AXILLARY NERVE DISTRIBUTION IN RELATION TO ARM LENGTH IN AN ADULT KENYAN POPULATION: A CADAVERIC STUDY IN ELDORET, KENYA

BY

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Thesis submitted in partial fulfilment of the requirements for the award of degree of Master of Medicine in Orthopaedic Surgery, Moi University, School of Medicine.

DECLARATION

Declaration by the Student

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DEDICATION

This thesis is dedicated to the donors of cadavers for their indispensable contribution towards this research.

ABSTRACT

Background: The axillary nerve, one of the terminal branches of the posterior cord of the brachial plexus is closely related to the surgical neck of the humerus. It is at a high risk of injury through fractures or during surgery. Variations in the distribution of this nerve have been described in different populations and but not in the adult Kenyan population. An understanding of the anatomy of this nerve will assist surgeons to avoid its injury.

Objective: To describe the distribution of the axillary nerve in relation to arm length in a selected adult Kenyan population.

Methods: A cross sectional study conducted at the Department of Human Anatomy, Moi University after IREC approval. Fifty one formalin prefixed left adult upper limbs disarticulated at the scapulothoracic junction were used. Only the left limbs were used since these were the majority. Dissection was done using the deltopectoral approach to demonstrate the origin, course and distribution of the axillary nerve beneath the deltoid muscle. The distance of the nerve from important bony landmarks such as the anterior and posterior edges of acromion, and the lateral epicondyle of the humerus were measured and recorded in structured data collection forms. Data was then entered into a Microsoft® Excel® database and exported to SPSS® version 21 for analysis and presented in graphs, tables, figures and photographs.

Results: The axillary nerve originated from the posterior cord of the brachial plexus (100%) and divided within the quadrangular space (100%) into anterior and posterior branches. The main trunk supplied teres minor (35.3%), teres major (15.7%) and subscapularis (3.9%) muscles. The anterior branch supplied the anterior (100%) and middle (92.1%) parts of the deltoid. The posterior branch innervated the posterior part of deltoid in 100% of specimens. The middle part of deltoid received dual innervation in 7.8% of cases. Articular innervation to the shoulder joint arose from the main trunk (80.4%) and anterior branch (19.6%). The upper lateral cutaneous nerve of the arm arose from the posterior branch in all specimens. The average distance of the nerve from the anterior and posterior edges of acromion (AEA and PEA respectively) were 6.46cm (range 5.15-8.68cm) and 5.88cm (range 4.42-9.99cm) respectively. The average arm length (AL) was 31.96cm (range 27.29-38.74cm). A 1cm increase in AL had a predictable increase in nerve distances from anterior and posterior edges of acromion by 0.104cm and 0.062cm respectively.

Conclusions: The axillary nerve has an anterior branch distributed over and consistently innervates the anterior and middle parts of deltoid muscle, while the posterior branch supplies the posterior part. Both teres major and subscapularis muscles had unusual innervation by the main trunk of the axillary nerve.

Recommendations: Surgeons should be careful during dissection of the proximal humerus and shoulder joint. A preoperative template of a quadrangular “safe zone/ area” as landmarks on the proximal deltoid muscle (using minimum distances of 5.15cm and 4.42cm for AEA and PEA respectively) should protect the axillary nerve and its branches during surgery.

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LIST OF ABBREVIATIONS AND ACRONYMS

AD	Anterior Distance
AEA	Anterior Edge of Acromion
AI	Anterior Index
AN	Axillary Nerve
AVN	Avascular Necrosis
I.R.E.C	Institutional Research and Ethics Committee
LSN and USN	Lower and Upper Subscapular Nerves
M.T.R.H	Moi Teaching and Referral Hospital
O.R.I.F	Open Reduction and Internal Fixation
PC	Posterior Cord (of the brachial plexus)
PD	Posterior Distance
PEA	Posterior Edge of Acromion
PI	Posterior Index
RN	Radial Nerve
SITS	Rotator cuff muscles: Supraspinatus, Infraspinatus, Teres minor, and Subscapularis.
SPSS	Statistical Package for Social Sciences

OPERATIONAL DEFINITION OF KEY TERMS

Arm length: The distance from the anterior edge of the acromion process of the scapula (AEA) to the lateral epicondyle of the humerus.

Axillary nerve: This is one of the larger terminal branches of the posterior cord of the brachial plexus. It innervates the anatomical structures around the shoulder joint.

Distribution of the axillary nerve: This refers to the pattern of branching (course) and termination of the nerve.

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CHAPTER ONE: INTRODUCTION

1.1 Background Information

The axillary nerve is one of the terminal branches of the posterior cord of the brachial plexus and contains fibers from the ventral rami of C5 and C6. It originates at the lower border of the subscapularis muscle (Gray et al., 2005).

From this origin, the nerve passes through the quadrangular space or interval (*Appendix 3*). This is a descriptive anatomical space whose muscular boundaries are the teres minor superiorly, teres major inferiorly, long head of triceps brachii medially, and the surgical neck of the humerus and glenohumeral joint laterally. The posterior circumflex humeral vessels accompany the nerve inferiorly within this space (DePhilip, 2008; Gray et al., 2005; Sinnatamby et al., 2011).

The axillary nerve is in intimate contact with the surgical neck of the humerus and the capsule of the shoulder joint within the quadrangular space. It gives off a branch to the shoulder joint before dividing into its main terminal branches (anterior and posterior). The anterior branch which is accompanied by the posterior circumflex humeral vessels curves around the surgical neck of the humerus to supply the deltoid muscle. The posterior branch originates medially adjacent to the inferior edge of the glenoid rim. It supplies the teres minor muscle and the skin over the lateral part of the proximal part of the arm (Gray et al., 2005).

Loukas et al., (2009) noted the presence of anatomical variations of the axillary nerve within the deltoid muscle. They reported that in 65% of cases, the nerve divided within the quadrangular space into anterior and posterior branches while in 35% of cases, the nerve split within the deltoid muscle. In addition, posterior branch of the axillary nerve gave a branch to the teres minor muscle and a superior lateral brachial cutaneous branch in all the specimens studied. Furthermore, the anterior branch of the axillary nerve provided a branch to the joint capsule, anterior and middle parts of the deltoid muscle in 100% of the cases and a branch to the posterior part of the deltoid muscle in 18% of the cases. Both the middle and posterior parts of the deltoid received dual nerve supply from both branches in 38% and 8% of cases respectively (Loukas et al., 2009).

1.2 Problem Statement

The axillary nerve is very important in the upper limb. As such, its injury invariably results in muscular paralysis and atrophy, and loss of shoulder joint movements such as abduction, flexion, extension and external rotation. Injury also results in sensory loss over the lateral aspect of the proximal arm.

The variable course of the nerve among different populations, and its intimate relationship with the proximal humerus and the shoulder joint capsule places it at a high risk of injury either through fractures, dislocations, surgery or direct blows to the deltoid muscle especially during contact sports (Perlmutter et al., 1998). Such injuries are associated with significant patient morbidity, disability and in certain cases medical litigation. In addition, these injuries significantly affect the functions of daily living such as bathing, perineal care, among others and overall, reduce the quality of life among the affected persons.

Locally, there is an increasing number of shoulder surgeries such as rotator cuff repairs, open reduction and internal fixation (O.R.I.F.), shoulder arthroscopy and surgeries around the proximal humerus. From the available literature, the course of the axillary nerve among the Kenyan population is currently unpublished. During the study period, a total of four cases of primary nerve injuries were encountered. Therefore, these factors highlight the need for an anatomical description of the nerve among our population.

1.3 Justification

The variable course and length of the axillary nerve presents a possibility of iatrogenic injury during surgery. Such injuries can be prevented by precise anatomical knowledge of the lengths, course and the relationship of the axillary nerve and its branches to the shoulder joint capsule and its common patterns of variation within deltoid muscle and the quadrangular space. In addition, the correlation of the location of the nerve from the anterior and posterior edges (AEA and PEA respectively) of the acromion process to the arm length (AL) can be used preoperatively to predict the location of the nerve.

This information will provide morphometric data that can be applied preoperatively and intraoperatively during surgical procedures involving the shoulder complex thereby reducing the occurrence of secondary axillary nerve injuries.

Variability on the course of the axillary nerve has a racial dimension which is currently unpublished in Kenya. Liu et al., (2011) found significantly different parameters between the Chinese and Caucasians. Are Kenyans any different? This study can therefore serve as a baseline for development of other subsequent related studies.

Furthermore, the performance of surgery in resource poor setting such as in Moi Teaching and Referral Hospital (M.T.R.H) is hampered by lack of technological adjuncts such as nerve conduction studies and electromyography which can assist in the reduction of surgical complications (Warrender et al., 2011).

1.4 Research Question

What is the distribution of the axillary nerve in relation to arm length in a selected adult Kenyan population?

1.5 Objectives

1.5.1 Broad Objective

To describe the course and distribution of the axillary nerve in relation to arm length in a selected adult Kenyan population.

1.5.2 Specific Objectives

1. To describe the course of the anterior and posterior branches of the axillary nerve in a selected adult Kenyan population.
2. To determine the length of the axillary nerve and its branches in a selected adult Kenyan population.
3. To correlate the pattern of axillary nerve distribution with arm length in a selected adult Kenyan population.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

2.1.1 Anatomy of the Shoulder Region

The bones that form the upper limb include the scapula, clavicle and the humerus (Gray et al., 2005; Sinnatamby et al., 2011). With the humerus being the longest and largest. It has upper and lower expanded parts, and a shaft. The proximal end is made up of the head, greater and lesser tubercles or tuberosities, anatomical and surgical necks. The head articulates with the glenoid cavity of the scapula to form the glenohumeral/ shoulder joint and is directed medially, backwards and upwards (Gray et al., 2005; Sinnatamby et al., 2011). The capsule of the shoulder joint is attached along the anatomical neck of the humerus. The lesser tubercle lies anterior to the anatomical neck while the greater tubercle is located lateral to the proximal part of the humerus. The rotator cuff muscles are attached to the greater tubercle. Between the tubercles is a bicipital groove or the intertubercular sulcus through which the tendon of long head of biceps brachii passes. The surgical neck is ill defined and is closely related to the posterior circumflex humeral vessels and the axillary nerve.

The deltoid muscle is the main anatomical obstacle during plate osteosynthesis for proximal humerus fractures (Huri et al., 2014). It is one of the intrinsic muscles of the shoulder joint. In addition, it works together with the rotator cuff muscles to stabilize this joint. The rotator cuff group of muscles include the supraspinatus, infraspinatus, teres minor and subscapularis collectively referred to as S.I.T.S.

The deltoid muscle has three anatomical parts (tripartite) that is anterior (unipennate), middle (multipennate) and posterior (unipennate). The main actions are flexion and medial rotation of the arm; abduction of the arm; extension and lateral rotation of the arm respectively (Abbott et al., 1952).

A cadaveric study on the position of the axillary nerve within the deltoid muscle showed that "the vertical distances from the upper deltoid border to the nerve in 17 of 67 cadavers was less than 4 cm in both shoulders (Kontakis et al., 1999). The least distance which was measured from the axillary nerve to the middle part the deltoid muscle was 2 cm. A significant negative correlation was found between the deltoid ratio (width/length) and the vertical distance. This study demonstrated that the risk of damage to the axillary nerve was greater in patients with shorter deltoid lengths especially during deltoid splitting approaches to the proximal humerus and shoulder joint.

2.1.2 Proximal Humerus Fractures in Relation to Axillary Nerve Injury

Fractures involving the proximal humerus account for about 5-6 % of all adult fractures (Court-Brown et al., 2006; Mafi et al., 2014). The prevalence increases with advancing age being highest in individuals aged 70 years and above (Bengner et al., 1988). Poor bone quality, osteoporosis and co-morbid illnesses all contribute to this increased prevalence. The main causes of fractures include falls, road traffic accidents, and contact sports among others. Management options for proximal humerus fractures include both operative and non-operative methods. In stable, minimally displaced fractures, non-operative methods are used. Surgical intervention is indicated in severely comminuted fractures, pathological fractures, and fractures associated with dislocations and/ or neurovascular injuries (Nho et al., 2007).

The nerve can also be injured traumatically e.g. fractures involving surgical neck of humerus, shoulder dislocations, contact sports (through contusions) and traction (Ondrejka, 1950; Pasila et al., 1978). Of all brachial plexus injuries, axillary nerve injuries account for about 6% (Safran, 2004). The nerve was injured in 42% of cases of anterior shoulder dislocation (Visser et al., 1999).

