

**An anthropometric evaluation of the glenohumeral joint in a
South African population**

Miss Raeesa Khan

(213516600)

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Declaration

I, Miss Raeesa Khan, declare as follows:

1. That the work described in this thesis has not been submitted to UKZN or other tertiary institutions for purposes of obtaining an academic qualification, whether by myself or any other party.

2. That my contribution to the project was as follows:

Development and design of the research idea and protocol

Conduction of the research methodology

Collection and analysis of the data

Interpretation of the data obtained

Formulation of all manuscripts

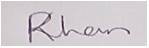
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3. That the contribution of others to this project were as follows:

Prof KS Satyapal (Supervisor), Dr L Lazarus (Co-Supervisor), Dr N Naidoo (Co-Supervisor)

Refining the research design and plan

Review of thesis and manuscripts before submission

4. Signed		Date: <u>12/03/2019</u>
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Dedication

“Education isn’t something you can finish”

Isaac Asimov

This thesis is dedicated to all the innovators in my academic journey, both past and present, from all realms of life.

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Glossary of Abbreviations

A	Anterior
BG	Bicipital groove
CL	Coracoid length
CGD	Coracoglenoid distance
CW	Coracoid width
GHJ	Glenohumeral joint
HD1	Horizontal diameter 1
HD2	Horizontal diameter 2
I	Inferior
L	Lateral
LHBBT	Long head of biceps brachii tendon
M	Medial
P	Posterior
S	Superior
THL	Transverse humeral ligament
VD	Vertical diameter

Glossary of Definitions

Anthropometry	The scientific study of the measurements and proportions of the human body
Arthrodesis	Surgical immobilization by fusion of the bones of a joint that has failed, is about to fail or a painful joint that cannot be reconstructed
Biceps tendinitis	Inflammation or irritation around the long head of biceps brachii tendon
Biceps tenodesis	Surgical procedure to repair the proximal aspect of the long head of biceps brachii tendon
Coracoplasty	A surgical procedure that combines coracoacromial ligament resection and acromioplasty
Subluxation	A partial dislocation of e.g. the humerus

Abstract

The glenohumeral joint (GHJ), the most mobile yet unstable joint in the body, is comprised of a large humeral head which fits into the relatively smaller socket formed by the glenoid fossa. While this articulation allows for a wide range of motion, it predisposes the shoulder to injury. There is a paucity of literature on the biomechanics of the GHJ in the South African population. The aim of the study was to evaluate the anthropometric parameters of the GHJ, with emphasis on the coracoid process, glenoid fossa, bicipital groove (BG), long head of the biceps brachii tendon (LHBBT) and the transverse humeral ligament (THL). This study comprised of two subsets (n = 404), viz. (i) anthropometric evaluation of the scapula and proximal humerus [n=324: Scapula – Right (R): 80, Left (L): 84; Male (M): 68, Female (F): 96; Humerii – (R): 80, (L): 80; (M): 68, (F): 96] and (ii) cadaveric dissection of the LHBBT and THL [n=80: (R): 40, (L): 40; (M): 44, (F): 36], both of which focused on morphological and morphometric parameters.

Results (i) (a) Shape of glenoid fossa = Type 1 (inverted comma): (R): 16.47%, (L): 10.98%; (M): 20.12%, (F): 7.32%; Type 2 (pear): (R): 14.02%, (L): 15.24%; (M): 18.29%, (F): 10.98%; Type 3 (oval) : (R): 18.29%, (L): 25.00%; (M): 27.44%, (F): 15.85%.

(b) Notch type of glenoid fossa: Type 1 (without a notch): (R): 1.83%, (L): 7.32%; (M): 6.71%, (F): 2.44%; Type 2 (with one notch): (R): 46.95%, (L): 43.90%; (M): 59.15%, (F): 31.70%. (c)

Mean parameters of coracoid process (mm): Length (CL): (R): 41.74±4.74, (L): 41.50±4.87; (M): 42.07±4.73, (F): 40.74±4.84; Width (CW): (R): 13.27±1.89, (L): 14.18±11.90; (M): 13.05±1.90, (F): 15.07±14.49.

(d) Mean parameters of glenoid fossa (mm): Horizontal diameter 1 (HD1): (R): 18.40±3.27, (L): 17.51±2.87; (M): 18.23±3.29, (F): 17.38±2.60; Horizontal diameter 2 (HD2): (R): 24.45±2.88, (L): 23.64±2.63; (M): 24.22±2.74, (F): 23.68±2.83; Vertical diameter (VD): (R): 35.23±3.10, (L): 34.88±3.03; (M): 35.26±3.18, (F): 34.64±2.79. (e) Mean coracoglenoid distance

(CGD) (mm): (R): 27.40 ± 8.34 , (L): 28.15 ± 3.53 ; (M): 28.19 ± 7.41 , (F): 27.00 ± 3.38 . (f) Mean dimensions of BG (mm): Length: (R): 66.64 ± 9.06 , (L): 68.31 ± 11.52 ; (M): 67.44 ± 9.12 , (F): 67.53 ± 12.25 ; Width: (R): 8.98 ± 1.49 , (L): 9.27 ± 1.30 ; (M): 9.18 ± 1.45 , (F): 9.05 ± 1.31 ; Depth: (R): 7.73 ± 1.31 , (L): 7.20 ± 1.18 ; (M): 7.43 ± 1.29 , (F): 7.53 ± 1.24 . (ii) (a) Mean parameters of the LHBBT (mm): Length: (R): 81.99 ± 21.28 , (L): 79.73 ± 17.27 ; (M): 79.82 ± 19.66 , (F): 82.14 ± 19.03 ; Width: (R): 4.28 ± 1.31 , (L): 4.67 ± 1.43 ; (M): 4.35 ± 1.17 , (F): 4.63 ± 1.60 . (b) Mean parameters of the THL (mm): Length: (R): 20.91 ± 5.24 , (L): 21.19 ± 6.36 ; (M): 21.52 ± 5.71 , (F): 20.48 ± 5.92 ; Width: (R): 16.65 ± 6.92 , (L): 16.63 ± 7.49 ; (M): 16.83 ± 6.65 , (F): 16.40 ± 7.84 .

In this study, Type 3 (oval) was observed to be most prevalent shape of the glenoid fossa, which corroborated the findings of previous studies. Type 2 (with one notch) was found to be the predominant notch type, differing from the literature reviewed. The mean VD, HD1, HD2, CL and CGD were larger in male individuals, while female individuals presented with larger means of CW. Both BG length and depth were increased on the right side; with the latter yielding a statistically significant difference thus suggesting that an increased depth is a common finding in the right side of individuals. Although the BG length and depth were noted to be greater in female individuals, male individuals presented with larger widths. The mean length and width of the THL were markedly smaller than those reported in previous studies. Any variation from the normal musculoskeletal composition of the GHJ is fundamental to understand rotator cuff disease, tendinitis and shoulder dislocation. This study may provide clinicians and biomechanical engineers with reliable anthropometric reference parameters of the GHJ for the design of prosthesis and may also act as diagnostic tools of degenerative pathology.

Chapter 1

1. Introduction

Since approximately 2% of the population is known to be present with varying degrees of shoulder instability, pathology of the shoulder is considered to be the third most common cause of musculoskeletal diseases in society (Matthews *et al.*, 2006). Variation from the normal musculoskeletal composition of the glenohumeral joint (GHJ) is fundamental to understand rotator cuff disease, glenohumeral osteoarthritis and shoulder dislocation (DePalma, 2008). Thus, the stable shoulder requires further study and the attention of clinicians (Coskun *et al.*, 2006).

The shoulder joint, also known as the GHJ, is formed by the articulation between the spheroidal head of the humerus and the glenoid fossa of the scapula (Standring *et al.*, 2016). While both articulating surfaces are covered with hyaline cartilage, the humeral head is much larger in relation to the glenoid fossa, thus the inherent joint instability (Provencher *et al.*, 2009; Standring *et al.*, 2016). The greater and lesser humeral tubercles are separated by a deep indentation known as the bicipital groove (BG) or intertubercular sulcus (Standring *et al.*, 2016). This groove lodges the long head of biceps brachii tendon (LHBBT) and transmits a branch of the anterior humeral circumflex artery toward the GHJ, superiorly (Standring *et al.*, 2016). Due to the close anatomical relation of these structures to the BG, it is an important landmark in joint replacement procedures (Robertson *et al.*, 2000). The transverse humeral ligament (THL) was first described in 1988 as a broad band of trapezoidal fibrous tissue between the greater and lesser tubercles of the humerus (Brodie, 1992). The THL retains the LHBBT within the BG as it emerges from beneath the coracohumeral ligament which provides a powerful retinaculum for stabilizing the LHBBT (Gleason *et al.*, 2006). Moreover, arthroscopic studies have shown that the LHBBT plays a role in

shoulder functionality and pathologic mechanisms when there is excessive abduction of the shoulder (DePalma, 2008).

Research on the shoulder joint and its relative anatomical structures provide the medical community with the opportunity for pre-operative preparation. This knowledge may also aid with post-operative treatment in an effort to enhance and improve the road to recovery. As the increase in degenerative shoulder pathology demands more focus, the provision of accurate and reliable diagnostic data with demographic relevance, may be beneficial due to the apparent lack in reported shoulder-related parameters in South African anatomical literature (Morag *et al.*, 2009). Thus, the aim of this study was to investigate the morphometric parameters of the GHJ with emphasis on the scapula, BG, LHBBT and THL and to document findings with regards to gender and laterality in a South African population.

The objectives of this study were:

- 1) To determine the morphology (shape) and morphometry (length and width) of the coracoid process and glenoid fossa in dry bone scapula specimens.
- 2) To determine the morphometry (length, width, depth) of the BG of the proximal humerus in dry bone humerii specimens.
- 3) To determine the morphometry of the LHBBT (length and width) and the THL (length and width) in cadaveric shoulders.
- 4) To compare the above-mentioned parameters with laterality, age and gender.

2. Literature Review

2.1 Historical Background

Although Hippocrates, the father of Western medicine, developed a method of traction for shoulder reduction in 4000 BC, shoulder manipulation methods date back to ancient Egyptian hieroglyphics (3200BC), a time during which leverage methods were readily used (Iqbal *et al.*, 2013). In the 1870s, Theodor Koch reintroduced these methods with a rather painless approach known as the ‘Kocher method’ that excluded traction, but employed leverage only (Anand *et al.*, 1990). During the 1800s, a Czechoslovakian surgeon, Eduard Albert coined the term “arthrodesis” and became the first to perform this procedure in the shoulder (Iqbal *et al.*, 2013). Towards the 1890s, shoulder instability was further elucidated by two researchers, Broca and Hartman, who described the association of the glenohumeral ligament with chronic shoulder instability (Rockwood, 2009).

At the start of the 20th century, Dr. Charles Neer became known for his advances in shoulder surgery as he explored replacement prosthesis as an alternative method of treatment (Neer, 1983). During the period of 1950-1960, shoulder hemi-arthroplasty was recommended for the treatment of a range of disorders, viz. osteoarthritis, rheumatoid arthritis, humeral head fractures and osteonecrosis (Rockwood, 2009). Within this period, the Latarjet and Brostow-Helfet methods became the two most popular procedures for the correction of shoulder instability (Rockwood, 2009). The 1970s marked a time of expansion in the orthopedic area, including the technical capabilities surrounding it (Neer, 1983). This led to a new classification system for humeral head fractures, the understanding of which was based upon the displacement of Codman’s segments of the proximal humerus with four main segments identified, i.e. shaft, head, greater tubercle and lesser tubercle (Rockwood, 2009). As the end of the 1980’s approached, cuff-tear arthropathy was

more clearly defined, with the suggestion of anterior acromioplasty as the new alternative for the treatment of impingement syndrome (Neer, 1983).

