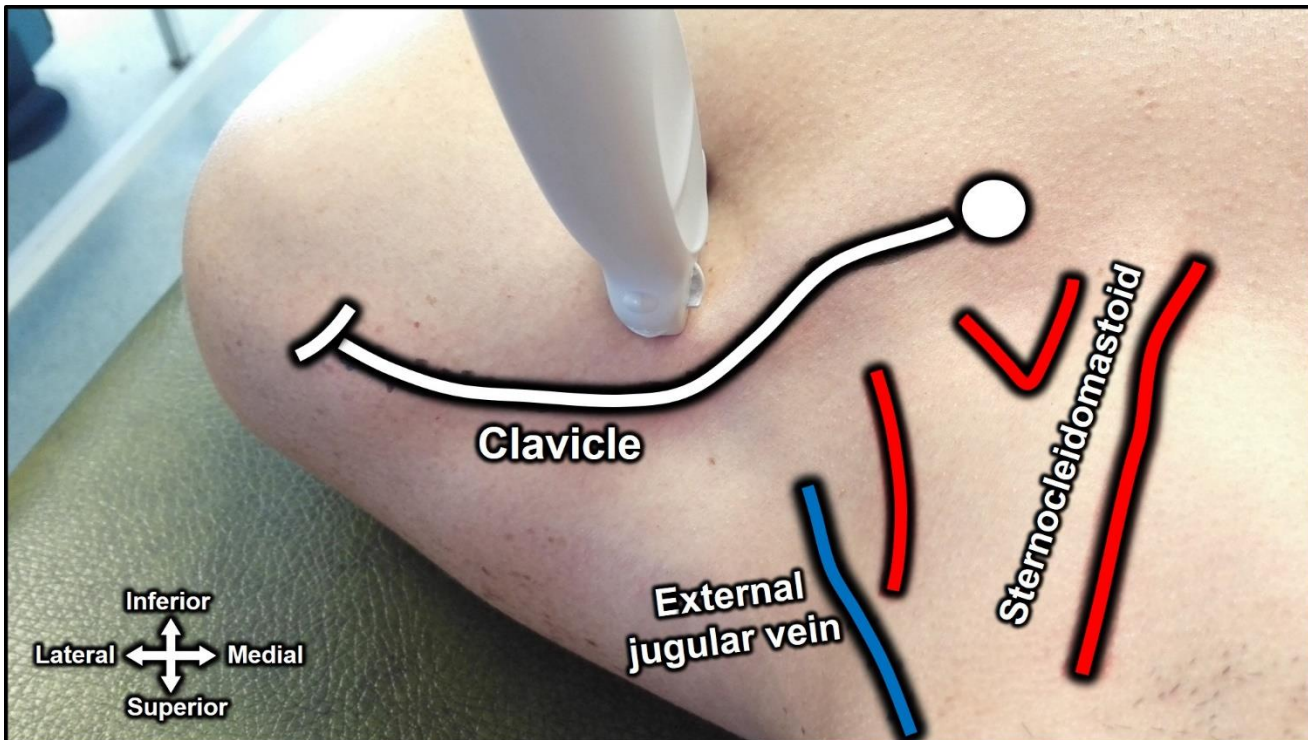


Figure 22: Probe placement in the infraclavicular approach

Step 4: Sonographic image

From superficial (top) to deep (bottom) on the sonographic image, one will be able to visualise two thick horizontal bands stretching across the screen. These bands are the pectoralis major muscle (closest to the top of the screen) and pectoralis minor muscle deeper to the former (Figure 23). Between the pectoralis major muscle and pectoralis minor muscle, a small hypoechoic vessel may be present, this is the pectoral branch of the thoraco-acromial trunk. Below the two muscles, the SCA – a dark, round, pulsating hypoechoic structure – should be visible. If the SCA is not easily identified, the probe can be moved more laterally towards the axilla where the BP can be found surrounding the AA. The cords of the BP are arranged radially around the SCA in the infraclavicular space (Figure 23). Based on previous studies, and corroborated by the results of this study, the medial cord can most often be found at a 2-3 o'clock position (if the round SCA is considered to be a clock-face with 12 o'clock being the most superior/superficial point). The posterior cord can be found at a 6 o'clock position with the lateral cord most commonly sitting 10-11 o'clock. In certain cases, the BP can be found positioned between

the SCA and SCV instead of radially around the SCA. The pleura and lungs are not visible as this level.