Conservative treatment of proximal humerus fractures involves use of sling immobilization, casts, and physiotherapy. Early physiotherapy is advocated in order to improve functional results (Handoll et al., 2012). The most common complications associated with closed treatment include malunion of fractures, impingement of the sub-acromial bursa, avascular necrosis (AVN) of the humeral head, shoulder pain, and stiffness secondary to osteoarthritis of the shoulder joint and rotator cuff insufficiency (Murray et al., 2011). " Most conservatively treated fractures will progress to full union with an estimated risk of non-union between 1.1% and 10% " (Cadet et al., 2013).

The surgical options offered depend on the fracture pattern and underlying bone quality. These options can be replacement for example hemiarthroplasty or reconstructive. Fracture reduction is achieved through open or minimally invasive techniques by the use of percutaneous pins/ wires/ screws or internal fixation using intramedullary nails, tension band constructs or screws and plates (Lin et al., 2014). The main disadvantages include pin migration, implant failure and catastrophic iatrogenic axillary nerve injury through direct nerve penetration (Kamineni et al., 2004; Lancaster et al., 2014; Pimple et al., 2005).

Other clinical procedures done around the shoulder complex can cause iatrogenic injuries to the axillary nerve and / or its branches. The deltoid muscle is generally a preferred site for intramuscular injections of vaccines and other medications in children and adults. Recent data show an increased incidence of iatrogenic injuries involving mainly the anterior branch of the axillary nerve, sub deltoid and sub acromion bursae and the radial nerve (Cook, 2011; Perlmutter et al., 1998; Perlmutter et al., 1997). This reflects a lack of awareness of the anatomical positions of the structures in and near the deltoid muscle.

The Seddon and Sunderland classification (Chhabra et al., 2014) scheme describes the possibilities for a dysfunction in a nerve: neurapraxia occurs when there is a conduction defect at the point of injury but no demonstrable microscopic evidence of injury. This normally resolves within hours to months as long as the insult is removed; in axonotmesis, the epineurium and perineurium are intact but the axon or nerve fibers are ruptured. The proximal stump of the nerve can regenerate. Finally, in neurotmesis, the continuity of the axon cannot be restored. The entire nerve trunk is ruptured. Surgical exploration is required to restore function especially in patients who do not regain function by the fourth month of injury (Terzis et al., 2010).

A patient with suspected axillary nerve injury should undergo thorough medical history and physical evaluation. This should also include testing for active and passive range of motion at the shoulder joint, wasting and weakness of the deltoid muscle and loss of sensation to the upper lateral aspect of the arm. The strength of internal and external rotation, abduction and adduction should also be assessed (Crouch et al., 2013).

2.1.3 Surgical Approaches to the Proximal Humerus and Shoulder Joint

For surgeons operating in the shoulder region, preoperative planning should include landmarks to assist in the identification of the axillary nerve. Many authors have suggested “safe zones” useful in the preoperative planning for shoulder and proximal humerus surgeries (Rotari et al., 2012).

A “quadrangular” zone located inferior to the acromion process of the scapula was suggested to be safe during placement of hardware. The nerve passed on average 48.6mm and 60.8mm below the posterior and anterior acromion edges respectively. Therefore “to minimize the risk of axillary nerve damage, the shortest distance should be used during dissection” (Cetik et al., 2006).

There is a strong correlation between arm length measured from the most lateral edge of the acromion to the lateral humerus epicondyle and nerve distance with the arm in neutral position ($r = 0.82$, $p < 0.001$). The nerve distance changed by 2mm for every 1cm change in upper arm length (Abhinav et al., 2008).

The axillary nerve may be injured during surgical procedures involving the shoulder joint complex (Apaydin et al., 2010; Marion et al., 2014; Park et al., 2014) e.g. anterior deltopectoral approach for open capsulorrhaphy, shoulder arthroplasty; Gardner’s anterolateral acromion approach for proximal humeral fractures (Gardner et al., 2008); lateral deltoid splitting approach for rotator tear repair, shoulder arthroplasty; posterior approach for posterior capsulorraphy and glenoid fractures (Price et al., 2004).

The anterior deltopectoral approach is considered the “work horse” incision of the shoulder. It provides excellent exposure to the shoulder joint and its coverings (Hoppenfeld, 2009). The patient is placed in a supine position with a sandbag or bump under the ipsilateral scapula to improve access. The important landmarks are the coracoid process of the scapula and the deltopectoral groove. An oblique 10 to 15cm incision is made just lateral to the coracoid process down to the point of insertion of the deltoid muscle in the deltoid tuberosity of the humerus and along the deltopectoral groove. Superficial dissection within this groove will reveal the cephalic vein. The pectoralis major and deltoid muscles are then retracted medially and laterally respectively. The short head of biceps brachii and the coracobrachialis muscles are then displaced medially to reveal fascia over the subscapularis tendon. This fascia is then incised laterally to expose the joint capsule. The axillary nerve is at risk as it crosses below the glenohumeral joint and inferior border of the subscapularis muscle. Therefore the surgeon should avoid placing retractors below the subscapularis and joint capsule (Mark Miller, 2008).

The lateral deltoid splitting approach provides limited access to the surgical neck and head of the humerus. This approach is limited distally by the axillary nerve in the undersurface of the deltoid muscle (Hoppenfeld, 2009; Robinson et al., 2007). After appropriate positioning and surgical preparation, a longitudinal incision is made from the tip of the acromion process (the proximal landmark) and the deltoid muscle split along its fibers up to a maximum 5cm distally. This will reveal the sub deltoid fascia and the tendon of supraspinatus on the greater tuberosity of the humerus. The axillary nerve is at risk if the incision is extended beyond 5cm from the acromion process. A stay suture can be inserted at the inferior apex of the split to prevent distal extension of the incision. Distal extension beyond 5cm of deltoid split can cause denervation of parts of the deltoid muscle located anteriorly to the split muscle (Hoppenfeld, 2009). Abduction of the arm is a major determinant of the position of the axillary nerve with respect to the acromion. It shortens the distance from the acromion process to the nerve. From the posterolateral corner of the acromion, the nerve lies about 6.5 cm in neutral and 5.1 cm at 90° of abduction respectively (Bailie et al., 1999).

In the posterior approach, the patient is placed in a lateral decubitus position with the affected side facing upwards. The nonoperative side should be well protected using pads. A linear incision about 6cm is made from the posterior corner of the acromion and along the length of scapular spine. The deltoid muscle which is attached on the scapular spine is identified and split along its fibers. Blunt dissection is done to identify an internervous plane between the teres minor and infraspinatus muscles. The posterio-inferior margin of the joint capsule is exposed by retracting the infraspinatus and teres minor muscles superiorly and inferiorly respectively. Dissection below the teres minor should be avoided because of risk of injury to the axillary nerve and the posterior circumflex humeral vessels (Hoppenfeld, 2009; Mark Miller, 2008; Terry Canale, 2008).

The Gardner's anterolateral approach allows minimally invasive exposure and treatment of proximal humerus fractures by using fixed angle plate and screw devices. In a cadaveric study, it was described that apart from the main motor nerve, no other branch crossed the fibrous raphe of the deltoid muscle therefore the muscle is split along this raphe. Care is taken to avoid excessive soft tissue dissection and muscle retraction (Gardner et al., 2005).

2.2 The Course and Length of the Axillary Nerve

The axillary nerve originates from the posterior cord of the brachial plexus. Its root value is C5 and C6 (Gurushantappa et al., 2015; Rastogi et al., 2013). At its origin, it lies lateral to the radial nerve, posterior to the axillary artery and on the surface of the subscapularis muscle. It then curves along the lower border of the subscapularis accompanied by the posterior circumflex humeral vessels to enter the quadrangular or quadrilateral space (*Appendix 3)* (Gray et al., 2005; Liu et al., 2011; Loukas et al., 2009; Sinnatamby et al., 2011; Tubbs et al., 2005). Compression of the nerve within this space is an uncommon cause of paresthesia and pain in the upper extremity leading to quadrangular or quadrilateral space syndrome (Brown et al., 1999; Cahill et al., 1983; Francel et al., 1991; Linker et al., 1993).

The nerve usually divides within this space into anterior and posterior branches which innervate the surrounding structures. The anterior branch accompanied by the posterior circumflex humeral vessels curves around the surgical neck of the humerus deep to the deltoid muscle. Lying medial to the anterior branch and within the quadrangular space, the posterior branch curves along the lateral head of the triceps muscle close to the inferior rim of the glenoid where it is at risk of injury (Ball et al., 2003).

A cadaveric study on the surgical anatomy of the axillary nerve branches to the deltoid muscle found that the anterior branch supplied both "the anterior and middle parts of the deltoid in 100% of the specimens" while the posterior branch supplied the posterior part of the deltoid in 97.7% of the specimens (Leechavengvongs et al., 2015).

A similar study that was done among adult Kenyan population at the Department of Human Anatomy, University of Nairobi on the branching patterns of the posterior cord of the brachial plexus from which the axillary nerve originates showed that variant anatomy of the posterior cord was common among the study subjects. Only 8 (10.7%) out of a sample size of 75 showed the classical branching pattern and in 10.3%, the upper subscapular nerve which innervates the subscapularis muscle originated from the axillary nerve instead of directly from the posterior cord of the brachial plexus (Gupta et al., 2005; Muthoka et al., 2011).

The anterior and posterior branches of the axillary nerve have varied lengths. The anterior branch is frequently longer than the posterior branch. Leechavengvong et al., 2015 reported that the average length of both anterior and posterior branches were 5.4cm (range, 1.6-9.2cm) and 4.5cm (range, 1.7-8.1cm) respectively. In addition, "there were no significant differences in the dimensions of the nerve or the distribution pattern between the right and the left sides or in respect of gender or age ($P > 0.05$)”.

2.3 The Correlation between Axillary Nerve Distribution and Arm Length (AL)

The location of the axillary nerve can be predicted preoperatively using the arm length of an individual. The arm length can be defined as the distance from the lateral aspect of the acromion process of the scapula to the lateral epicondyle of the humerus (Rotari et al., 2012). The correlation between arm length and the position of the branches of the axillary nerve has significant positive correlation. This can be used to predict the course or location of the nerve prior to surgery especially in the deltoid splitting approaches to the proximal humerus and shoulder joint. Traditionally, this distance has been taken as 5cm from the lateral edge of the acromion process of the scapula however, individual anatomical variations exists in the population (Rotari et al., 2012).

CHAPTER THREE: METHODOLOGY

3.1 Study Design

This was a cross sectional study. The study duration was from 1st January 2016 to 31st August 2016.

3.2 Study Site

This research was conducted in the Department of Human Anatomy Laboratory, Moi University School of Medicine which is based at the Moi Teaching and Referral Hospital (M.T.R.H) situated in Eldoret town 320kms North West of Nairobi, Kenya.

The Department of Human Anatomy is one of the departments which constitute College of Health Sciences (C.H.S), Moi University and is equipped with anatomy and histology laboratories that facilitate training of both undergraduate and postgraduate students.

The hospital (M.T.R.H) is the second largest referral facility in Kenya (after Kenyatta National Hospital). It has a bed capacity of over 1,000 and serves as a referral hospital for the western part of Kenya, with a catchment population of about 16 million people (approximately 33% of Kenyan population). The hospital provides various services ranging from primary to specialized care and serves urban, peri-urban and rural populations from near and far counties. The hospital also serves patients from neighboring countries like Uganda, Sudan, South Sudan and Rwanda.

3.3 Study Population

This study included adult formalin prefixed cadaveric shoulders from the Department of Human Anatomy, Moi University School of Medicine. The available limbs were disarticulated at the scapulothoracic region therefore determination of sex was impossible.

3.4 Eligibility Criteria

3.4.1 Inclusion Criterion

Formalin embalmed left side upper extremities.

3.4.2 Exclusion Criteria

The deformed or pre-dissected limbs were excluded from the study.

3.5 Sample Size Determination

In Moi University Anatomy Laboratory, the maximum number of cadaveric upper limbs (either right or left) that could be attained was approximately sixty. Therefore, a census study of fifty one left upper extremities that met the eligibility criteria was done.

Only the left upper limbs were used as these were the majority. In addition, this was also to avoid the possibility of duplication of data from the same cadaver.