Currently, new advances in imaging modalities have provided a step closer to solving shoulder instability - from arthrography which was previously used for soft tissue imaging, to sonography which was developed 15 years later (Iqbal *et al.*, 2013).

2.2 Gross Anatomy

2.2.1 Scapula

The scapula is a flat triangular bone of the pectoral girdle, lying just posterior to the chest wall, between the second and seventh ribs (Standring *et al.*, 2016). The scapula has costal and dorsal surfaces; superior, lateral and medial borders; and inferior, superior and lateral angles (Standring *et al.*, 2016). Three processes of the scapula exist, viz. the spine, its continuation- the acromion and the coracoid process (Snell, 2008) (Figure 1).

The inferior angle of the scapula lies over the seventh rib (Snell, 2008). It is easily palpated when the arm is elevated above the head (Standring *et al.*, 2016). The superior angle is situated at the junction of the superior and medial borders and is obscured by the upper part of the trapezius (Snell, 2008). It lies over the dorsal surface of the second rib and can be palpated posterior to the clavicle (Standring *et al.*, 2016). The lateral angle is truncated and broad, comprising of the glenoid fossa, scapular neck and the forward-projecting coracoid process (Snell, 2008). The supraglenoid tubercle is a small, rough, sloping area that is situated at the cranial margin of the fossa and provides attachment to the LHBBT. The infraglenoid tubercle, which is inferior to the glenoid fossa, is located on the lateral part of the scapula (Standring *et al.*, 2016) (Figure 1).

2.2.1.1 Coracoid Process

The coracoid process arises from the antero-lateral aspect of the scapula (Standring *et al.*, 2016). It projects upward and forward above the glenoid fossa and provides attachment for the surrounding muscles and ligaments (Snell, 2008). The tip of the coracoid process is palpable by pressing backwards and laterally, just below the level of the clavicle (Standring *et al.*, 2016) (Figure 1). The coracoid process resembles the shape of a hook, with a smooth saddle-shaped inferior aspect (Standring *et al.*, 2016). In the Italian study conducted by Gumina *et al.* (1999), the coracoid process was reported to present with differences in shape, length and direction (Kavita *et al.*, 2013).

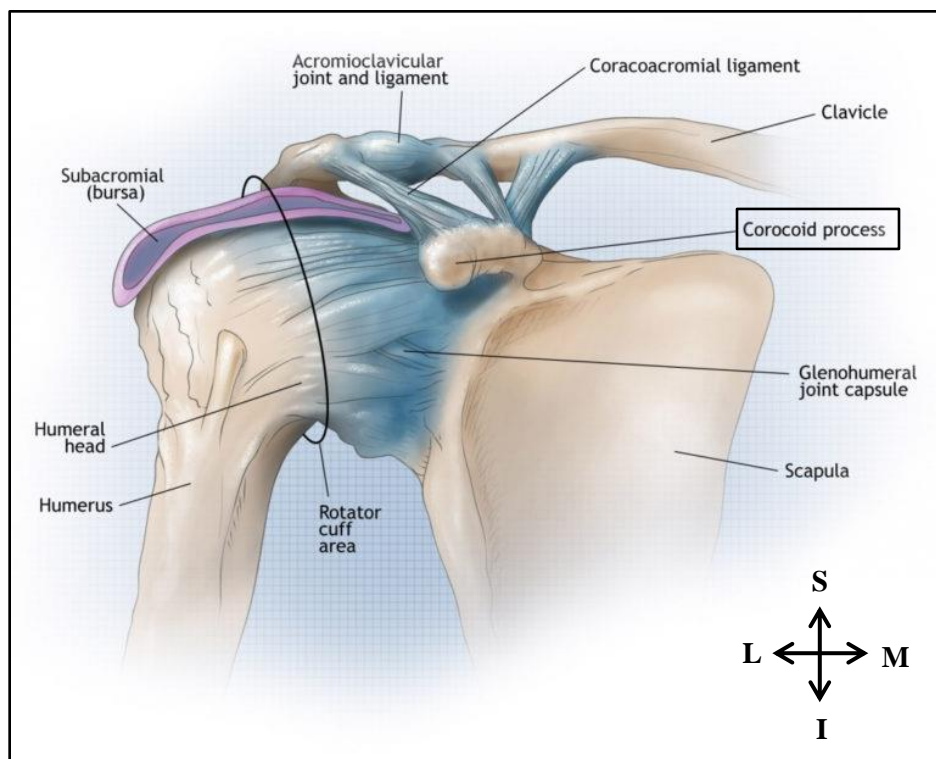


Figure 1. Anterior view of right glenohumeral joint

(Adapted from Mosby and Gamble, 2013)

Key: I- Inferior; L- Lateral; M- Medial; S- Superior

Gallino *et al.* (1998) studied the length of the coracoid process in an Egyptian population and found that the length of the coracoid process varied considerably (Fathi *et al.*, 2017). Coskun *et al.* (2006) and Kavita *et al.* (2013) observed short coracoid lengths, whilst Mahto and Omar (2015) reported longer coracoid processes (Table 1).

Table 1. Mean lengths of coracoid process in different populations

Authors (year)	Population	Mean length of coracoid process (mm)
Coskun <i>et al.</i> (2006)	Turkish	19.40±7.90
Kavita <i>et al.</i> (2013)	Indian	4.11±4.30
Mahto & Omar (2015)	Indian	43.32±1.54
Mahto & Omar (2015)	Chinese	42.47±1.02

2.2.1.2 Glenoid Fossa

The glenoid fossa is known as the head of the scapula and is characterized by the presence of a pear-shaped fossa, with a wider inferior half, the size and shape of which often varies (Standing *et al.*, 2016). Although it is inclined and retroverted, it acts as the shallow socket of the GHJ and is located on the lateral side of the scapular body (Provencher, 2009).

Rajan and Kumar (2016) documented three different glenoid fossa shapes, viz. inverted comma, pear and oval. According to the aforementioned author, the pear-shaped glenoid fossa was most prevalent, while the oval-shaped glenoid fossa was the least common type (Rajan and Kumar, 2016). In the study conducted by Coskun *et al.* (2006), the glenoid fossa was further classified according to the presence of a notch, viz. Type 1 -glenoid fossa without a glenoid notch; Type 2 - glenoid fossa with a pronounced glenoid notch and Type 3 - glenoid fossa with double glenoid notches. Previous studies conducted on soft tissue shoulder specimens, have noted that in the presence of a double glenoid notch, the glenoid labrum is generally not attached to the glenoid rim

at the site of the notch. This may be considered a predisposing factor of the anterior GHJ dislocation (Rajan and Kumar, 2016). Dislocation of the GHJ usually results from fractures of the glenoid fossa rim, as a result, knowledge on the shape and morphometrical parameters of the glenoid fossa is essential for a successful shoulder arthroplasty, as loosening of the GHJ may occur, necessitating a revision surgery (Gupta *et al.*, 2015).

Previous studies detailing the glenoid fossa reported similar values with vertical and horizontal diameters in the ranges of 33.50mm-36.00mm and 23.20mm-29.00mm, respectively (Table 2). While the Indian population presented with the smallest VD and HD of the glenoid fossa, the Canadian population was observed to have the largest VD and HD of the glenoid fossa as compared to previous studies (Coskun *et al.*, 2006; Jung *et al.*, 2012; Hassanein, 2012; Chhabra *et al.*, 2015) (Table 2). Due to the wider inferior half of the glenoid fossa, Rajan and Kumar (2016) considered the inclusion of an additional horizontal diameter which represented the HD of the upper half of the glenoid fossa.

Table 2. Literature summary of the mean vertical and horizontal diameters of the glenoid fossa within different populations

Authors (year)	Population	Vertical diameter(mm)	Horizontal diameter (mm)
Von Schroeder (2001)	Canadian	36.00	29.00
Piyawinijiwong (2004)	Thai	33.60	27.00
Coskun <i>et al.</i> (2006)	Turkish	33.60	24.00
Kavita <i>et al.</i> (2013)	Indian	35.00	24.90
Mahto and Omar (2015)	Indian	34.70	23.40
Rajan and Kumar (2016)	Indian	33.50	23.20

2.3 Humerus

The humerus is the longest and largest bone in the upper limb, with a shaft that is limited by two expanded ends, viz. head/proximal humerus and distal humerus (Standring *et al.*, 2016).

2.3.1 Humeral Head

The humeral head forms approximately one-third of a sphere and has an area that is four times greater than that of the glenoid fossa (Standring *et al.*, 2016). At rest, with the arm adducted, the antero-inferior quadrant of the humeral head articulates with the glenoid fossa of the scapula (McMinn, 2003). The smooth articular surface is covered with hyaline cartilage, with the center being the thickest (Standring *et al.*, 2016) (Figure 2). This articulation allows for an optimum range of lateral rotation and abduction from its rest position (McMinn, 2003).

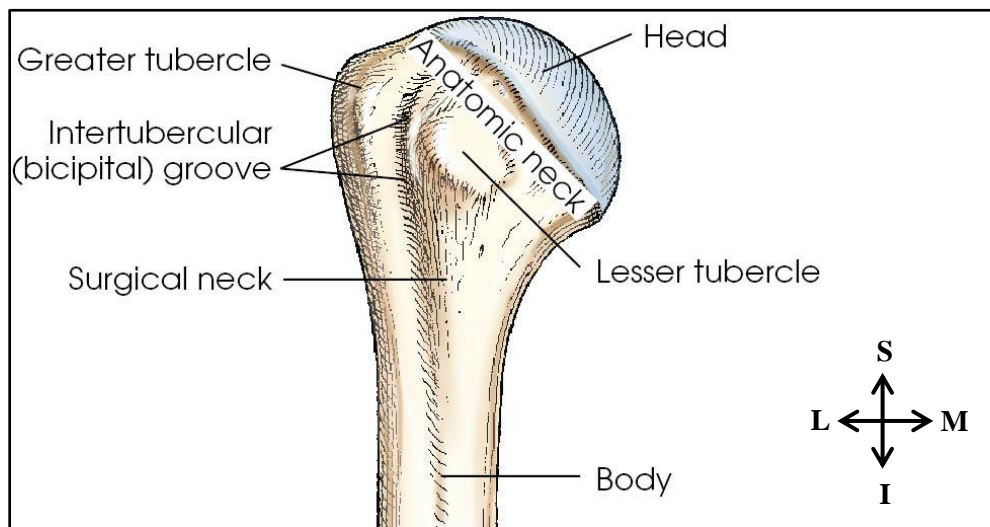


Figure 2. Anterior view of right proximal humerus with its constituent parts

(Adapted from Mosby and Gamble, 2013)

Key: I- Inferior; L- Lateral; M- Medial; S- Superior

2.3.2 Bicipital Groove

The bicipital groove (BG) which is found in the proximal part of the humerus, forms an indentation between the greater and lesser humeral tubercles (Standring *et al.*, 2016). The lateral edge of the lesser tubercle forms the medial border of the BG, while the proximal one-third of the anterior border of the greater tubercle forms the lateral lip of the BG (Standring *et al.*, 2016).