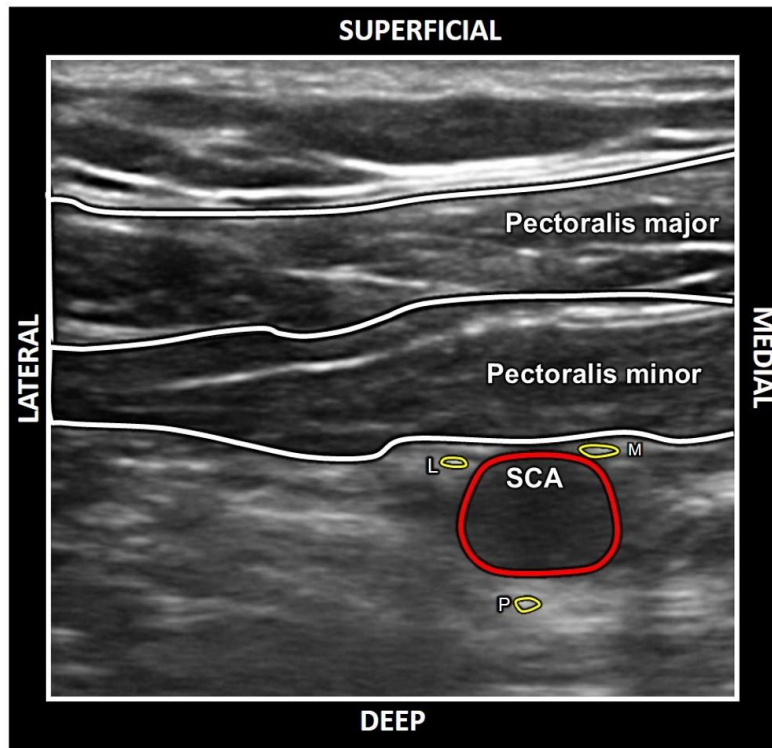


Figure 23: Sonographic scan showing the muscular- and vascular structures in the IFC. L - lateral cord of the BP, M - medial cord of the BP, P - posterior cord of the BP.

Step 5: Needle insertion

The needle should be inserted in an in-plane approach, advancing in a superior to inferior direction at the superior pole of the probe (side closest to the rib). If there is insufficient space for the needle to be inserted between the inferior border of the clavicle and probe, it can be inserted at the inferior pole of the probe (then the needle will be directed at a superior angle). If space is not an issue, the needle will be directed towards the bottom/deep border of either the SCA or the AA. As the needle is advanced, it will pass a few structures each providing different levels of resistance. Along its course it will pierce the clavpectoral fascia, which surrounds the pectoralis minor and major muscles, and the muscles themselves. The needle tip will be directed towards the posterior cord first, which is located at the 6 o'clock position in relation to the SCA/AA, the anaesthetic is first injected in relation to the posterior cord before being slightly withdrawn and redirected to

the medial and lateral cords, located at the 2-3 o'clock and 10-11 o'clock positions respectively. The anaesthetic should spread in a uniform 'U' shape around the artery.

8. Limitations

The amount of variations of the BP were limited, this could have been due to the small sample size, or due to the sample not being categorised into separate groups. Factors such as fitness levels may affect the overall depth and location of nerve bundles which were not highlighted throughout the study. Although intra observer method was performed, the inter observer method was not allowing room for error in accuracy of measurements taken.

9. Conclusion

Sonographic visualisation during clinical procedures is of growing importance in the medical field, assisting doctors and surgeons as a diagnostic tool, to assist with the pre-operative planning and for real-time visualisation of the anatomy during clinical procedures. Sonographic guidance in regional anaesthesia is clinically beneficial for nerve localisation and to reduce the number of attempts to correctly position the needle close to the target nerve(s) and thus, decreasing the number of reported complications or failed blocks. This is particularly clear from the results of this study when performing sonographic-guided BP blocks. If we can visualise the structures in real time we will be able to define the depth that the needle need to travel to reach the target nerve(s), the optimal site for injecting the local anaesthetic in close proximity to the nerve(s) and avoid damage to related neurovascular structures, with resultant complications. In addition, the clear visualisation of the local anaesthetic as it surrounds the BP may decrease the volume of the anaesthetic needed to elicit adequate anaesthesia, thereby avoiding possible anaesthetic toxicity.

For the three approaches analysed, each approach has its own pros and cons. From previous studies, it is clear that both supraclavicular and infraclavicular nerve blocks, have

the most benefits. This is because of the rapid onset of anaesthesia and a higher success rate. We hope that this study can highlight these benefits while the step-by-step guideline and description of the anatomy can assist in increasing the confidence of clinicians performing these procedures. It can also be used for postgraduate teaching – training of anaesthesiologists during their residency. From this study, we hope that registrars not only see the benefit of sonographic guidance and the importance of a good anatomical basis when interpreting the sonographs, but also the benefits of being able to perform regional nerve blocks when indicated.

10. Author contributions

Miss Sabashnee Govender was the primary investigator in the study; preparing the study design, conducting the study, capturing data and drafted the manuscript. Mr Zithulele Tshabalala assisted in the study design, supervision during the study, the revision of the manuscript and approval of the article. Prof. Brendon Girdler-Brown was the statistician providing statistical advice on the required statistical tests, the interpretation of the results thereof and approval of the article. Prof. Albert-Neels van Schoor was the senior secondary investigator. He assisted in the study design, supervision during the study, the revision of the manuscript and the approval of the thesis.

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