3.6 Materials and Methods

The axillary nerve was dissected in the formalin fixed cadaveric specimens. A digital calibrated caliper [(Neiko® Tools Digital Caliper serial number 0.3.04.0487ECC) accurate to 0.01mm (*Appendix 1*)] was used to measure individual arm lengths and the lengths of the axillary nerve.

Dissections were done according to the descriptions by The Cunningham's Manual of Practical Anatomy 15th Edition (Romanes, 2003). Through the deltopectoral groove, the deltoid muscle was dissected from the acromion and separated from the spine of the scapula and reflected downwards. Next, the inner surface of the deltoid muscle was exposed and reflected forwards to reveal the axillary nerve and the posterior circumflex humeral vessels which were exposed by removal of the sub-deltoid/clavipectoral fascia. These structures were then traced on the surgical neck of the humerus through the quadrangular space "inferior to the teres minor and the articular capsule of the shoulder joint" (Romanes, 2003).

Hypodermic needles were pierced through the axillary nerve. This was to help in the representation of the course of the nerve on the outer surface of deltoid muscle and to minimize errors during subsequent measurements as shown in the photograph in figure 3.6.1 below.

The distance from the lateral edge of the acromion to the lateral humeral epicondyle was measured and recorded as the arm length (AL).

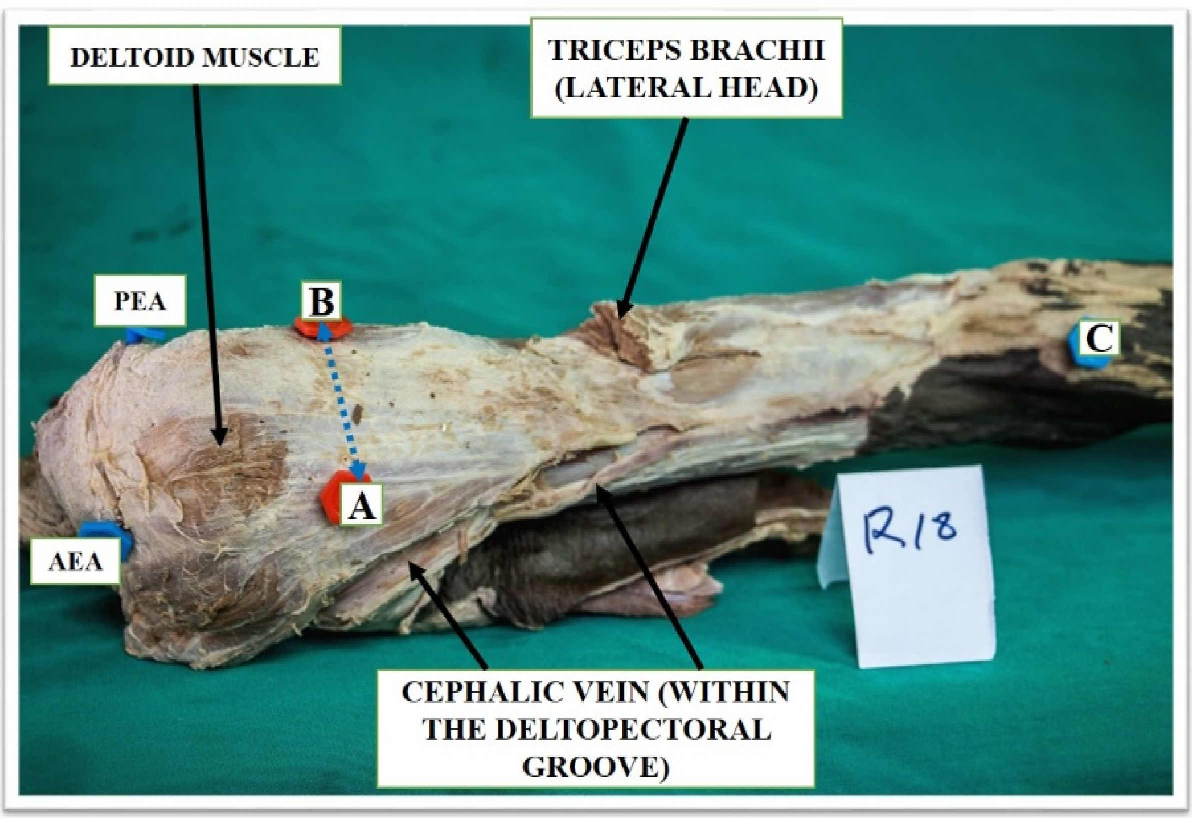

Figure 3.6.1: Dissected specimen with the important landmarks represented using colored pins. (AEA- anterior edge of acromion; PEA- posterior edge of acromion; A ↔ B course of the axillary nerve; C- lateral epicondyle of the humerus).

The course of the axillary nerve was determined as a line on the outer surface of the deltoid muscle using hypodermic needles as external landmarks *(Figures 3.6.1 and 4.3.1)*. Using a digital caliper, the distance from the anterior edge of the acromion (AEA) to the axillary nerve was measured and recorded as the anterior distance (AD) (*Appendix 4*).

The distance from the posterior edge of the acromion (PEA) to the axillary nerve was measured and recorded as the posterior distance (PD) (*Appendix 4*). All measurements taken were recorded in centimeters (cm).

Correlation analysis was then performed between arm length (AL), and the anterior and posterior distances.

The ratio between arm length (AL) and the anterior distance (AD) was calculated for each cadaver and recorded as the anterior index (AI) (defined as the distance of the nerve from the anterior edge of the acromion divided by arm length i.e. $AI = \frac{AD}{AL}$). In addition, the ratio between arm length (AL) and the posterior distance (PD) was calculated and recorded as the posterior index (PI) (defined as the distance of the nerve from the posterior edge of the acromion divided by arm length i.e. $PI = \frac{PD}{AL}$).

The main branches of the axillary nerve (anterior and posterior) were dissected and their lengths measured in centimeters from the point of origin at the division of the main trunk within the quadrangular space to termination in the deltoid muscle. Photographs of dissected specimens and nerves were recorded using a digital camera (Sony® DSC-W180 10.1 megapixels).

3.7 Data Collection, Processing and Analysis

The observed measurements of the axillary nerve and its relation to osseous landmarks were recorded in structured data collection forms (*Appendix 2*). The raw data was then entered into a Microsoft® Access database which was encrypted with password to ensure confidentiality. The password was only accessible to the main investigator.

Data coding, cleaning and analysis was done using Statistical Package for Social Sciences (SPSS) version 21 for Windows® (SPSS, Chicago, IL, USA). Descriptive statistics were done to explore and summarize the variables; for categorical variables frequencies and proportions were reported in tables. For numeric (continuous) variables, box plots were plotted to show distributions, means (standard deviations) or medians (interquartile range). These were computed and presented in tables.

Bivariate analysis was done to determine correlation (Pearson's correlation) between variables. Simple linear regression was used to analyze arm length (AL) using both anterior and posterior distances. The level of significance was set at 0.05. The test statistics and corresponding p-values were reported. Computer hardware, memory sticks and compact disks were used to store the data obtained for future backup.

3.8 Study Limitations

The exact anatomical position of the axillary nerve could be altered during dissection. This was minimized by plotting the course of the nerve on the external surface of the limbs with the use of hypodermic needles before any measurements were taken.

3.9 Ethical Considerations

Ethical approval was sought from the Institutional Research and Ethics Committee (IREC) Moi University, M.T.R.H and the Department of Human Anatomy prior to commencement of the study (*Appendices 6-9*).

The study was conducted in accordance with the Anatomy Act Chapter 243-9 (REVISED EDITION OF 2012) of The Laws of Kenya which entitles a person registered as a student in an approved school of anatomy or medicine to examine and conduct anatomical research on human cadavers as long as the requirements stipulated in the act are strictly adhered to. Data confidentiality was strictly maintained and this included the use of passwords in the database.

The reports of analysed results were disseminated through an oral defense of this thesis and thereafter presented at relevant conferences/seminars, publication in a peer reviewed scientific journal and a printed thesis.

CHAPTER FOUR: RESULTS

4.1 The course of the Anterior and Posterior Branches of the Axillary Nerve

The axillary nerve originated from the posterior cord of the brachial plexus in all the specimens. It descended posterior to the third part of the axillary artery, lateral to the radial nerve and obliquely on the surface of the subscapularis muscle. In this proximal course, the nerve was located in an imaginary triangle bounded laterally by the tip of the acromion process and the medial border of the coracobrachialis muscle, medially by the upper lateral part of the pectoralis minor muscle, and inferiorly by the axillary artery.

It then curved posterolaterally on the inferior border of the subscapularis muscle to end in the quadrangular space (n =51) whose boundaries included the surgical neck of the humerus laterally, teres minor muscle superiorly, proximal part of the long head of triceps brachii medially and teres major muscle inferiorly.

4.1.1 Pattern of Distribution of the Main Trunk of the Axillary Nerve

a. **Articular branches to the shoulder joint:** The main trunk of the axillary nerve innervated the shoulder joint in a total of 41 cases (80.4%) with the anterior division supplying the remainder as shown in table 4.1.1.1 below. No articular branch arose from the posterior division of the axillary nerve.

Table 4.1.1.1: Innervation to the shoulder joint

Axillary Nerve Branches	**Total number**	**Percentage**
Main trunk	41	80.4%
Anterior division	10	19.6%
Posterior division	0	0%
Total	51	100%

The main nerve supply was from the main trunk of the axillary nerve

b. Muscular branches: In a 28 specimens, the main trunk of the axillary nerve innervated the teres major, teres minor and subscapularis muscles as shown in table 4.1.1.2 and figures 4.1.1.1 and 4.1.1.2 below.

Table 4.1.1.2: Muscular innervation by main trunk of the axillary nerve

Muscle	**Number of cases (n=28)**	**Percentage**
Teres major	8	28.57%
Teres minor	18	64.29%
Subscapularis	2	7.14%

In 8 specimens, the nerve to teres major arose directly from the main trunk of the axillary nerve as shown in figures 4.1.1.1 and 4.1.1.2 below.

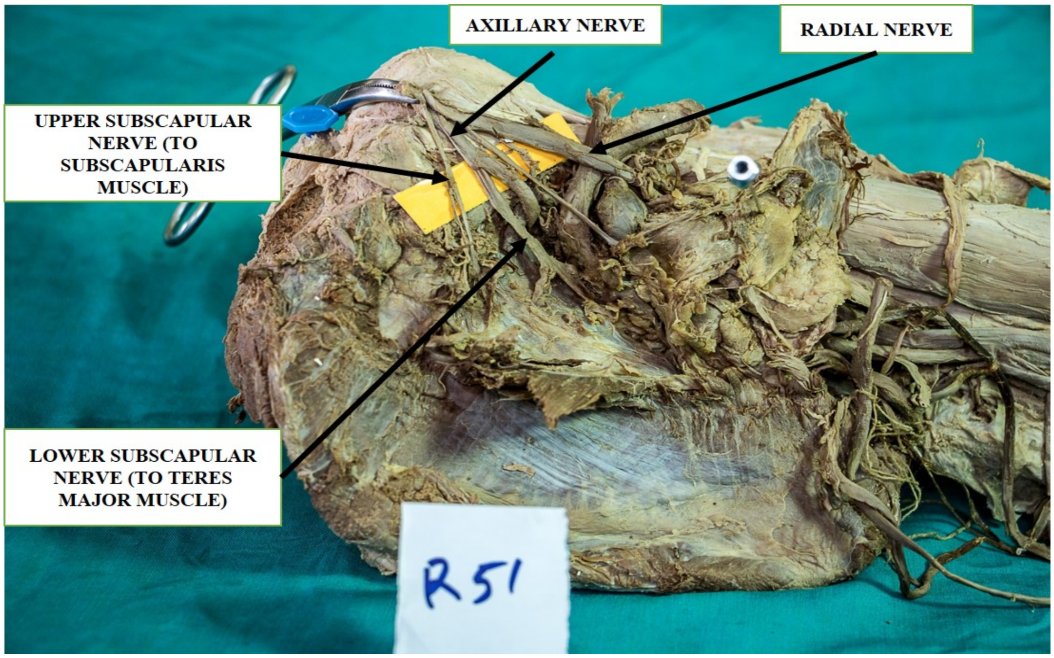

Figure 4.1.1.1: The terminal branches from the posterior cord of the brachial plexus.