Due to the functional significance of the structures closely related to it, the BG is an important landmark for the replacement of shoulder prosthesis (Murlimanju *et al.*, 2012). Mapping the dimensions of the BG is useful in prosthetic design and development, sizing and positioning (Robertson *et al.*, 2000). Studies on the morphometry of the BG recorded the largest average length to be 86.0 ± 10.10 mm on the right side and 87.3 ± 6.40 mm on the right and left side, respectively (Murlimanju *et al.*, 2012) (Rajan and Kumar, 2016). The maximum average width was found to be 8.7 ± 2.20 mm on the right and left sides (Murlimanju *et al.*, 2012; Rajani *et al.*, 2013) (Table 3).

Table 3. Literature summary of the morphometric parameters of the bicipital groove

Authors (year)	Length (mm)		Width (mm)		Depth (mm)	
	Right	Left	Right	Left	Right	Left
Murlimanju <i>et al.</i> (2012)	86 ± 10.10	83.3 ± 11.50	8.3 ± 2.40	8.7 ± 2.20	4.7 ± 2.00	4.2 ± 1.60
Rajani <i>et al.</i> (2013)	85 ± 0.90	83 ± 10.10	8.7 ± 2.20	8.9 ± 1.10	5.0 ± 1.00	6.0 ± 1.00
Rajan and Kumar (2016)	84.79 ± 5.84	87.33 ± 6.40	6.84 ± 1.01	7.74 ± 1.96	4.21 ± 0.58	4.21 ± 0.58

2.3.3 Long head of biceps brachii tendon (LHBBT)

The LHBBT arises from the supraglenoid tubercle and descends within the synovial membrane of the shoulder joint through the subacromial space towards the BG (Joshi *et al.*, 2014). The LHBBT is approximately 5mm-6 mm in diameter and 90 mm in length (Ahrens and Boileau, 2007). The LHBBT varies in size, with a wide flat intra-articular portion and a smaller round extra-articular portion (Ahrens and Boileau, 2007) (Figure 3). The intra-capsular portion of the LHBBT lies immediately inferior to the coracohumeral ligament and is located between the supraspinatus and subscapularis muscles (Standring *et al.*, 2016). Due to its frequent association with pain in the anterior shoulder region, the proximal aspect of the LHBBT has been identified as a common area involved in tendinitis, rupture, subluxation or instability and pulley lesions (Frost *et al.*, 2009). Morphometric investigation of the LHBBT is especially relevant due to the function and treatment of it in tendinitis and subluxations (Joshi *et al.*, 2014).

2.3.4 Transverse humeral ligament (THL)

The THL was first described as a 'broad band of trapezoidal fibers' located between the greater and lesser tubercles of the humerus (Brodie, 1992). The THL crosses over the BG converting it into a canal for the passage of the LHBBT, its synovial sheath and the ascending branch of the anterior circumflex humeral artery (Standring *et al.*, 2016) (Figure 3). In the anatomical position, with sudden abduction and external rotation of the arm, the LHBBT is forced medially against the lesser tubercle and superiorly against the THL (Hollinshead, 1958). This compensatory mechanism provides a powerful retinaculum for stabilizing the LHBBT (Gleason *et al.*, 2006).

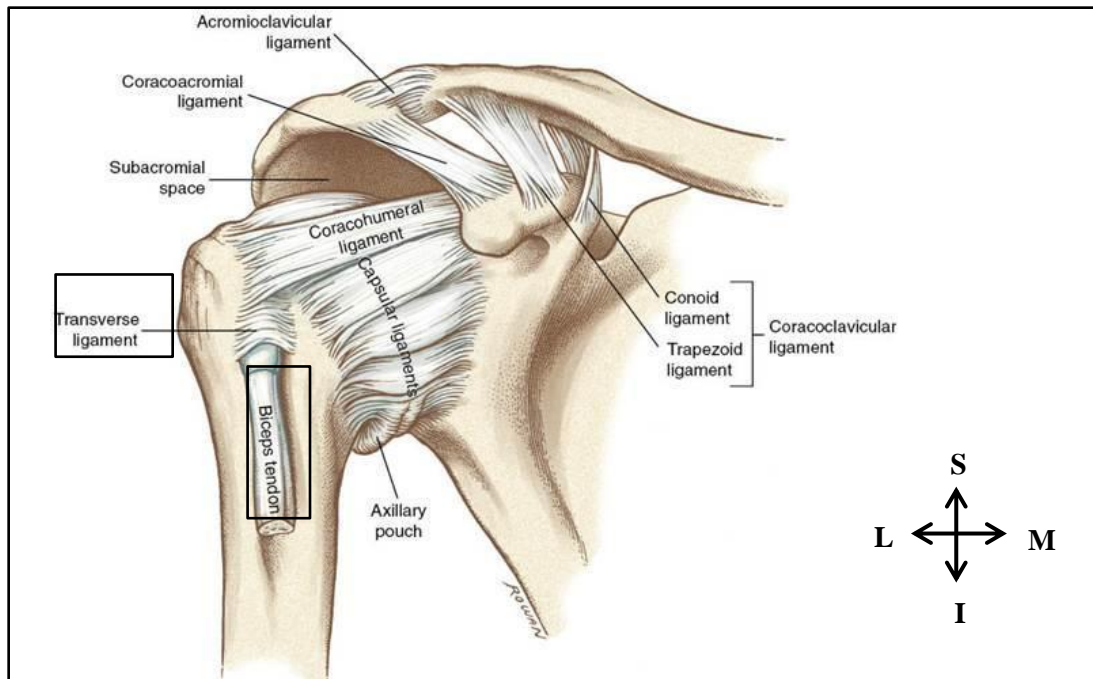


Figure 3. Anterior view of the right glenohumeral joint showing the transverse humeral ligament and long head of biceps brachii tendon

(Adapted from Nemann, 2008)

Key: I- Inferior; L- Lateral; M- Medial; S- Superior

Together, the location and structural features of the BG may be used as a reference landmark for the positioning of the lateral fin of the humeral prosthesis in the cases of humeral fractures. These findings can also be applicable for humeral stem orientation in total shoulder arthroplasty to further recreate humeral head retroversion (Johnson *et al.*, 2013), thus, the need for the provision of accurate morphometric parameters of the THL (Naranja *et al.*, 2000; Kontakis *et al.*, 2001). Studies conducted by Snow *et al.* (2013) and Chidambaram *et al.* (2015) documented average THL lengths of 14mm and 8mm, respectively. In addition, Snow *et al.* (2013) and Chidambaram *et al.* (2015) recorded mean widths (14mm and 6mm, respectively) the magnitudes of which were to the respective lengths. These highlighted existence of variation in the morphometry of the THL. For

this reason, inadequate anatomical descriptions of the THL exist with no consensus regarding the exact structure and morphometry of it (Clark *et al.*, 1992; Jost *et al.*, 2000; Werner *et al.*, 2000).

2.4 Clinical Relevance

The recognition of shoulder surgery as a separate orthopedic sub-specialty was introduced to improve the basic sciences and biomechanics of the shoulder and its associated pathologies (Boileau *et al.*, 1997). Advancements in surgical techniques and implant designs have also contributed to this rapidly expanding specialty (Boileau *et al.*, 1997). Moreover, arthroscopy has fast-progressed from diagnosis and ablative procedures to reconstructive surgery (Boileau *et al.*, 1997). Updated knowledge of the shoulder joint and its relative anatomical structures, viz. scapula and humerus, may assist surgeons with the diagnosis and successful management of shoulder instability, rotator cuff disease, fractures and other tissue trauma (Voight *et al.*, 2000).

The exact dimensions of the scapula, particularly those of the coracoid process and glenoid fossa, are considered to be fundamental in the patho-mechanics of rotator cuff disease, tendon tears, total shoulder arthroplasty and recurrent shoulder dislocation; as these structures are the initiators behind the biomechanics of the shoulder (Provencher *et al.*, 2009). The variation in the length and width of the coracoid process is reported to be responsible for altering the size and shape of the space between the coracoacromial arch and the rotator cuff, thus leading to subcoracoid impingement and tendinosis (Okoro *et al.*, 2009). The morphology and morphometry of the coracoid process have been studied previously as key elements that provide potential intervention in shoulder pathology and surgery (Verma *et al.*, 2017). The glenoid fossa morphology (shape and notch type) and morphometry are considered essential information for predisposing factors in

anterior dislocation of the GHJ, for successful shoulder arthroplasty in glenoid fractures and in glenoid prosthesis designs (Gupta *et al.*, 2015).

The variation in length and width of the LHBBT and THL has received renewed interest as these factors may be important in surgical tendon reattachment and tenotomy (Mazzocca *et al.*, 2007).

In addition to the soft tissue stabilizers (viz. superior glenohumeral, coracohumeral ligament, supraspinatus muscle and subscapularis muscles), the shape of the BG also contributes to the stability of the LHBBT (Walch *et al.*, 1999; Jost *et al.*, 2000). Furthermore, effective shoulder arthroscopy requires sound knowledge and understanding of all anatomical structures and regions related to and involved in shoulder pain and dysfunction (Walch *et al.*, 1999).

3. Materials and Methods

3.1 General

This study comprised of two subsets: (i) Dry bone evaluation of the scapula and humerus, (ii) Cadaveric investigation of the LHBBT and THL (Appendix A). It was performed in accordance with Chapter 8 of the National Health Act No. 61 of 2003. Full ethical approval was granted by the Biomedical Research Ethics Committee (BREC) at the University of KwaZulu-Natal (Ethical clearance number: BE308/18).

The samples pertaining to subsets (i) and (ii) were both obtained from the existing bone bank and cadaver storage at the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, University of KwaZulu-Natal.

3.1.1 Sample Series

Subset (i): Dry bone evaluation of the scapula and humerus

This subset included a sample size of one hundred and sixty-four unpaired dry bone scapulae (n=164; Right: 80, Left: 84) and one hundred and sixty unpaired dry bone humerii (n=160; Right: 80, Left: 80). While the coracoid process and glenoid fossa of each scapula were subjected to morphometric and morphological evaluation, dimensional analysis of the humeral BG was conducted accordingly.

Subset (ii): Cadaveric dissection of LHBBT and THL

A total of forty cadaveric shoulders (n = 80) were bilaterally dissected to determine the relevant lengths and widths of the LHBBT and THL.

3.1.2 Inclusion and Exclusion Criteria

The inclusion and exclusion criteria were specific to each subset.

Subset (i): Dry bone evaluation of the scapula and humerus

Inclusion criteria: Dry bone scapulae and humerii with no previous damage were included.

Exclusion criteria: Dry bone scapula and humerii with previous damage were excluded

Subset (ii): Cadaveric dissection of LHBBT and THL

Inclusion Criteria: Adult cadaveric specimens with no previous shoulder surgery, osteophytic changes or any macroscopic evidence of shoulder pathology were included.

Exclusion Criteria: Adult cadaveric specimens with any macroscopic evidence of shoulder pathology or osteophytic changes were excluded.