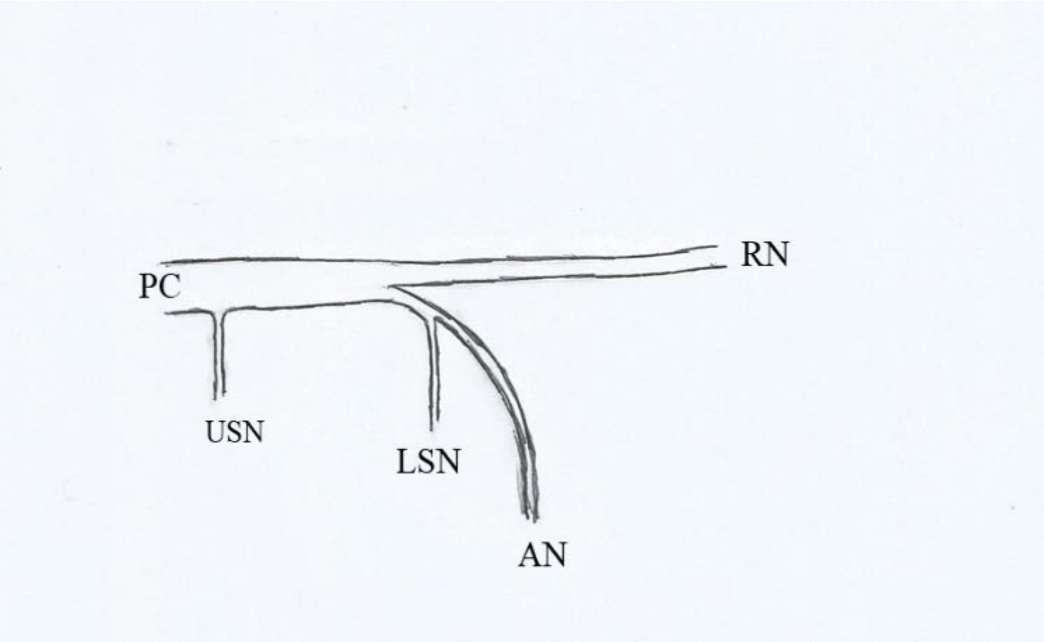

Figure 4.1.1.2: The terminal branches from the posterior cord of the brachial plexus. PC- posterior cord of brachial plexus, RN- radial nerve, USN- upper subscapular nerve, LSN- lower subscapular nerve, AN- axillary nerve

In 2 specimens, the nerve to subscapularis muscle arose directly from the main trunk of the axillary nerve as shown in figures 4.1.1.3 and 4.1.1.4 below.

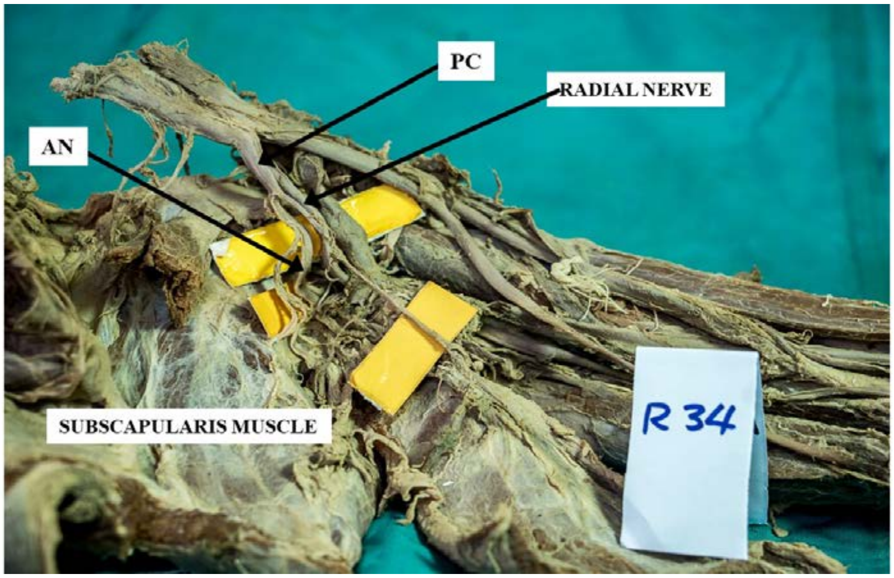

Figure 4.1.1.3: The terminal branches from the posterior cord of the brachial plexus. PC- posterior cord of brachial plexus, AN- axillary nerve.

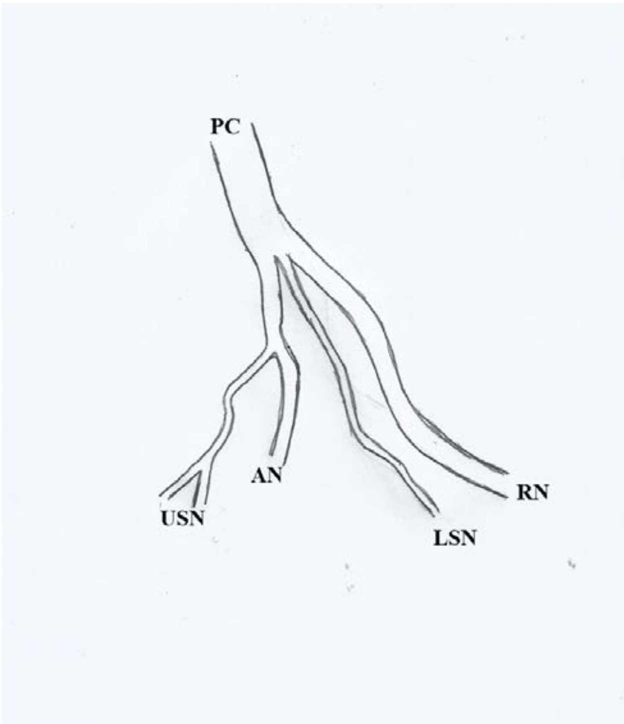

Figure 4.1.1.4: The terminal branches from the posterior cord of the brachial plexus. PC- posterior cord of brachial plexus, RN- radial nerve, USN- upper subscapular nerve, LSN- lower subscapular nerve, AN- axillary nerve.

4.1.2 The Anterior Branch of the Axillary Nerve

This was the main/larger terminal branch of the axillary nerve which began within the quadrangular space in all the 51 specimens dissected. This branch was always accompanied by the posterior circumflex humeral vessels as shown in figure 4.1.2.1 below.

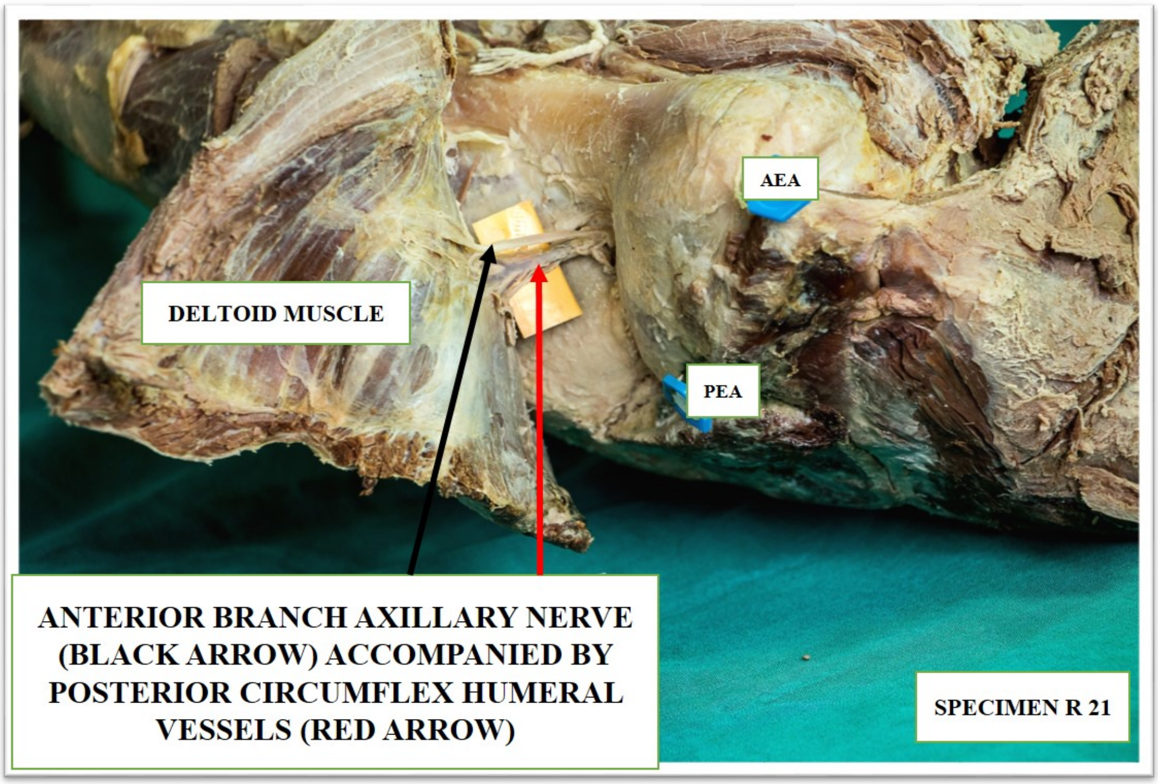

Figure 4.1.2.1: The anterior branch of the axillary nerve accompanied by the posterior circumflex humeral vessels (AEA- anterior edge of acromion; PEA- posterior edge of acromion).

The anterior branch then curved posterolaterally in intimate contact with the surgical neck of the humerus to enter a subfascial plane under the cover of the deltoid muscle.

It terminated by dividing into intermuscular twigs which innervated the various parts of the deltoid muscle as described below:

a. **Articular branches:** The anterior division supplied the glenohumeral joint in 19.6% of the specimens (*Table 4.1.1.1*).

b. Muscular branches: In its intramuscular course, it divided into two main parts to supply the anterior and middle parts of the deltoid muscle in 51 (100%) and 47 (92.1%) of specimens respectively (*Figure 4.1.2.2 and Table 4.1.2.1*). There was no branch to the posterior part of the deltoid muscle from the anterior division of the axillary nerve. In addition, one specimen received dual innervation to the middle part of the deltoid from both the anterior and posterior divisions of the axillary nerve.

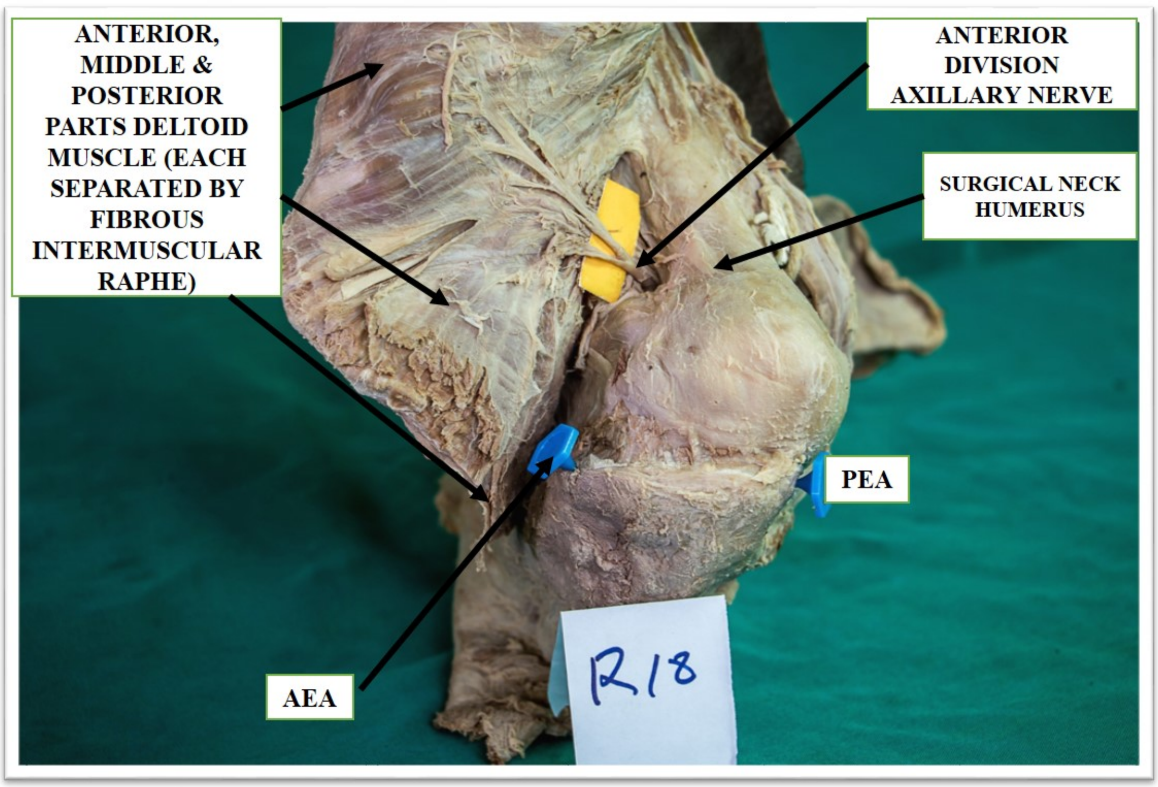

Figure 4.1.2.2: The intermuscular course of the anterior branch of the axillary nerve. Note the intimate relation of the nerve to the surgical neck of the humerus (AEA- anterior edge of acromion; PEA- posterior edge of acromion).