3.2 Methodology

3.2.1 Subset (i): Dry bone evaluation of the scapula and humerus

The parameters of the dry bone scapula and humeral specimens were measured with a digital caliper (Linear Tools 2012, 0-150mm, LIN 86500963). Each measurement was done three times to reduce intra-observer error.

3.2.1.1) The following morphometric parameters of the scapula were investigated in accordance with the proposed descriptions of Mamatha *et al.* (2011) and Kavita *et al.* (2013)(Figure 4):

a) *Length of the coracoid process* (mm) (ab): Measured from the tip of the coracoid process to the lateral end of the scapular notch at the superior scapular border.

b) *Width of the coracoid process* (mm) (cd): measured as the antero-posterior distance which is situated 1cm posterior to the coracoid process tip.

c) *Coracoglenoid distance* (mm) (ef): The minimum distance measured from the anterior rim of the glenoid fossa to the tip of the coracoid process.

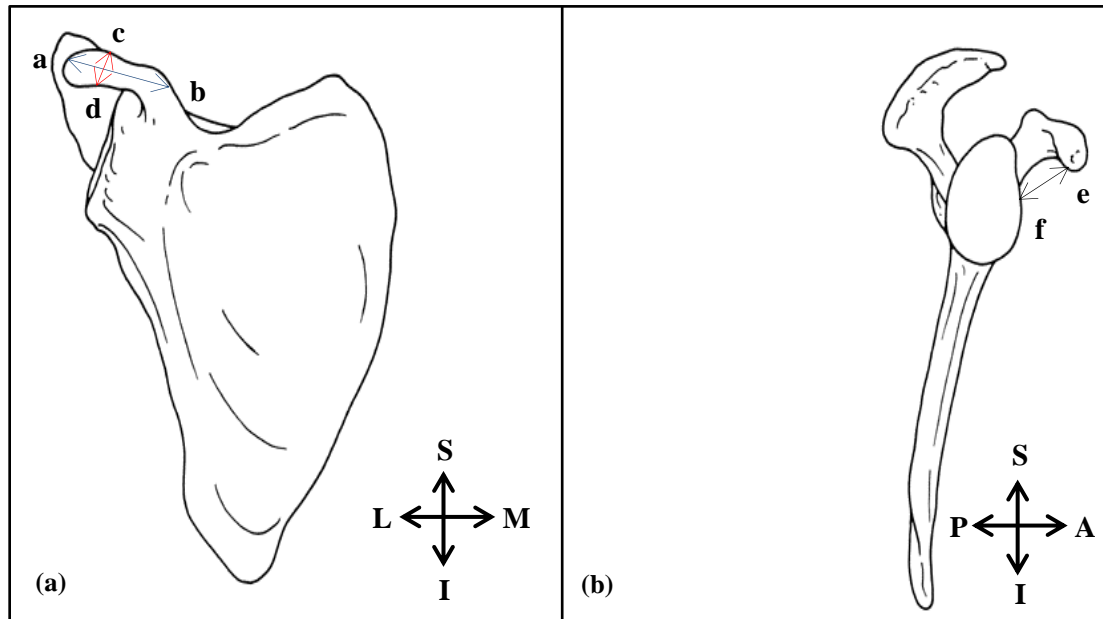


Figure 4. Right scapula displaying morphometric parameters of the coracoid process (a) coracoid length and coracoid width (b) Coracoglenoid distance (Adapted from Mamatha et al. 2011)

Key: A- anterior; ab- length of coracoid; b- anterior end of suprascapular border; c- anterior tip of coracoid process; cd- width of coracoid process; d- posterior tip of coracoid process; e- tip of coracoid process; ef- coracoglenoid distance; f- anterior rim of glenoid fossa; I- inferior; L- lateral; M- medial; P- posterior; S- superior

With regard to the glenoid fossa, the following morphometric parameters were investigated according to the method employed by Mamatha *et al.* (2011) (Figure 5):

a) *Vertical diameter (VD) of glenoid fossa* (mm) (AB): The maximum distance measured from the inferior point on the glenoid margin to the most prominent aspect (summit) of the supraglenoid tubercle.

b) *Horizontal diameter 1 (HD1) of glenoid fossa* (mm) (EF): The maximum breadth of the articular margins of the glenoid fossa.

c) *Horizontal diameter 2 (HD2) of glenoid fossa* (mm) (CD): This represented the antero-posterior diameter of the upper half of the glenoid fossa at the mid-point between the superior rim and the mid-point on the vertical diameter.

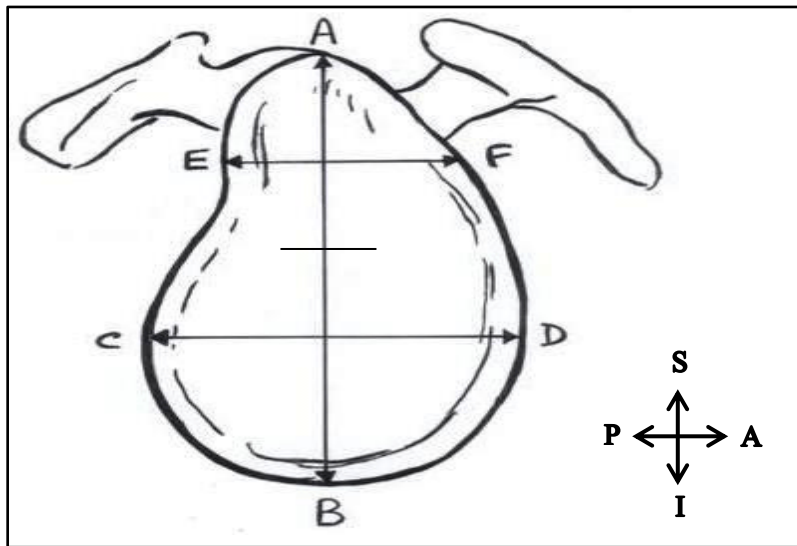


Figure 5. Lateral view of the glenoid fossa outlining the vertical (AB) and horizontal diameters (EF & CD)

(Adapted from Mamatha et al., 2011)

Key: A- Anterior; AB- vertical diameter of glenoid fossa; CD- horizontal diameter 2 of glenoid fossa; EF- horizontal diameter 1 of glenoid fossa; I- Inferior; P- Posterior; S- Superior

In addition, the classification scheme of Mamatha *et al.* (2011) and Coskun *et al.* (2006) will be adopted to investigate the shape and notch type of the glenoid fossa, respectively.

a) *Shape of the glenoid fossa*: This was classified as Type 1: comma-shaped; Type 2: pear-shaped or Type 3: oval-shaped (Figure 6).

b) *Notch type of the glenoid fossa*: This was classified as Type 1: glenoid fossa without a glenoid notch; Type 2: glenoid fossa with a pronounced glenoid notch and Type 3: glenoid fossa with a double glenoid notch.

3.2.1.2) Dimensional parameters (viz. length, width and depth) of the BG on the proximal humerus were quantified according to the method of Rajan and Kumar (2016).

a) *Length of BG* (mm): The point measured midway between the greater and lesser tubercles to the end of the medial lip of the BG.

b) *Width of BG* (mm): Measured between the mid-point of the medial and lateral lips of the BG.

c) *Depth of BG* (mm): Measured between the greater and lesser tubercles of the humerus.

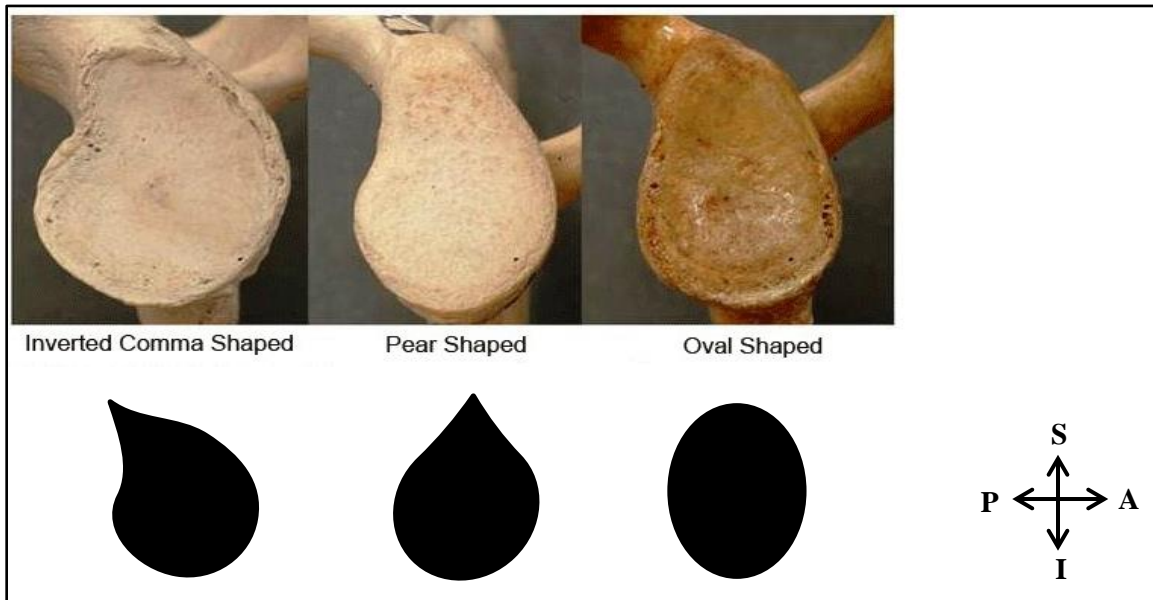


Figure 6. Lateral view: Morphological classification of the glenoid fossa

(Adapted from Mamatha et al., 2011)

Key: A- Anterior; I- Inferior; S- Superior; P- Posterior

3.2.2 Subset (ii): Cadaveric dissection of the long head of the biceps brachii tendon and the transverse humeral ligament

Dissection Procedure

Following standard dissection procedure as outlined in Grant's Dissector by PW Tank (2009), the parameters pertaining to the LHBBT and THL were dissected as follows:

In the supine position, incisions were made from:

- i) the jugular notch to the xiphoid process
- ii) the jugular notch along the clavicle to the lateral end of the acromion
- iii) the xiphoid process along the subcostal margin to the mid-axillary line

The skin was then incised in the anterior region of the thorax. The remaining superficial fascia and breast were removed followed by the careful insertion of the fingers deep to the inferior border of pectoralis major (Tank, 2009). With the arm abducted and internally rotated, the inferior border of the pectoralis major was identified in the axilla. A 4cm vertical incision was done, starting 1cm superior to the inferior border of the pectoralis tendon. The overlying fatty tissue was then cleared until the fascia overlying the pectoralis major, coracobrachialis and biceps were identified (Tank, 2009). The inferior border of the pectoralis major was then identified and an incision on the fascia overlying the coracobrachialis and biceps was made in a proximo-distal direction. Blunt finger dissection was applied under the pectoralis major tendon to palpate the LHBBT along the medial border of the pectoralis major tendon. A retractor was placed over the medial border of the humerus to pull the coracobrachialis and the short head of biceps tendon medially (Tank, 2009). The LHBBT and THL were visualized, with the LHBBT within the BG. The width of the LHBBT was

measured. Length and width of the THL were also quantified. All measurements were done three times to reduce intra-observer errors.