Table 4.1.2.1: Pattern of innervation to the deltoid muscle.

Axillary nerve division	Anterior part of deltoid muscle	Middle part of deltoid muscle	Posterior part of deltoid muscle
Anterior	51 (100%)	47 (92.1%)	0
Posterior	0	4 (7.8%)	51 (100%)

The anterior part of the deltoid muscle was innervated by the anterior division, while the posterior part by the posterior division in all the 51 specimens.

4.1.3 The Posterior Branch of the Axillary Nerve

This was the smaller terminal branch of the axillary nerve. It separated from the anterior branch of the axillary nerve inferior to the glenoid at around six o'clock position within the quadrangular space in 100% of cases and curved posteromedially as shown in figure 4.1.3.1 below.

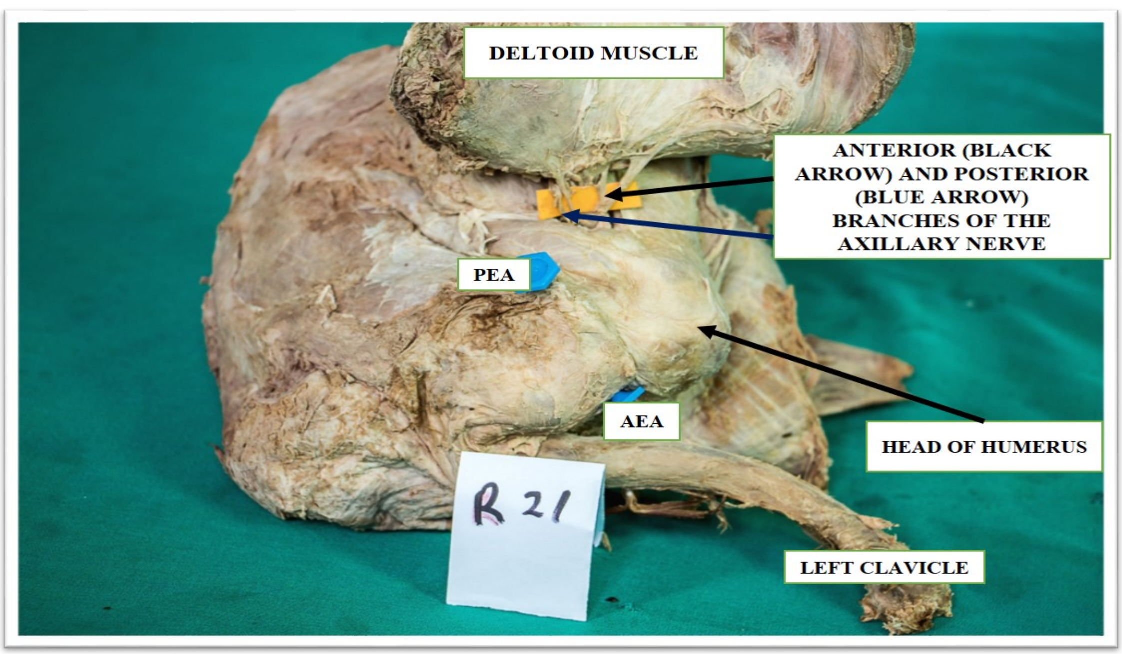

Figure 4.1.3.1: The anterior and posterior branches of the axillary nerve. (AEA- anterior edge of acromion; PEA- posterior edge of acromion).

The posterior branch terminated into the following branches:

a. Muscular branches:

1. **Teres minor muscle:** The nerve to teres minor muscle arose from the posterior branch of the axillary nerve in 33 (64.7%) of cases as shown in table 4.1.3.1 below. From its origin within the quadrangular space, it curved posteromedially to enter the muscle on its inferior surface.

Table 4.1.3.1: Pattern of innervation to the teres minor muscle

Nerve	**Number of specimens**	**Percentage**
Posterior division of axillary nerve	33	64.7%
Main trunk of axillary nerve	18	35.3%
Anterior division of axillary nerve	0	0%
Total	51	100%

The posterior division of the axillary nerve was the main supply to the teres minor muscle.

2. **The deltoid muscle:** The posterior part of the deltoid muscle was innervated by the posterior branch of the axillary nerve in 100 % of cases (*Figures 4.1.3.1 and 4.1.3.2*). In addition, the middle part of the deltoid was innervated by the posterior branch of the axillary nerve in 4 (7.8%) of cases.

A fibrous intermuscular raphe separated the different parts of the deltoid muscle as shown in figure 4.1.3.2 below.

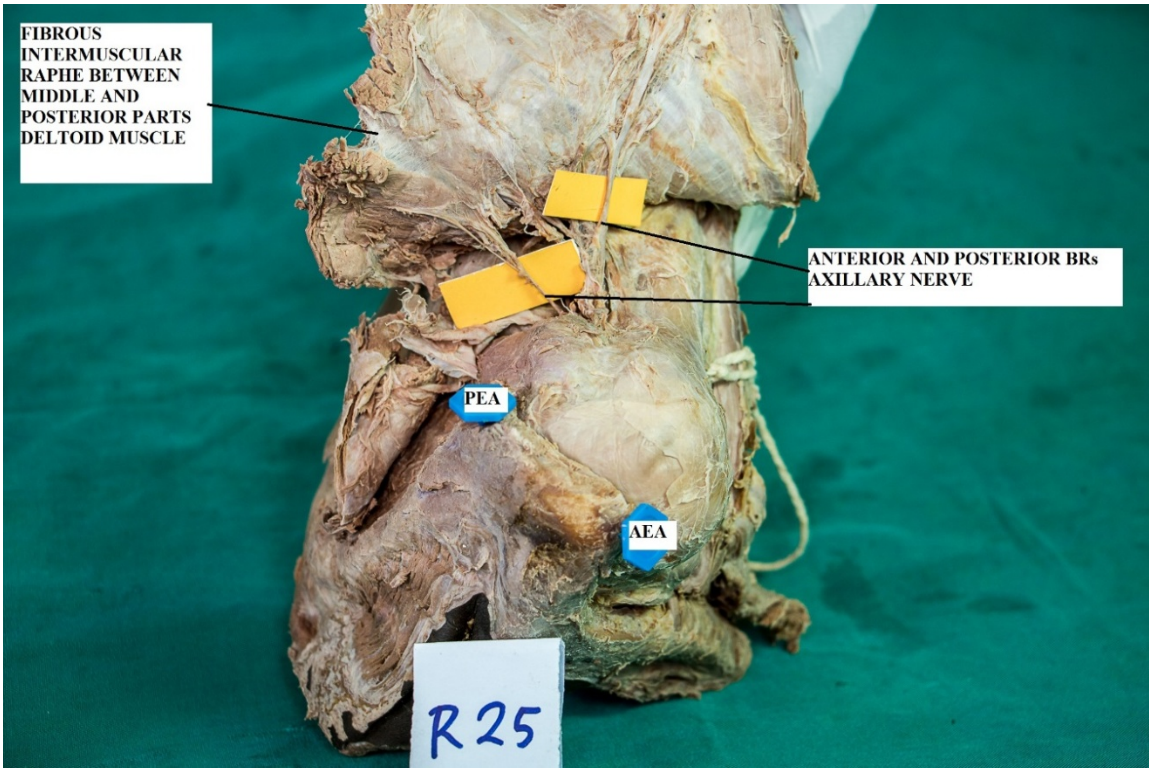

Figure 4.1.3.2: The posterior branch of axillary nerve innervating the posterior part of the deltoid muscle. (AEA- anterior edge of acromion; PEA- posterior edge of acromion).

There was no muscular branch to the anterior part of the deltoid muscle from the posterior branch of the axillary nerve observed (*Table 4.1.2.1*).

b. **Cutaneous branches:** The superior lateral cutaneous nerve of the arm originated from the posterior branch of the axillary nerve in all the specimens studied. This branch curved posterolaterally and deep to the posterior part of the deltoid muscle to end within the subcutaneous tissue. It did not pierce the muscle in any of the specimens studied.

4.2 The length of the axillary nerve and its branches

Table 4.2.1: The length of the axillary nerve and its branches

Axillary nerve	Mean Length (cm)	Range (cm)
Main Trunk	6.14 (SD 1.6)	2.2-10.1
Anterior Branch	7.2 (SD 1.8)	2.4-10.4
Posterior Branch	4.4 (SD 1.4)	2.5-8.9

The mean length of the axillary nerve was 6.14cm (SD 1.6) [95% CI 5.70, 6.58] with a range of 2.2 to 10.1 cm. The average length of the anterior branch of the axillary nerve was 7.2 cm (SD1.8) [95% CI 6.71, 7.71] (range from 2.4 to 10.4cm). The average length of the posterior branch of the axillary nerve was 4.4 cm (SD 1.4) [95% CI 4.02, 4.82] (range from 2.5 to 8.9cm).

4.3 The Correlation between Axillary Nerve Distribution and Arm Length (AL): the Anterior and Posterior Indices (AI and PI respectively)

The average AD was 6.46cm (SD 0.7cm) [95% CI 6.26, 6.66] with a range of 5.15cm – 8.68cm as shown in figure 4.3.1 below.

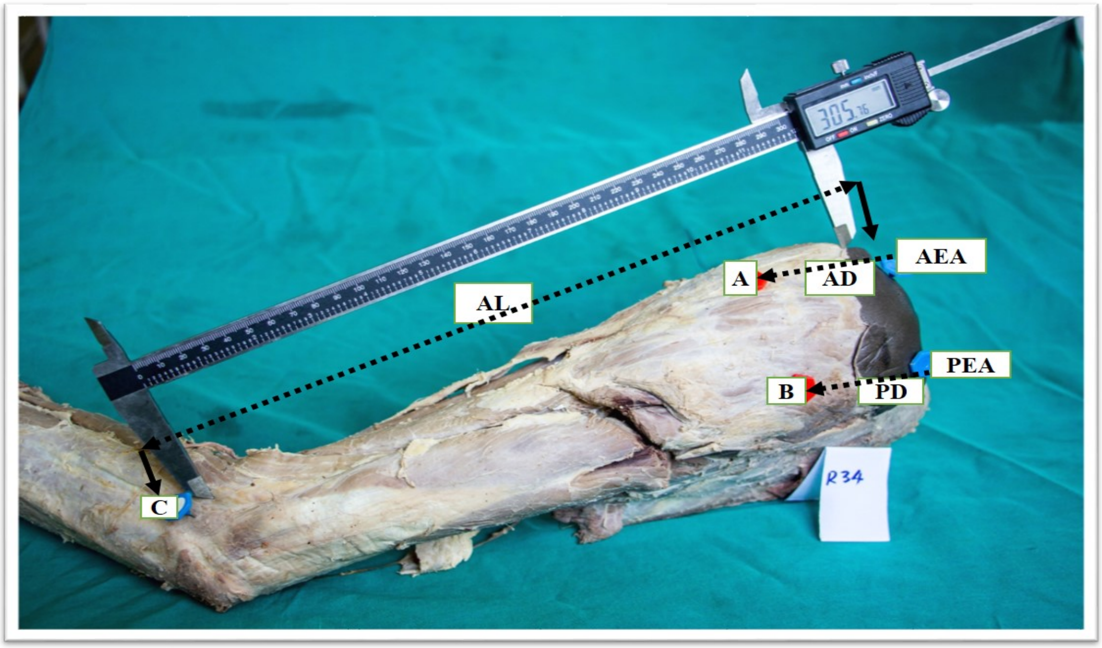

Figure 4.3.1: Measurements used to map out the axillary nerve (AL- arm length; AD- anterior distance from anterior edge of acromion AEA to axillary nerve; PD- posterior distance from posterior edge of acromion PEA to axillary nerve).