3.3 Statistical Analysis

3.3.1) Level of Significance

The statistical analysis was performed using SPSS version 25 (Copyright IBM corporation 1989, 2017, Chicago, Illinois, USA). A p-value of less than 0.05 was considered to be statistically significant. The means and frequencies of the continuous and categorical variables, respectively, were compared for difference or equivalence between parameters and demographically-relevant population factors. All parameters which were recorded three times each regarding the two subsets were done by one observer. Intra observer reliability was determined using the multivariate analysis test of the general linear model.

Since this study included the analysis of both morphometric/continuous and morphological/categorical variables the following statistical tests were performed:

- Pearson Chi-Square Test.
- Pearson Product Moment Correlation Co-efficient Test.
- One-way Anova Test.
- Independent Samples T-Test.
- Multivariate analysis test of the general linear model.

(i) Dominance of Demographic Factors

Factors such as gender and age were determined. The level of significance with regard to these factors and the study parameters (i.e. morphology, morphometry) were assessed.

(ii) Laterality

The right and left shoulders of cadaveric specimens were compared.

3.3.2 Weighted Mean

In cases where frequencies apply, the weighted mean was calculated using the formula: $\frac{\sum nx}{n}$,

where n= sample number and x= incidence within the sample.

4. Organization of this study

This thesis is prepared in the manuscript format according to the guidelines outlined by the College of Health Sciences, University of KwaZulu-Natal

With the exception of Chapters 1 (Introduction) and 5 (Synthesis), the remaining chapters of this thesis are presented in accordance with the two subsets of this study. Research questions pertaining to this study were also documented (Table 4) with respective research answers found in Chapter 5 (Table 5).

Subset (i): Dry bone evaluation of the scapula and humerus

This subset was comprised of one hundred and sixty-four (n=164) dry bone scapulae and one hundred and sixty (n=160) dry bone humeri.

The objectives of this subset were:

- To determine the morphology (shape and notch type) and morphometry (vertical and horizontal diameters) of the glenoid fossa.
- To determine the morphometry (length and width) of the coracoid process.
- To determine the coracoglenoid distance.
- To determine the dimensions (length, width, depth) of the bicipital groove.

The two manuscripts that emanated from this subset are included in Chapters 2 and 3.

Chapter 2:

Title of manuscript: An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population

Authors: R Khan, KS Satyapal, N Naidoo, L Lazarus

Chapter 3:

Title of manuscript: Dimensional analysis of the bicipital groove in a South African population

Authors: R Khan, KS Satyapal, N Naidoo, L Lazarus

Subset (ii): Cadaveric dissection of the LHBBT and THL

This subset comprised of forty (n=80) adult cadaveric shoulder specimens which were bilaterally examined.

The objectives of this subset were:

- To determine the morphometry (length and width) of the LHBBT.
- To determine the morphometry (length and width) of the THL.
- To determine the correlation of the above-mentioned parameters with age.

The manuscript that emanated from this subset is included in Chapter 4.

Chapter 4:

Title of manuscript: Long head of biceps brachii tendon and transverse humeral ligament morphometry and their associated pathology

Authors: R Khan, KS Satyapal, N Naidoo, L Lazarus

Table 4. Research questions pertaining to this study

Subset	Chapter	Research Questions
(i)	Chapter 2: An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population	1) What is the morphology of the glenoid fossa?
		2) What is the morphometry (length and width) of the coracoid process?
		3) What are the vertical and horizontal diameters of the glenoid fossa?
		4) What is the coracoglenoid distance?
(i)	Chapter 3: Dimensional analysis of the bicipital groove in a South African population	5) What are the dimensions of the bicipital groove?
(ii)	Chapter 4: Long head of biceps brachii tendon and transverse humeral ligament morphometry and their associated pathology	6) What is the size (length and width) of the LHBBT?
		7) What is the size (length and width) of the THL?

Chapter 2

Since the coracoid process and glenoid fossa play key roles in the pathomechanics of the stability of the GHJ in subcoracoid impingement and in glenoid prosthesis designs, this chapter describes the anthropometric evaluation of the coracoid process and glenoid fossa.

One manuscript emanated from this chapter:

Title of Manuscript: An anthropometric evaluation of the scapula with emphasis on the coracoid process and glenoid fossa in a South African population.

Authors: R Khan, KS Satyapal, N Naidoo, L Lazarus

This manuscript has been submitted to 'Folia Morphologica' (Manuscript number: #62596) and is currently under review.

Title:

An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population

Running head:

Anatomical investigation of the coracoid process and glenoid fossa in South Africa

Authors:

R Khan¹, KS Satyapal¹, N Naidoo², L Lazarus¹

Name of institution:

¹Department of Clinical Anatomy
School of Laboratory Medicine and Medical Sciences
University of Kwa-Zulu Natal
Durban
South Africa

²Department of Basic Medical sciences
College of Medicine
Mohammed Bin Rashid University of Medicine and Health Sciences
Dubai
United Arab Emirates

Correspondence to:

Prof KS Satyapal
Department of Clinical Anatomy
School of Laboratory Medicine and Medical Sciences
University of Kwa-Zulu Natal
Private Bag X54001
Durban
4000
South Africa
Tel: + 27 31 260 7110; + 27 83 777 8780, fax: + 27 31 260 7890
e-mail: satyapalk@ukzn.ac.za

Title:

An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population

Running head:

Anatomical investigation of the coracoid process and glenoid fossa in South Africa

Abstract

The exact dimensions of the scapula, including the coracoid process and glenoid fossa, are fundamental in the patho-mechanics of the glenohumeral joint (GHJ); as these structures act as initiators of shoulder movement. The aim of the study was to evaluate the anthropometric parameters of the GHJ, with emphasis on the coracoid process and glenoid fossa. The morphometric (Linear Tools 2012, 0-150mm, LIN 86500963) and morphological parameters of a total of one hundred and sixty-four ($n = 164$) dry bone scapulae [Right (R): 80; Left (L): 84, Male (M): 68; Female (F): 96] were recorded. *Results:* (i) Shape of glenoid fossa: Type 1 - (R) 16.47%, (L) 10.98%; Male (M) 20.12%, Female (F) 7.32%; Type 2 – (R) 14.02%, (L) 15.24%; (M) 18.29%, (F) 10.98%; Type 3- (R) 18.29, (L) 25.00%; (M) 27.44%, (F) 15.85%. (ii) Notch type: Type 1 – (R) 1.83%, (L) 7.32%; (M) 6.71%, (F) 2.44%; Type 2 – (R) 46.95%, (L) 43.90%; (M) 59.15%, (F) 31.70%. (iii) Vertical diameter of glenoid fossa (VD) (mm): (R) 35.23 ± 3.10 , (L) 34.88 ± 3.03 ; (M) 35.26 ± 3.18 , (F) 34.64 ± 2.79 . (iv) Horizontal diameter 1 (HD1) of glenoid fossa (mm): (R) 18.40 ± 3.27 , (L) 17.51 ± 2.87 ; (M) 18.23 ± 3.29 , (F) 17.38 ± 2.60 . (v) Horizontal diameter 2 (HD2) of glenoid fossa (mm): (R) 24.45 ± 2.88 , (L) 23.64 ± 2.63 ; (M) 24.22 ± 2.74 , (F) 23.68 ± 2.83 . (vi) Length of coracoid process (CL) (mm): (R) 41.74 ± 4.74 , (L) 41.50 ± 4.87 ; (M) 42.07 ± 4.73 , (F) 40.74 ± 4.84 . (vii) Width of coracoid process (CW) (mm): (R) 13.27 ± 1.89 , (L) 14.18 ± 1.90 ; (M) 13.05 ± 1.90 , (F) 15.07 ± 1.49 . (viii) Coracoglenoid distance (CGD) (mm): (R) 27.40 ± 8.34 , (L) 28.15 ± 3.53 ; (M) 28.19 ± 7.41 , (F) 27.00 ± 3.38 . The CL, VD, HD1 and HD2 were observed to be larger on the right side, while the CW and CGD were larger on the left side. The VD, HD1, HD2, CL and CGD appeared larger in male individuals, while the CW was found to be larger in female individuals. The findings observed in this study may provide knowledge regarding the role of the coracoid parameters in etiology of subcoracoid impingement while knowledge on the glenoid fossa

parameters and variations are essential for evaluation in shoulder arthroplasty for glenoid fractures and anterior dislocations, and for glenoid prosthesis designs for the South African population.

Key words: glenohumeral joint, coracoid process, glenoid fossa, shape, anthropometric parameters

ABBREVIATIONS	
A	Anterior
CL	Coracoid Length
CW	Coracoid Width
CGD	Coracoglenoid Distance
GHJ	Glenohumeral Joint
HD1	Horizontal Diameter 1
HD2	Horizontal Diameter 2
I	Inferior
L	Lateral
M	Medial
P	Posterior
S	Superior
VD	Vertical Diameter

Introduction

With approximately 2% of the world's population presenting with varying degrees of shoulder instability, pathology of the shoulder is currently considered to be the third most common cause of musculoskeletal diseases in society (Matthews *et al.*, 2006; Lynch *et al.*, 2013). Variations in the coracoid process and glenoid fossa are fundamental to understand rotator cuff disease, glenohumeral osteoarthritis, subcoracoid impingement and shoulder dislocation (Coskun *et al.*, 2006).

The shoulder joint, also known as the GHJ, is an articulation between the spheroidal head of the humerus and the glenoid fossa of the scapula, making the GHJ the most mobile joint in the human body (Standring *et al.*, 2016). While both articulating surfaces are covered with hyaline cartilage, the humeral head is much larger in relation to the glenoid fossa thereby creating inherent joint instability which may lead to impingement and subluxation (Provencher *et al.*, 2009; Standring *et al.*, 2016). The coracoid process arises from the antero-lateral aspect of the scapula (Standring *et al.*, 2016). It projects upward and forward above the glenoid fossa and provides attachment for the surrounding muscles and ligaments (Snell, 2008). In an Italian study conducted by Gumina *et al.* (1999), the coracoid process exhibited differences in shape, length and direction (Kavita *et al.*, 2013). Since the coracoid process serves as a critical anchor for many tendinous and ligamentous attachments, morphometry that varies from standard reference data may serve as a determinant of subcoracoid impingement and may allow for early identification, thus preventing progression to a chronic disease (Fathi *et al.*, 2017). The glenoid fossa, located on the lateral side of the scapular body, is inclined and retroverted, and functions as the shallow socket of the GHJ (Provencher *et al.*, 2009; Standring *et al.*, 2016). It is characterized as a pear-shaped fossa, with a wider inferior half, the size and shape of which vary greatly (Standring *et al.*, 2016). Studies have documented

glenoid morphology and morphometry to provide literature on the glenoid fossa to aid in the stability of the GHJ (Coskun *et al.*, 2006; Kavita *et al.*, 2013; Mahto and Omar, 2015).

The morphology and morphometry of the glenoid fossa demands attention in shoulder arthroplasty for the treatment of glenoid fractures and in prosthetics for glenoid design and reconstruction (Rajan and Kumar, 2015). Knowledge on the coracoid process may also aid with post-operative treatment of coracoplasty in efforts to improve the road to recovery. As the increase in prevalence of degenerative shoulder disease demands more focus, the provision of accurate and reliable diagnostic data with demographic relevance, may be beneficial to the healthcare system due to the apparent lack of shoulder-related literature in South Africa. Therefore, the aim of this study was to evaluate the anthropometric parameters of the scapula, with emphasis on the coracoid process and glenoid fossa.