The average PD was 5.88cm (SD 0.95cm) [95% CI 5.61, 6.15] with a range of 4.42cm – 9.99cm (*Table 4.3.1*).

Table 4.3.1: Axillary nerve distances from acromion process of the scapula (AD-anterior distance, PD-posterior distance, AL-arm length).

Number	**Parameter**	**Range (cm)**	**Mean ±SD, n=51**
1	AD	5.15 – 8.68	6.46 (0.70)
2	PD	4.42 – 9.99	5.88 (0.95)
3	AL	27.29 – 38.74	31.96 (2.27)

The arm length (AL) had a mean of 31.96cm (SD 2.27cm) [95% CI 31.32, 32.60] with a range of 27.29cm – 38.74cm as shown in figure 4.3.2 below.

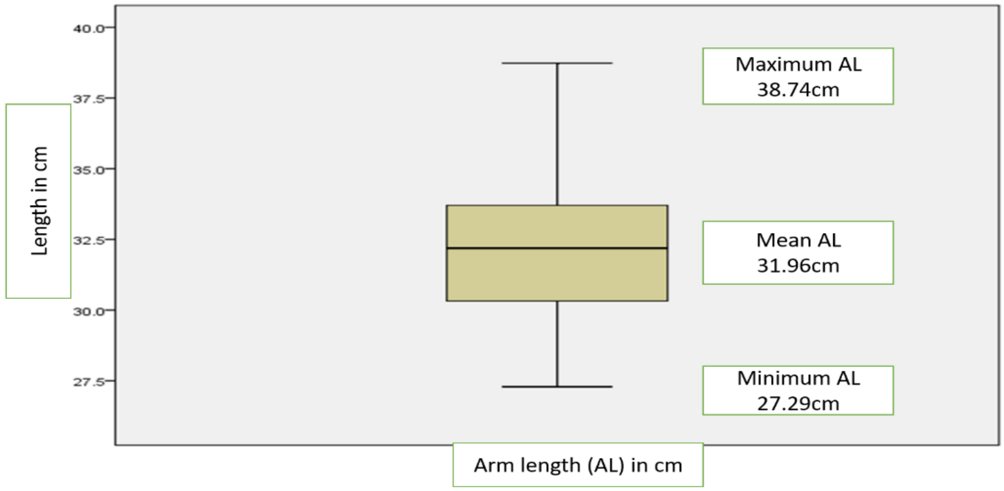

Figure 4.3.2: Average arm length (AL)

The correlation between AD and AL (the anterior index, AI) was statistically significant (r=0.335; p=0.016) as shown in figure 4.3.3 below. The regression model revealed that with 1cm increase in AL, the AD is predicted to increase by 0.104cm which is a significant change p=0.016.

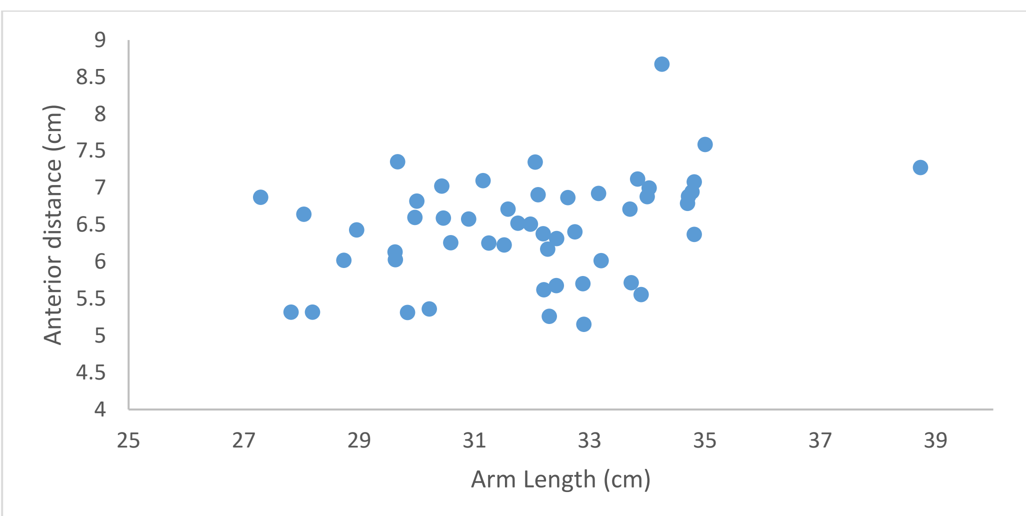

Figure 4.3.3: Graph illustrating the correlation between AD and AL (anterior index, AI)

The correlation between PD and AL (posterior index, PI) was not statistically significant (r=0.147; p=0.304). The regression model shows that 1cm increase in AL the PD is predicted to increase by 0.062 cm though the relationship is not significant p=0.304 as shown in figure 4.3.4 below. The average AI and PI were 0.2±0.022cm [95% CI 0.20, 0.21] (range 0.157-0.253cm) and 0.185±0.033 [95% CI 0.18, 0.19] (range 0.14-0.35cm) respectively.

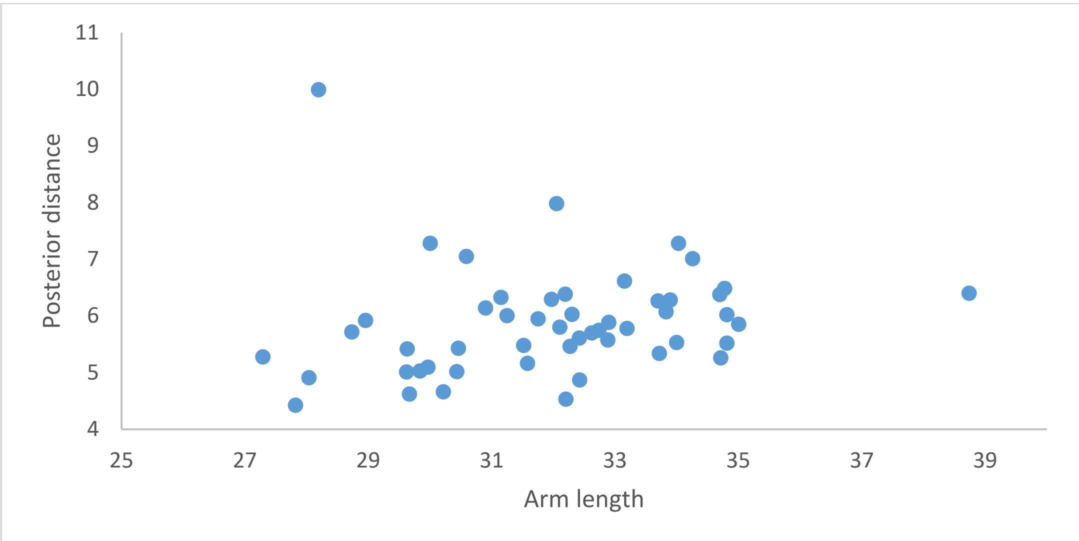

Figure 4.3.4: Graph illustrating the correlation between PD and AL (posterior index, PI)

CHAPTER FIVE: DISCUSSION

5.1 The course of the Main Trunk of the Axillary Nerve and its Branches

The axillary nerve (C5, 6) is one of the two large terminal branches of the posterior cord of the brachial plexus. The radial nerve (C5-C8, T1) is the other branch as described by (Gray et al., 2005 and Sinnatamby et al., 2011 *(Figures 4.1.1.1 and 4.1.1.3).*

In this study of 51 adult cadaveric specimens, the axillary nerve originated from the posterior cord of the brachial plexus in all specimens. This is the conventional and consistent origin of this nerve and concurs with Gray et al., 2005 and Gurushantappa et al., 2015.

However, variations in the classical branching pattern of the posterior cord of the brachial plexus have been shown to exist in different populations. In this study, the upper and lower subscapular nerves which usually innervate the subscapularis and teres major muscles respectively originated directly from the axillary nerve in 8 (15.7%) and 2 (3.9%) cases respectively instead of the posterior cord. This is in agreement with a cadaveric study on 75 brachial plexuses from 68 human cadavers done in Kenya by Muthoka et al., 2011 which reported that only 8 (10.7%) showed the classical pattern of division of the posterior cord of the brachial plexus. This high individual and population variation has been attributed to the unusual embryological development of the roots, trunks and divisions of the brachial plexus as documented by Rastogi et al., 2013.

This has major clinical implications during surgical procedures of the axilla and root of the neck, and during infraclavicular anesthetic blocks of the posterior cord. Such unusual branching can lead to iatrogenic injury and peripheral nerve impingement syndromes. In addition, injury to axillary nerves that give origin to the upper, middle or lower subscapular nerves can lead to catastrophic and extensive functional impairment of the arm according to Muthoka et al., 2011.

From its origin, the main trunk of the axillary nerve descended on the anterior surface of the subscapularis muscle and curved inferolaterally to end by dividing into its terminal branches within the quadrangular space in all of the specimens studied. The anterior branch was always located deeper than the posterior branch. This is in agreement with Cetik et al., 2006 and Leechavengvong et al., 2015.

In contrast, Loukas et al., 2009 reported that the axillary nerve divided within the quadrangular space in 65% and within the deltoid muscle in 35% of cases respectively in a study of 50 cadaveric specimens. Likewise, Gurushantappa et al., 2015 studied 25 adult cadavers and demonstrated that the nerve divided within the quadrangular space and deltoid muscle in 88% and 12% of cases respectively.

These differences in the branching of the main trunk of the axillary nerve can be due to the unusual embryological development of the divisions of the brachial plexus according to Gupta et al., 2004.

In this present study, the anterior branch of the axillary nerve originated from within the quadrangular space. It then curved posterolaterally along the surgical neck of the humerus and was always accompanied by the posterior circumflex humeral vessels in all the specimens with the nerve located superior to the vessels. This concurs with Apaydin et al., 2010 and Gurushantappa et al., 2015. This branch is therefore at risk of injury in shoulder dislocation, fractures involving the proximal humerus and during open reduction and internal fixation of such fractures as documented by Gardner et al., 2005; Lancaster et al., 2014; Lin et al., 2014; Ondrejka, 1950 and Pasila et al., 1978.

The posterior branch of the axillary nerve also originated from within the quadrangular space. It had an intimate relation with the inferior rim of the glenoid in all specimens studied. It innervated the posterior part of the deltoid muscle and teres minor muscle in 100% and 64.7% of specimens respectively. Finally, it terminated deep to the posterior part of the deltoid muscle to end as the superior lateral cutaneous nerve of the arm. No articular branch arose from it. Concurrent results were reported in a study of 19 freshly frozen cadavers. It was described that the posterior branch lay directly on the shoulder joint capsule and the glenoid rim. It gave muscular branches to the posterior part of the deltoid and the teres minor and ended by becoming the superior lateral cutaneous nerve according to Ball et al., 2003. From an arthroscopic perspective, Price et al., 2014 reported that the posterior branch of the axillary nerve and its branches to the teres minor and the superior lateral cutaneous nerve lay closest to the glenoid rim at the 6 o'clock position.

The branches from the posterior part of the axillary nerve are therefore vulnerable to injury during manipulation of the inferior part of the shoulder joint capsule e.g. arthroscopic thermal shrinkage, anterior shoulder dislocation and quadrilateral space syndrome as documented by Cahill et al., 1983; Francel et al., 1991 and Linker et al., 1993.

The teres minor muscle is classically described as part of the rotator cuff group of muscles according to Gray et al., 2005 and Sinnatamby et al., 2011. It is considered as a dynamic stabilizer of the shoulder joint and functions as an external rotator of this joint with the arm in abduction. The present study found that in 64.7% of cases, the nerve to teres minor arose from the posterior branch of axillary nerve while in 35.3% it arose directly from the main trunk of the axillary nerve.

In contrast, Loukas et al., 2009 reported that the branch to teres minor muscle arose from the posterior branch of the axillary nerve in 100% of specimens studied. Similarly, Gray et al., 2005 reported that the nerve to teres minor arose from the main trunk of the axillary nerve within the quadrangular space. In contrast, Sinnatamby et al., 2011 reported that this muscle is innervated by the posterior branch of the axillary nerve.