Material and methods

The study sample was comprised of one hundred and sixty-four (n=164; Right: 80; Left: 84, Male: 68; Female: 96) dry bone scapulae. Specimens were obtained from the existing bone bank at the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, University of KwaZulu-Natal. The study was conducted under the auspices of the institutional ethical clearance review committee (Ethical Clearance Number: (BE308/18).

All dry bone scapulae displaying evidence of previous damage were excluded. The parameters of the dry bone scapula were measured three times each with a digital caliper (Linear Tools 2012, 0-150mm, LIN 86500963).

The statistical analysis was performed using IBM SPSS, version 25 (Copyright IBM corporation 1989, 2017, Chicago, Illinois, USA). A p-value of less than 0.05 was considered to be statistically significant. The mean values with standard deviations were calculated from the three measurements recorded for each parameter of the scapulae. Intra observer reliability was determined using the multivariate analysis test of the general linear model (Table 4).

In cases where frequencies were applied, the weighted mean was calculated using the formula:

$\frac{\sum nx}{n}$, where n= sample number and x= incidence within the sample population.

The following morphometric parameters of the scapula were investigated in accordance with the proposed descriptions of Mamatha *et al.* (2011) and Kavita *et al.* (2013):

a) *Length of the coracoid process* (mm) (ab): Measured from the tip of the coracoid process to the anterior end of the scapular notch at the superior scapular border (Figure 1a)

b) *Width of the coracoid process* (mm) (cd): Antero-posterior distance measured 1cm posterior to the tip of the coracoid process (Figure 1a)

c) *Coracoglenoid distance* (mm) (ef): distance measured from the anterior rim of the glenoid fossa to the tip of the coracoid process (Figure 1b)

d) *Vertical diameter (VD) of glenoid fossa* (mm) (AB): Maximum distance measured from the inferior point on the glenoid margin to the most prominent part of the supraglenoid tubercle (Figure 2).

e) *Horizontal diameter 1 (HD1) of glenoid fossa* (mm) (EF): Antero-posterior diameter of the superior half of the glenoid fossa, situated mid-point between the superior rim and the mid-point on the vertical diameter (Figure 2).

f) *Horizontal diameter 2 (HD2) of glenoid fossa* (mm) (CD): Maximum breadth of the articular margins of the glenoid fossa, just perpendicular to the vertical diameter (Figure 2)

In addition, morphological observations regarding the shape and notch type of the glenoid fossa were documented.

g) *Shape of the glenoid fossa*: The classification scheme proposed by Mamatha *et al.* (2011) was adopted and fossae were categorized as: Type 1 (inverted comma-shaped), Type 2 (pear-shaped) or Type 3 (oval-shaped)

h) *Glenoid Notch Type*: The notch type classification scheme proposed by Coskun *et al.* (2006) was utilized in this study as follows: Type 1 (glenoid fossa without a glenoid notch); Type 2 (glenoid fossa with a pronounced glenoid notch) and Type 3 (glenoid fossa with double glenoid notches).

Results

Morphology of the glenoid fossa

(i) Gender

Three shapes of the glenoid fossa were identified in this study, viz. Type 1 (inverted comma shaped): Male 20.12%, Female 7.32%; Type 2 (pear shaped): Male 18.29%, Female 10.98%; Type 3 (oval shaped): Male 27.44%, Female 15.85%. A p-value of 0.310 was recorded for the comparison between glenoid shapes in males and females (Table 1, Figure 3).

Only two notch types were identified in this study, viz. Type 1 (without a notch): Male 6.71%, Female 2.44%; Type 2 (one notch): Male 59.15%, Female 31.70%. A p-value of 0.525 was recorded for the comparison between notch types in males and females (Table1, Figure 3).

(ii) Laterality

Both right and left sides displayed three glenoid shapes: Type 1(inverted comma shaped): Right 16.47%, Left 10.98%; Type 2 (pear shaped): Right 14.02%, Left 15.24% and Type 3 (oval shaped): Right 18.29%, Left 25.00%. A p-value of 0.068 was recorded among shape types on the right and left sides (Table1, Figure 3).

Only two notch types were identified in this study, viz. Type 1 (without a notch): Right 1.83%, Left 7.32% and Type 2 (with one notch): Right 46.95%, Left 43.90%. A p-value of 0.019 was recorded between notch types on the right and left sides (Table 1, Figure 3).

Morphometry of glenoid fossa and coracoid process

(i) Gender

The mean VD observed in this study was 35.26 ± 3.18 mm in male individuals and 34.64 ± 2.79 mm in female individuals, with a p-value of 0.214 recorded between VDs in male and female individuals. The mean HD1 was recorded to be 18.23 ± 3.29 mm and 17.38 ± 2.60 mm in males and females, respectively. A p-value of 0.092 was yielded for comparison of HD1 between the sexes. The mean HD2 was recorded as 24.22 ± 2.74 mm in males and 23.68 ± 2.83 mm in females. A p-value of 0.240 was recorded for comparison between the sexes (Table 2).

The mean CL was observed as 42.07 ± 4.73 mm and 40.74 ± 4.84 mm in males and females individuals, respectively with a p-value of 0.091 recorded for comparison between the sexes. The

mean CW was observed in this study as 13.05 ± 1.90 mm in males and 15.07 ± 14.49 mm in females with a p-value of 0.155 recorded for comparison between the sexes. The mean CGD reported in this study was 28.19 ± 7.41 mm in males and 27.00 ± 3.88 mm in females. A p-value of 0.253 was recorded for comparison between the sexes (Table 2).

(ii) Laterality

The mean VD was observed in this study as 35.23 ± 3.10 mm on the right and 34.88 ± 3.03 mm on the left. A p-value of 0.471 was recorded between for the comparison between the right and left sides. The mean HD1 was noted to be 18.40 ± 3.27 mm on the right and 17.51 ± 2.87 mm on the left. A p-value of 0.063 was observed for the comparison between the right and left sides. The mean HD2 reported in this study with a mean of 24.45 ± 2.88 mm on the right and 23.64 ± 2.63 mm on the left with a p-value of 0.064 recorded for the comparison between the right and left sides (Table 2).

The mean CL was observed in this study as 41.74 ± 4.74 mm on the right and 41.50 ± 4.87 mm on the left. A p-value of 0.756 was recorded for the comparison between the right and left sides. The mean CW was found to be 13.27 ± 1.89 mm on the right sides and 14.18 ± 11.90 mm on the left sides and yielded a p-value of 0.499 for the comparison between the right and left sides. The mean CGD was found in this study to be 27.40 ± 8.34 mm on the right and 28.15 ± 3.53 mm on the left with a p-value of 0.453 recorded for the comparison between the right and left sides (Table 2).

(iii) Intra observer reliability

The mean parameters of CL, CW, CGD, VD, HD1 and HD2 did not yield any statistically significant differences, thus indicating optimum intra-observer reliability of the respective values as similar readings were recorded for all these parameters (Table 4).

Discussion

Degenerative diseases and glenohumeral instability are the leading causes of shoulder pain in the elderly, athletes and young adults (Sahni and Narang, 2014). Both the morphology and morphometry of the coracoid process have been studied previously as these are key elements that provide potential intervention in shoulder pathology and surgery (Verma *et al.*, 2017).

All three shapes of the glenoid fossa were found to be most prevalent in male individuals (Figure 3). Both glenoid notch types (Type 1 and Type 2) were found to be predominant in males with no reported incidence of Type 3 (double notch) (Figure 3). The variation in glenoid notch types serves as a predisposing factor in anterior dislocation of the GHJ as it has been observed that the glenoid labrum is not attached to the glenoid rim at the site of a notch (Coskun *et al.*, 2006). It has been reported that variation in the pear shape and double notch type of the glenoid fossa are indicative of adaptive changes due to the presence of a vertical axis being created when the arm is elevated (Aiello and Dean, 1990). This vertical axis allows for the head of the humerus to slide into the small upper part of the glenoid fossa, resulting in the variation of shape and notch types that exist in it (Aiello and Dean, 1990). However, this study did not observe Type 3 (with double notches).

In this study, the shape of the glenoid fossa was categorized according to the classification scheme proposed by Mamatha *et al.* (2011). Type 3 (oval) was the predominant glenoid shape on both right and left sides, which further corroborated the findings of Mamatha *et al.* (2011) and Gupta *et al.* (2015), respectively. On the contrary, Type 2 (pear) was the least prevalent shape on the right side, which differed from higher prevalence reported in previous studies (Dhinsda and Singh, 2014; Chhabra *et al.*, 2015; Mamatha *et al.*, 2015) (Table 3). Type 1 (inverted comma) was seen to be the least prevalent shape on the left side in this study and revealed a lower prevalence than

that of the reviewed literature (Dhinsda and Singh, 2014; Gupta *et al.*, 2015; Hassanein, 2015; Mamatha *et al.*, 2015).

In the current study, incidences recorded for all three shapes of the glenoid fossa on both right and left sides were distinctively lower than the weighted means deduced from previous studies (Table 3). Mamatha *et al.* (2011) was likely to offset the weighted mean values due to the larger sample size (n=202). Therefore, the study by Mamatha *et al.* (2011) contributed a higher sample number to the calculation of the weighted mean and possibly resulted in an over-estimation of the values.

The glenoid fossa notch type was previously classified by Coskun *et al.* (2006). In this study, Type 2 (one notch) was observed in this study as the most prevalent type on both the right and left sides. Although this finding revealed no similarity to the study of Coskun *et al.* (2006) and Hassanein (2015), the comparison of notch types between the right and left sides yielded a statistically significant p-value ($p = 0.008$). According to Jung *et al.* (2012), the presence of a distinct notch on the glenoid fossa does not allow for attachment of the glenoid labrum as the rim is situated at the notch. Studies have identified the coracoid process and the glenoid fossa as predisposing factors in anterior dislocation of the joint (Bueno *et al.*, 2012; Kavita *et al.*, 2013).

The mean VD, HD1, HD2, CL and CGD were observed to be larger in males while females presented with a larger mean CW and this finding may provide specific information on the male and female population in South Africa as it may aid clinicians in gender-based information for the treatment of shoulder pathologies and prosthetic designs. The mean VD in this study was found to be larger on the right side. This confirmed the findings of Dhinsda and Singh (2014), Mahto and Omar (2015), Gupta *et al.* (2015) and Hassanein (2015). Although HD1 has only been investigated in a limited number of studies, the values of the current study were similar to the studies conducted

by Mamatha *et al.* (2011) and Chhabra *et al.* (2015), where the mean HD1 was found to be larger on the right side (Table 3). The mean HD2 was also observed to be larger on the right side, agreeing with the reports of previous studies (Mamatha *et al.*, 2011; Gupta *et al.*, 2015; Hassanein, 2015; Mahto and Omar, 2015) (Table 3).

The coracoid process is a hook-shaped bone structure projecting antero-laterally from the superior aspect of the scapular neck (Mohammed *et al.*, 2016). The coracoid process, aptly defined by Matsen *et al.* (1990) as the “lighthouse of the shoulder”, is a reference landmark in arthroscopy for access into the shoulder (Mercer *et al.*, 2011). The coracoid process serves as an important anchor for several tendinous and ligamentous structures including the pectoralis minor tendon, coracobrachialis, short head of the biceps brachii muscle, the coracohumeral, coracoacromial, coracoclavicular and suprascapular ligaments (Mohammed *et al.*, 2016).