Therefore it can be concluded from this present study that lesions that affect the posterior branch of the axillary nerve which innervates the teres minor muscle can cause functional motor impairment with loss of sensation to the skin over the deltoid in 64.7% of cases. However, in 35.3% of the population from the present study, loss of sensation to the skin over the deltoid muscle is not a reliable indicator of coexistent injury to the nerve to teres minor as this may be supplied by a branch directly from the main trunk of the axillary nerve.

The pattern of innervation to the deltoid muscle has been shown to have individual and population variations. In this study, the axillary nerve had a consistent and predictable location within the sub fascial space deep to the deltoid muscle in all specimens. This finding is in agreement with Rotari et al., 2012. This consistent and predictable location is clinically important in the identification of the nerve during surgeries involving the deltoid muscle.

The anterior division of the axillary nerve innervated the anterior part of the deltoid muscle in 100% (n=51) and middle part of the deltoid in 92.1% (n=47) in all specimens studied. While the posterior division innervated the middle part of the deltoid in 7.8% (n=4) and the posterior part of the deltoid in 100% (n=51) of specimens. In one specimen (1.9%), the middle part of the deltoid muscle received dual innervation from both the anterior and posterior branches of the axillary nerve. The anterior branch did not supply the posterior part of deltoid. Similarly, the posterior branch did not innervate the anterior part of the deltoid. These findings concur with those reported by Cetik et al., 2006.

In contrast, both Ball et al., 2003 and Leechavengvong et al., 2015 described a consistent supply to posterior part of the deltoid muscle from the anterior branch of the axillary nerve. Likewise, Gurushantappa et al., 2015 reported that the anterior branch of the axillary nerve supplied the posterior part of the deltoid muscle in 8% of specimens studied.

These variable findings and descriptions on the innervation of the deltoid muscle have clinical implications on the surgical interventions and subsequent motor function upon injury. From the observations in the present study, reconstruction of the axillary nerve should involve both the anterior and posterior branches of the axillary nerve in order to restore full motor function of the deltoid muscle. In contrast, the reconstruction of the anterior branch is more appropriate for the restoration of arm abduction strength since the function of the posterior part of the deltoid that is extension of the arm can be compensated by other muscles acting on the shoulder including latissimus dorsi and teres major as documented by Crouch et al., 2013.

The controversy is whether nerve transfer to the anterior branch of the axillary nerve will restore function to the posterior part of the deltoid which is not innervated by the anterior branch as discovered in the present study.

5.2 The Length of the Main Trunk of the Axillary Nerve and its Branches

The main trunk and the branches of the axillary nerve were followed from origin to their muscular insertions and the lengths recorded. The lengths of both the anterior and posterior branches of the axillary nerve have surgical implications during nerve repairs, transfers, transpositions or grafting. The axillary nerve has a short muscular course. Therefore, this has a good prognosis for recovery following surgical repair and nerve grafting.

Leechavengvong et al., 2011 found an average length of 5.4cm (range 1.6-9.2cm) and 4.5cm (range 1.7-8.1cm) for the anterior and posterior branches respectively. These measurements are concur with the findings in this present study.

5.3 The Correlation between Axillary Nerve Distribution and Arm Length (AL): the Anterior and Posterior Indices (AI and PI respectively)

After studying the location of the axillary nerve in relation to the anterior and posterior edge of the acromion process of the scapula, the average anterior distance (AD) was 6.46cm (range 5.15-8.68cm) while the average posterior distance (PD) was 5.88cm (range 4.42-9.99cm). The arm length had a mean of 31.96 cm (range 27.29-38.74cm). Statistical analysis of these measurements revealed that for the AI, for every 1cm increment in the arm length, the AD was predicted to increase by 0.104cm (p=0.016). This represented a significant change. While for the PI, for every 1cm increase in the arm length, the PD was predicted to increase by 0.062. This however was not statistically significant (p=0.304).

These findings concur with those described by Cetik et al., 2006 on 24 embalmed adult cadaveric shoulders. It was reported that the axillary nerve curved inferior to the anterior and posterior edges of the acromion process at an average distance of 6.08cm and 4.87cm respectively. They found significant correlation between arm length and both the AD and PD.

In a cadaveric study of 30 shoulders by Abhinav et al., 2008, the distance of the axillary nerve from the lateral edge of the acromion was measured. These measurements were then correlated in varying degrees of adduction and abduction of the shoulder joint. It was reported that the average arm length (AL) was 31.0cm (range 27-34.5cm). The axillary nerve was located at an average length of 6.0cm (range 4.5-6.5cm) from the lateral edge of the acromion. This distance reduced significantly when the arm was abducted. Abduction moved the nerve closer to the acromion thereby putting the nerve at risk during surgery. The present study did not consider the nerve distances with abduction or adduction due to the stiff nature of the cadaveric specimens.

Liu et al., 2011 studied 44 embalmed adult cadaveric shoulders and found that the arm length varied amongst the Chinese and Caucasian populations. The average arm length ranged from 23.3-33.3cm in their study. These lengths are shorter in comparison to those found in this present study because of the shorter stature of the adult Chinese in comparison to the adult Kenyan. Therefore in order to avoid iatrogenic injury to the axillary nerve during drilling and screw insertion, drill guide protective systems should be placed directly on bone during open reduction and internal fixation (O.R.I.F) of proximal humerus fractures as described by Liu et al., 2011.

In the current study, the average anterior and posterior indices were 0.20 (range 0.157-0.253) and 0.185 (range 0.14-0.35) respectively. These findings concur with those reported by Cetik et al., 2006 who found figures of 0.20 and 0.16 for AI and PI respectively.

A quadrangular safe area or zone located above the axillary nerve is proposed from the present study. This zone is useful and safe during deltoid splitting incisions in proximal humerus fractures, intramuscular injections and shoulder arthroscopy. This quadrangular shaped area is similar to that described by Cetik et al., 2006 as shown appendix 5.

From this study, the maximum anterior and posterior distances (AD and PD) were 8.68cm and 9.99cm respectively. The minimum AD was 5.15cm while the PD was 4.42cm. Therefore, a surgical deltoid split should not be advanced beyond 5.15cm and 4.42cm in anterior and posterior deltoid splits respectively to minimize the possibility of iatrogenic injury to the axillary nerve.

Finally, the use of deltoid ratio that is, length and width of the deltoid muscle versus the distance from the acromion to the axillary nerve has been proposed in the past. Kontakis et al., 1999 demonstrated that "…the shorter the deltoid length, the greater the danger of damaging the nerve in the short distance during surgical splitting of the muscle…" From the present study, measuring the deltoid length and width intraoperatively is a difficult task for the surgeon. The surgeon is advised to use easily palpable bony landmarks such as the anterior and posterior edges of the acromion process of the scapula, and the lateral epicondyle of the humerus to easily predict the course of the axillary nerve.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The axillary nerve has an anterior branch which is distributed over and consistently innervates the anterior and middle parts of deltoid muscle, while the posterior branch is distributed over and supplies the posterior part of deltoid.

The lengths of the main trunk of the axillary nerve and its branches are highly variable.

A 1cm increase in arm length had a predictable increase in nerve distances from anterior and posterior edges of acromion by 0.104cm and 0.062cm respectively.

6.2 Recommendations

Surgeons should be careful during dissection of the proximal humerus and shoulder joint. A preoperative template of a quadrangular “safe zone/ area” as landmarks on the proximal deltoid muscle using minimum distances of 5.15cm and 4.42cm from anterior and posterior edges of acromion process of the scapula respectively should protect the axillary nerve and its branches during surgery.

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APPENDICES

Appendix 1: Equipment and instruments

1. Measuring instruments: Vernier calipers and calibrated rulers.
2. Dissecting instruments: scalpel, blade holders, forceps, and retractors.
3. Digital camera (Sony® DSC-W180 10.1 megapixels)
4. Stationery
5. Gloves
6. Printer
7. Hypodermic needles and pins

Tools used for dissection and measurements

Appendix 2: Data collection form

1. Date………………………………………………………………………………..
2. Identification code………………………………………………………………
3. Measurement 1 AL (arm length) ………………….…………………………….cm
4. Measurement 2 AD (anterior distance) ……………….………………………….cm
5. Measurement 3 PD (posterior distance) ……………………………….………cm
6. Measurement 4 AI……………………………………………………………….
7. Measurement 5 PI……………………………………………………………….
8. Measurement 4 B_1 (length of the main trunk of axillary nerve) ………………...cm
9. Measurement 5 B_2 (length of the anterior branch of the axillary nerve) …...……cm
10. Measurement 6 B_3 (length of the posterior branch of the axillary nerve) ……….cm
11. Innervation pattern of the deltoid muscle:
    a. Anterior branch to anterior deltoid…………………………
    b. Anterior branch to the middle deltoid………………………
    c. Anterior branch to the posterior deltoid……………………
    d. Posterior branch to the posterior deltoid……………………
12. Teres minor muscle innervation……………………………
13. Teres major muscle innervation……………………………
14. Subscapularis muscle innervation…………………………
15. Shoulder joint innervation………………………………….
16. Any observed anatomical variation (s)? Specify…………………….