Individuals showed larger mean CL on the right side in the present study. This finding compared favorably and concurred with the studies conducted by Fathi *et al.* (2017) and Verma *et al.* (2017). However, it differed from the reports of Coskun *et al.* (2006) and Kavita *et al.* (2013) where the mean CL was relatively decreased (Table 3). Individuals on the left side showed a larger mean CW and compared favorably with the study by Coskun *et al.* (2006), whereas the study by Fathi *et al.* (2017) and Verma *et al.* (2017) showed much smaller mean CWs as compared to the present study (Table 3). The mean CGD was increased on the left side and differed with the study by Kavita *et al.* (2013), where CGD was reported to be larger on the right side (Table 3).

The weighted means could suggest that the present study provides a more accurate means of determining the values. The presence of unequal right and left sides (R=80, L=84) could account for the difference in prevalence of the present study with the weighted mean as this is not a bilateral

representation. The current study may be improved in the future by investigating bilateral scapulae of the same individual, thus providing more reliable results. It is recommended that inter-observer reliability indices are incorporated to further reduce standard errors in measurement and observation. Investigation of the coracoid process and glenoid fossa should also be conducted on imaging resources as these diagnostic tools would prove beneficial in clinical practice.

Conclusion

In the present study, Type 3 (oval) was observed to be the predominant glenoid fossa shape with a higher incidence in male individuals and on the right side. Although only notch Types 1 (without a notch) and 2 (with one notch) were observed in this study, Type 2 (one notch) was the most prevalent, presenting with a significant p-value ($p = 0.019$), suggesting that notch Type 1 (without a notch) and 2 (with one notch) are common findings in the right and left side of individuals. Updated anatomical knowledge regarding the variation of the bony glenoid fossa and coracoid process may present as a pre-requisite for the successful management of shoulder surgery in coracoplasty and in glenoid prosthesis designs for the South African population by taking into account gender and laterality-based data.

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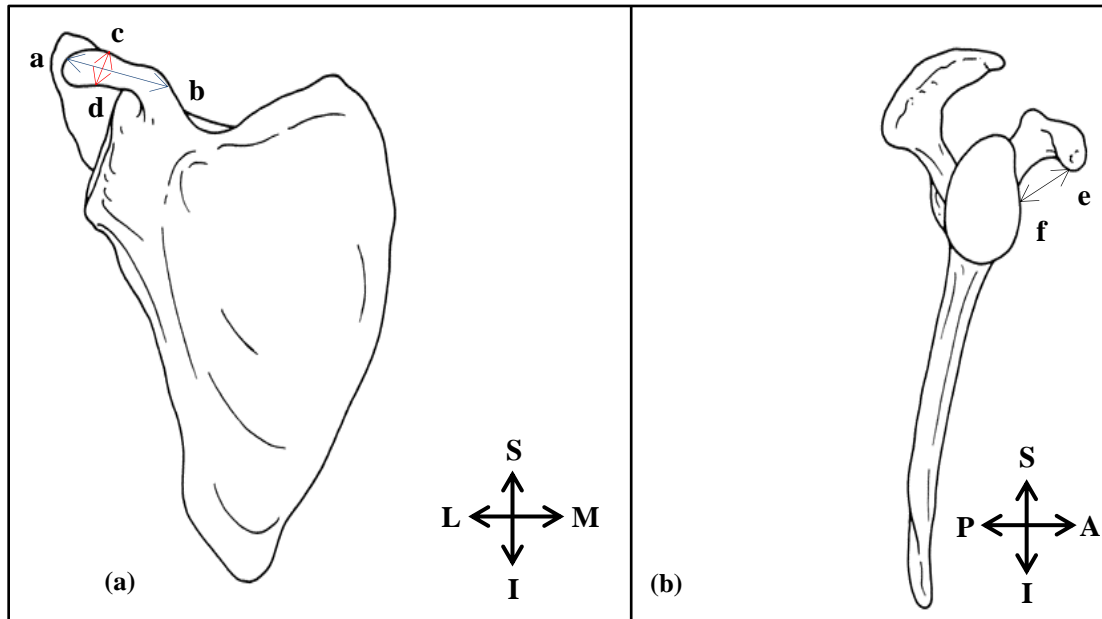
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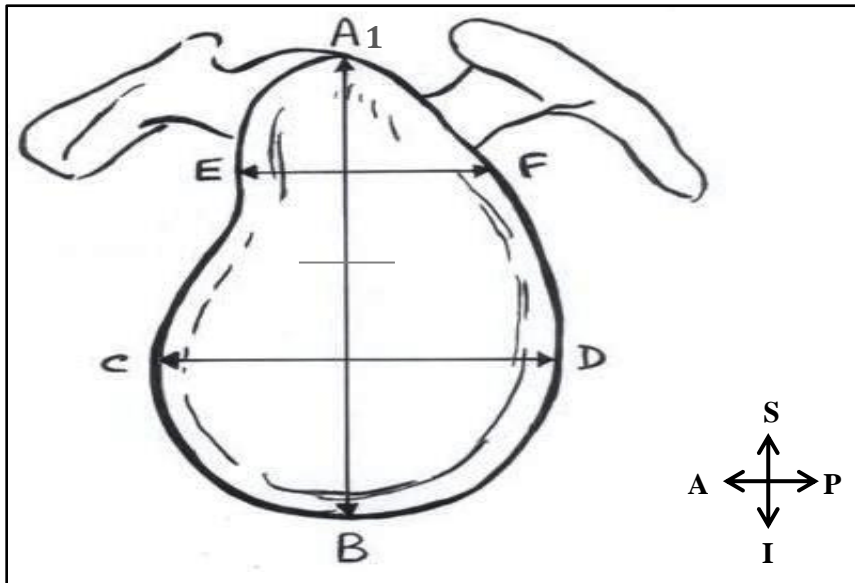
Figure Legends

Figure 1. Right scapula displaying morphometric parameters of coracoid process (a) coracoid length and coracoid width (b) coracoglenoid distance



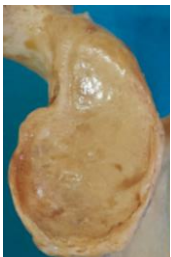


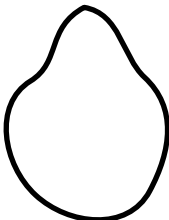

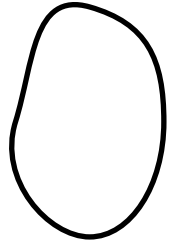

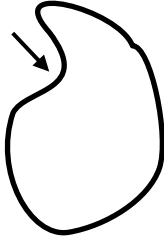
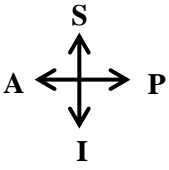
Key: A- anterior; **ab**- length of coracoid; **b**- anterior end of suprascapular border; **c**- anterior tip of coracoid process; **cd**- width of coracoid process; **d**- posterior tip of coracoid process; **e**- tip of coracoid process; **ef**- coracoglenoid distance; **f**- anterior rim of glenoid fossa; **I**- inferior; **L**- lateral; **M**- medial; **P**- posterior; **S**- superior

Figure 2. Lateral view of glenoid fossa outlining the vertical (AB) and two horizontal diameters (EF & CD) (Adapted from Mamatha et al., 2011)



Key: **A-** anterior; **A1-** supraglenoid tubercle of glenoid fossa; **AB-** vertical diameter of glenoid fossa; **B-** inferior rim of glenoid fossa; **C-** anterior articular margin; **CD-** horizontal diameter 2 of glenoid fossa; **D-** posterior articular margin; **E-** anterior rim of upper half of glenoid fossa; **EF-** horizontal diameter 1 of glenoid fossa; **F-** posterior rim of upper half of glenoid fossa ; **I-** inferior; **P-** posterior; **S-** superior

Figure 3: Morphology of the glenoid fossa. Shape: (a)- Type 1(inverted comma); (b)- Type 2 (pear); Notch: (c)- Type 1 (without a notch); (d)- Type 2 (with one notch)

Shape		 <p style="text-align: center;">a – Type 1</p>		 <p style="text-align: center;">b – Type 2</p>	
Notch Type		 <p style="text-align: center;">c – Type 1</p>		 <p style="text-align: center;">d – Type 2</p>	

Key: A- anterior; I- inferior; P- posterior; S- superior

Table 1. Morphological parameters of the coracoid process

Parameters		Morphology (%) of the Glenoid Fossa					
		Notch Type			Shape		
		1 (without a notch)	2 (one notch)	3 (double notch)	1 (inverted comma)	2 (pear)	3 (oval)
Laterality	Right (n=80)	1.83	46.95	0	16.47	14.02	18.29
	Left (n=84)	7.32	43.90	0	10.98	15.24	25.00
p-value		0.019*			0.068		
Gender	Male (n=68)	6.71	59.15	0	20.12	18.29	27.44
	Female (n=96)	2.44	31.70	0	7.32	10.98	15.85
p-value		0.525			0.310		

* Significant p-value

Table 2. Morphometric parameters of the coracoid process and glenoid fossa

Parameters		Glenoid Fossa Morphometry (mm)			Coracoid Process Morphometry (mm)		
		VD	HD1	HD2	CL	CW	CGD
Laterality	Right (n=80)	35.23±3.10	18.40±3.27	24.45±2.88	41.74±4.74	13.27±1.89	27.40±8.34
	Left (n=84)	34.88±3.03	17.51±2.87	23.64±2.63	41.50±4.87	14.18±11.90	28.15±3.53
p-value		0.471	0.063	0.064	0.756	0.499	0.453
Gender	Male (n=68)	35.26±3.18	18.23±3.29	24.22±2.74	42.07±4.73	13.05±1.90	28.19±7.41
	Female (n=96)	34.64±2.79	17.38±2.60	23.68±2.83	40.74±4.84	15.07±14.49	27.00±3.38
p-value		0.214	0.092	0.240	0.091	0.155	0.253

Key: VD: vertical diameter, HD1: horizontal diameter 1; HD2: horizontal diameter 2; CL: coracoid length; CW: coracoid width,

CGD: coracoglenoid distance

Table 3. Incidence of the shape of the glenoid fossa as reported in earlier studies

Authors (year)	Sample size (n)	Incidence (%) (x)					
		Type 1 (Inverted comma shaped)		Type 2 (Pear shaped)		Type 3 (Oval shaped)	
		Right (%)	Left (%)	Right (%)	Left (%)	Right (%)	Left (%)
Dhinsda and Singh (2014)	80	29.26	35.89	48.78	46.15	21.95	17.94
Chhabra <i>et al.</i> (2015)	126	12.68	21.82	54.92	47.28	32.40	30.90
El-Din <i>et al.</i> (2015)	160	<u>16.25</u>	20.00	35.00	27.50	48.75	52.50
Gupta <i>et al.</i> (2015)	60	40.00	36.67	43.33	40.00	<u>16.67</u>	23.33
Hassanein (2015)	68	31.58	30.00	44.74	46.67	23.68	23.33
Mamatha <i>et al.</i> (2015)	202	34.00	33.00	46.00	43.00	20.00	<u>24.00</u>
Weighted Mean		25.80	28.34	45.05	40.67	29.15	30.98
This Study (2018)	164	<u>16.46</u>	10.98	14.03	15.24	<u>18.29</u>	<u>25.00</u>