Appendix 3: The quadrangular space

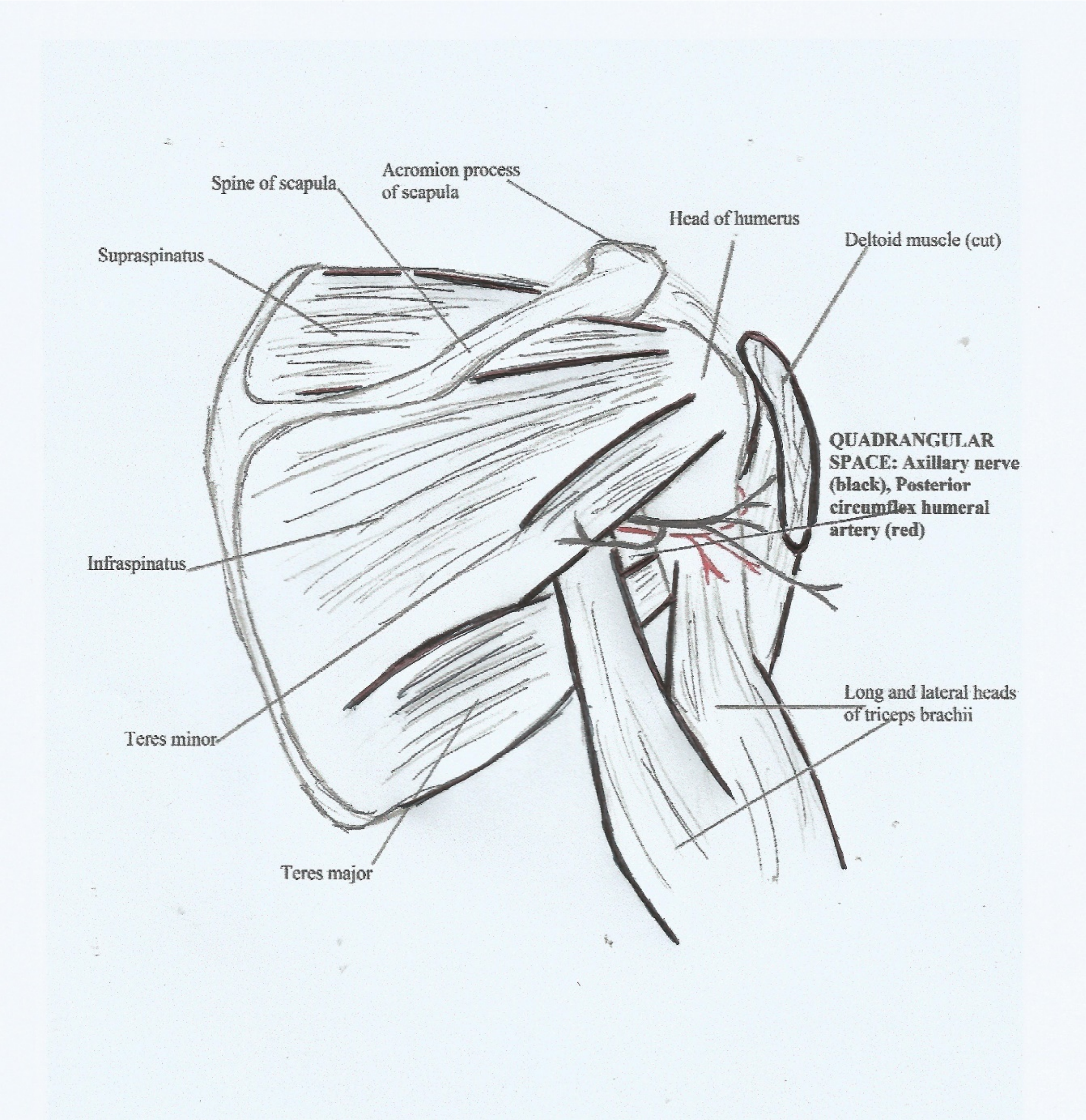
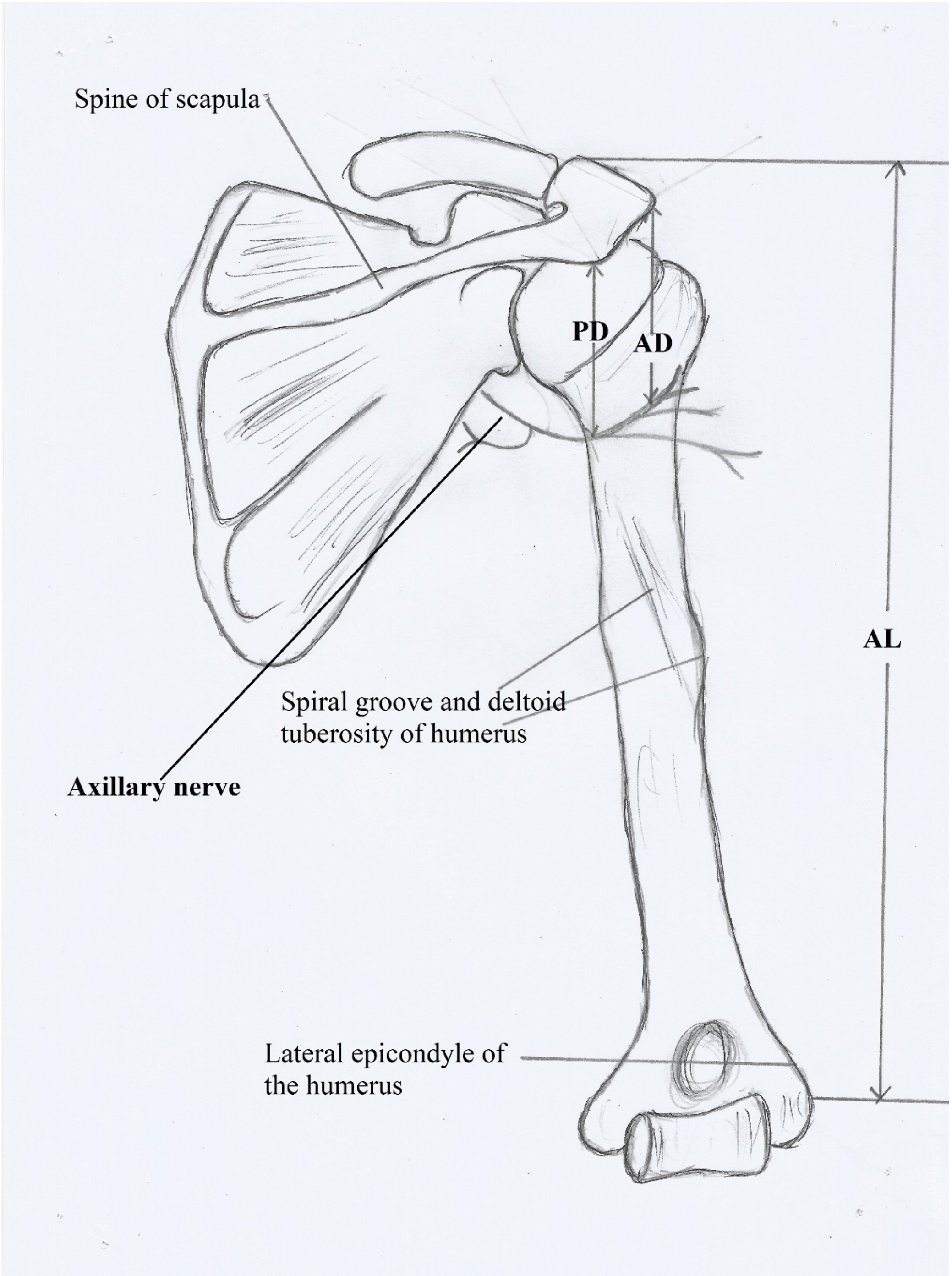


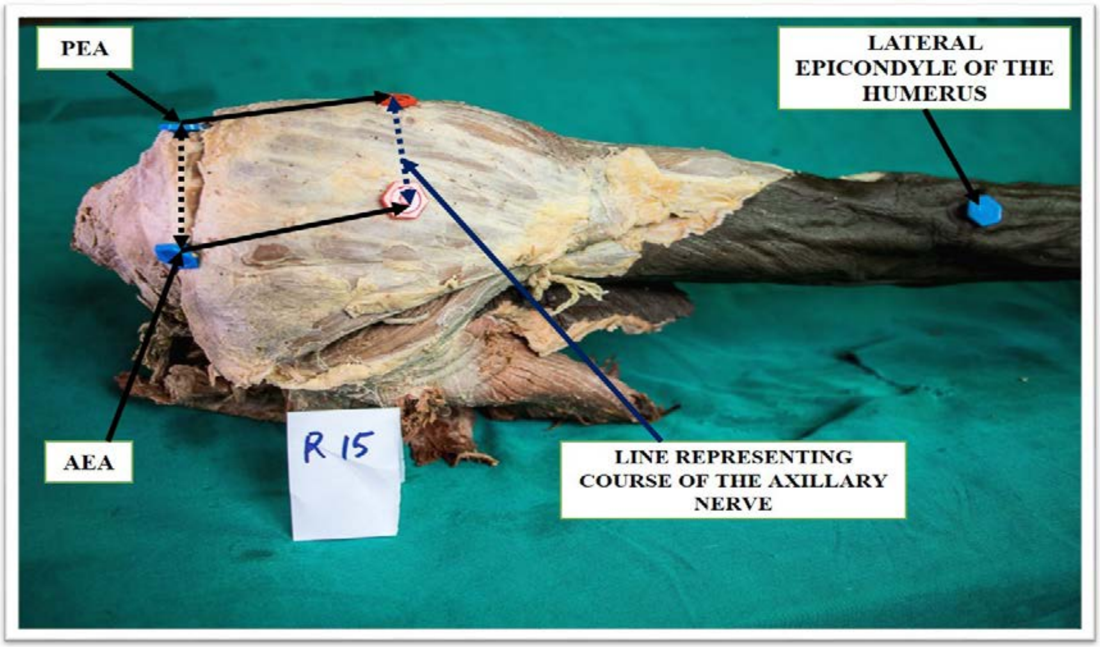
Illustration of the Quadrangular space, its contents and boundaries (posterior view)
(adapted from Netters Atlas of Human Anatomy, 2014)

Appendix 4: Measurements used to map out the axillary nerve



Measurements used to map out the axillary nerve (AL, arm length; AD, anterior distance from anterior edge of acromion to axillary nerve; PD, posterior distance from posterior edge of acromion to axillary nerve) **(Adapted from Netters Atlas of Human Anatomy, 2014).**

Appendix 5: Safe area for deltoid dissections



The quadrangular shaped safe area for deltoid dissections. (AEA- anterior edge of acromion; PEA- posterior edge of acromion).

Appendix 6: Institutional Research and Ethics Committee (I.R.E.C) Approval Letter

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471//2/3

MOI UNIVERSITY
SCHOOL OF MEDICINE
P.O. BOX 4606
ELDORET

Reference: IREC/2015/117
Approval Number: 0001443

28th July, 2015

Dr. Robert Oluoch,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
28 JUL 2015
APPROVED
P. O. Box 4606-30100 ELDORET

Dear Dr. Oluoch,

RE: FORMAL APPROVAL

The Institutional Research and Ethics Committee has reviewed your research proposal titled:-

"Axillary Nerve Distribution in Relation to Arm Length in An Adult Kenyan Population: A Cadaveric Study."

Your proposal has been granted a Formal Approval Number: ***FAN: IREC 1443*** on 28th July, 2015. You are therefore permitted to begin your investigations.

Note that this approval is for 1 year; it will thus expire on 27th July, 2016. If it is necessary to continue with this research beyond the expiry date, a request for continuation should be made in writing to IREC Secretariat two months prior to the expiry date.

You are required to submit progress report(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change (s) or amendment (s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

For

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc	Director	-	MTRH	Dean	-	SOP	Dean	- SOM
	Principal	-	CHS	Dean	-	SON	Dean	- SOD

Appendix 7: Letter of Approval of Amendment (I.R.E.C) – Increase of Sample Size

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471//2/3

MOI UNIVERSITY
SCHOOL OF MEDICINE
P.O. BOX 4606
ELDORET
Tel: 33471/2/3

Reference IREC/2015/117
Approval Number: 0001443

12th May, 2016

Dr. Robert Oluoch,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
12 MAY 2016
APPROVED
P. O. Box 4606-30100 ELDORET

Dear Dr. Oluoch,

RE: APPROVAL OF AMENDMENT

The Institutional Research and Ethics Committee has reviewed the amendment made to your proposal titled:-

"Axillary Nerve Distribution in Relation to Arm Length in An Adult Kenyan Population: A Cadaveric Study".

We note that you are seeking to make amendments as follows:-

1. To increase the sample size from the previous calculated of 38 to 51.
2. To change sample size determination to include all limbs that will meet the inclusion criteria.

The amendments have been approved on 12th May, 2016 according to SOP's of IREC. You are therefore permitted to continue with your research.

You are required to submit progress(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change(s) or amendment(s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc:	CEO	-	MTRH	Dean	-	SPH	Dean	-	SOM
	Principal	-	CHS	Dean	-	SOD	Dean	-	SON

Appendix 8: Letter of approval of Amendment (I.R.E.C) – Change of Study Topic

INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471//2/3

MOI UNIVERSITY
SCHOOL OF MEDICINE
P.O. BOX 4606
ELDORET
Tel: 33471/2/3

Reference IREC/2015/117
Approval Number: 0001443

22nd September, 2017

Dr. Robert Oluoch,
Moi University,
School of Medicine,
P.O. Box 4606-30100,
ELDORET-KENYA.

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
22 SEP 2017
APPROVED
P. O. Box 4606-30100 ELDORET

Dear Dr. Oluoch,

RE: APPROVAL OF AMENDMENT

The Institutional Research and Ethics Committee has reviewed the amendment made to your proposal titled:-

"Axillary Nerve Distribution in Relation to Arm Length in a Selected Adult Kenyan Population: A Cadaveric Study".

We note that you are seeking to make an amendment as follows:-

1. To change the title to above from "***Axillary Nerve Distribution in Relation to Arm Length in an Adult Kenyan Population: A Cadaveric Study"***

The amendment has been approved on 22nd September, 2017 according to SOP's of IREC. You are therefore permitted to continue with your research.

You are required to submit progress(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change(s) or amendment(s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

DR. S. NYABERA
DEPUTY-CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc:	CEO	-	MTRH	Dean	-	SPH	Dean	-	SOM
	Principal	-	CHS	Dean	-	SOD	Dean	-	SON

Appendix 9: Approval to Conduct Research from the Department of Human Anatomy, Moi University

MOI UNIVERSITY
COLLEGE OF HEALTH SCIENCES
SCHOOL OF MEDICINE
Department of Human Anatomy

INTERNAL MEMO

FROM: HOD, Dept. Human Anatomy

DATE: 17/08/2015

TO: Dr. R. Oluoch - (SM/PGORT/05/14
(IREC APPROVAL) IREC/2015/117
NO. 0001443

RE: MU/CHS/SOM/HA/22

RE: **CONSENT TO CARRY OUT RESEARCH IN THE HUMAN ANATOMY DEPARTMENT**

Following the IREC approval dated 28th July 2015, the Department authorizes you to conduct research using the upper extremities.

Your will use intact upper extremities in the anatomy Department. While conducting your research, you will be expected to adhere to the requirements of the Human Anatomy Act (2012) Chapter 249.

DR. A. N. NJOROGE
HEAD, DEPT. OF HUMAN ANATOMY