*underlined text shows similarities of current studies with previous studies

Table 4. Intra observer reliability

Descriptive Statistics			Multivariate Analysis: Effect			
Parameter	Dataset	Mean \pm Std. Deviation (mm)	Pillai's Trace	Wilk's Lambda	Hotelling's Trace	Roy's Largest Root
CL	1	40.97 \pm 1.54	0.017	0.983	0.017	0.017
	2	41.62 \pm 4.79				
	3	40.97 \pm 1.54				
CW	1	13.67 \pm 8.92	0.001	0.999	0.001	0.001
	2	13.74 \pm 8.61				
	3	13.63 \pm 8.92				
CGD	1	27.79 \pm 6.34	0.001	0.999	0.001	0.001
	2	27.79 \pm 6.34				
	3	28.04 \pm 6.38				
VD	1	34.62 \pm 1.47	0.023	0.978	0.023	0.023
	2	35.05 \pm 3.06				
	3	35.00 \pm 3.09				
HD1	1	17.95 \pm 3.09	0.000	1.000	0.000	0.000
	2	18.02 \pm 3.16				
	3	17.97 \pm 3.16				
HD2	1	24.04 \pm 2.78	0.996	0.004	0.996	0.996
	2	24.10 \pm 2.75				
	3	23.49 \pm 2.65				

Key: CL: coracoid length; CW: coracoid width; CGD: coracoglenoid distance; VD: vertical diameter; HD1: horizontal diameter 1; HD2: horizontal diameter 2

Chapter 3

This chapter focuses on the dimensions of the bicipital groove (BG), particularly length, width and depth.

The morphology of the BG has been observed to present with significant variations which ultimately affect the biomechanics of the long head of biceps brachii tendon (LHBBT) and its associated pathologies. Dimensions of the BG are also required for the selection of the size and shape of prosthesis designs, particularly in a South African setting where such data is sparse.

One manuscript emanated from this chapter:

Title of Manuscript: Dimensional Analysis of the Bicipital Groove in a South African population

Authors: R Khan, KS Satyapal, N Naidoo, L Lazarus

This manuscript has been submitted to ‘International Journal of Morphology’ (Manuscript number: IJM-012-19) and is currently under review.

Paper 2

Title:

Dimensional Analysis of the Bicipital Groove in a South African population

Running title:

Dimensions of the Bicipital Groove

Authors:

Raeesa Khan¹, Kapil S Satyapal¹, Nerissa Naidoo², Lelika Lazarus¹

¹Department of Clinical Anatomy
School of Laboratory Medicine and Medical Sciences
University of KwaZulu Natal
Durban
South Africa

²Department of Basic Medical sciences
College of Medicine
Mohammed Bin Rashid University of Medicine and Health Sciences
Dubai
United Arab Emirates

Address for correspondence:

Dr. Lelika Lazarus
Department of Clinical Anatomy
School of Laboratory Medicine and Medical Sciences
College of Health Sciences
University of KwaZulu-Natal
Private Bag X54001
Durban
4000
South Africa
Tel: + 27 31 260 7899; + 27 83 275 1910
e-mail: ramsaroopl@ukzn.ac.za

Abstract

The bicipital groove (BG) forms an indentation between the greater and lesser humeral tubercles and lodges the long head of biceps brachii tendon (LHBBT) along with the ascending branch of the circumflex humeral artery. This study aimed to determine the dimensions (length, width, depth) of the BG in a select South African population. The dimensions of the BG in one hundred and sixty (n=160; Right: 80; Left: 80, Male: 100; Female: 60) unpaired dry bone humeri were measured with a digital caliper (Linear Tools 2012, 0-150mm, LIN 86500963) and was analyzed using SPSS (V25). *Results:* Bicipital groove dimensions: (a) Length (mm): Right 66.64±9.06, Left 68.31±11.52; Male 67.44±9.12, Female 67.53±12.25; (b) Width (mm): Right 8.98±1.49, Left 9.27±1.30; Male 9.18±1.45, Female 9.05±1.31; (c) Depth (mm): Right 7.73±1.31, Left 7.20±1.18; Male 7.43±1.29, Female 7.53±1.24. The mean BG length observed in this study disagreed with previous studies where smaller lengths were reported. In addition, the comparison of the mean BG depth in this study also revealed a statistically significant difference which may suggest that increased depth in the BG is a common finding in right side of BG specimens. This finding was unique as BG depth is associated with biceps tendon pathology and augments South African shoulder-related literature. Since biceps tendon pathology is associated with decreased biceps activity and pain, investigation of the BG may provide useful data to evaluate individuals with potential abnormality of the biceps tendon. It may also be used as a landmark for humeral head replacement in the treatment of proximal humerus fractures.

KEYWORDS: bicipital groove, morphometry, long head of biceps brachii tendon, proximal humerus.

ABBREVIATIONS	
BG	Bicipital groove
I	Inferior
L	Lateral
LHBBT	Long head of biceps brachii tendon
M	Medial
S	Superior
THL	Transverse humeral ligament

Introduction

According to WHO, approximately 2% of the general population presents with some instability of the shoulder joint, with a total of 1.7% of these individuals experiencing shoulder dislocation (WHO, 2017). The morphology of the bicipital groove (BG) has been observed to present with significant variability which is considered to affect the transverse humeral ligament (THL) and the biomechanics of the long head of biceps brachii tendon (LHBBT) (Karistinos and Poulos, 2007). The BG, located within the proximal part of the humerus, forms an indentation between the greater and lesser humeral tubercles (Standring *et al.*, 2016). The medial border and lateral lip of the BG are bound by the lateral edge of the lesser tubercle and the proximal one-third of the anterior border of the greater tubercle, respectively (Standring *et al.*, 2016). In addition to the lateral and medial walls, the BG may also be identified by the presence of a floor (Standring *et al.*, 2016). These three boundaries receive bilaminar insertions from the pectoralis major, teres major and latissimus dorsi muscles (Arunkumar *et al.*, 2016). The BG is also converted into a canal by the fibrous THL which extends between the greater and lesser humeral tubercles (Rajan and Kumar, 2016). The ensheathed LHBBT, which passes through the glenohumeral joint (GHJ) to the humeral head then lodges with the ascending branch of the circumflex humeral artery within the canal of the BG before it enters the arm (Drake *et al.*, 2009). The presence of the THL, situated over the LHBBT, prevents subluxation during biomechanical movements of the arm, thus providing stability and allowing for optimal function (Rajani and Man, 2013). Although abnormalities of the LHBBT and its synovial sheath have been identified in numerous causes of shoulder pain and disability, few studies have documented the morphometry of the proximal humerus (Wafae *et al.*, 2010; Murlimanju *et al.*, 2012). Moreover, this particular region remains unreported in South African literature. The morphology of the BG has been observed to present with significant variability

(deep and narrow grooves vs. wide and shallow grooves) which is considered to affect the biomechanics of the LHBBT, associated pathologies (tenosynovitis and pulley lesions) and traumatic injuries (viz. proximal tears of the biceps brachii muscle and subluxation) (Karistinos and Poulos, 2007). Individuals participating in sporting activities that require repetitive overhead motions are also at risk (Srimani *et al.*, 2017). While the structures related to the BG serve as important anatomical landmarks in shoulder replacement procedures, the morphometric data of the BG is also required in design of prosthesis (Robertson *et al.*, 2009). Therefore, this study aimed to determine the dimensions of the BG in a select South African population.

Method and materials

The study sample was comprised of one hundred and sixty (n=160; Right: 80; Left: 80) unpaired dry bone humerii. Specimens were obtained from the existing osteological bank at the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, University of KwaZulu-Natal, South Africa. The study was conducted under the auspices of the institutional ethical clearance review committee (Ethical Clearance Number: (BE308/18). Dry bone humerii displaying no evidence of previous damage and/or fracture were included in this study. The dimensions of the dry bone humerii were measured with a digital caliper (Linear Tools 2012, 0-150mm, LIN 86500963). The mean values with standard deviations were calculated from the three measurements recorded for each parameter of the BG. Intra observer reliability was determined using the multivariate analysis test of the general linear model (Table 3).

Dimensional parameters (viz. length, width and depth) of the BG on the proximal humerus were quantified according to the method of Rajan and Kumar (2016) (Figure 1):

a) *Length of BG* (mm) (l): This was measured from the midpoint between the humeral tubercles to the end of the medial lip of the BG.

b) *Width of BG* (mm) (w): This was measured between the mid-point of the medial and lateral lips of the BG.

c) *Depth of BG* (mm) (d): This was measured as the distance between the greater and lesser humeral tubercles and their midpoint.

The statistical analysis (viz. Independent Sample T-test and Pearson Chi Square Test) was performed using the Statistical Package for Social Sciences (SPSS) (Copyright IBM corporation 1989, 2017, Chicago, Illinois, USA). A p value < 0.05 was statistically significant.

Results

The mean length of the BG was observed as 66.64 ± 9.06 mm and 68.31 ± 11.52 mm on the right and left sides, respectively (Table 1). A p value of 0.309 was recorded for the comparison of the BG length between the right and left sides. Mean widths were recorded as 8.98 ± 1.49 mm on the right side and 9.27 ± 1.30 mm on the left side (Table 1). A p value of 0.189 was recorded for the comparison of the BG width between the right and left sides. In this study, the mean depth was found to be 7.73 ± 1.31 mm on the right side and 7.20 ± 1.18 mm on the left side. A p value of 0.008 was recorded for the comparison of the BG depth between right and left sides (Table 1).

The mean length of the BG was 67.44 ± 9.12 mm and 67.53 ± 12.25 mm in male and female individuals, respectively, with a p value of 0.955 recorded for the comparison of BG length between males and females (Table 1). Male individuals presented with a mean BG width of

9.18±1.45mm, while female individuals were found to have a mean BG width of 9.05±1.31mm (Table 1). A p value of 0.573 was recorded for the comparison between male and female individuals. The mean depth was recorded as 7.43±1.29mm and 7.53±1.24mm in male and female individuals, respectively, with a p value of 0.622 recorded for the comparison of the BG depth between male and female individuals (Table 1).

Only one parameter, viz. BG depth, yielded statistically significant p-values for different effects of the multivariate analysis. The descriptive statistics also indicated that the mean value, deduced from the first set of measurements, is dissimilar to the mean values of the second and third sets of measurements. This discrepancy in readings may be due to presence of one or more outliers in the respective dataset. The difference in readings was further confirmed by the statistically significant p-value of 0.044, indicating the reduced reliability of the values recorded for this BG parameter. As the biostatistician verified the accuracy of the sample size, the reduced reliability may be due to investigator fatigue.

The mean parameters of the BG length and width did not yield any statistically significant differences, thus indicating optimum intra-observer reliability of the respective values as similar readings were recorded for all these parameters (Table 3).

Discussion

The Global Burden of Disease has identified musculoskeletal conditions as the second highest contributor to global disability (WHO, 2017). Approximately 20-33% of the population is known to live with a painful musculoskeletal condition, the prevalence of which varies with age and diagnosis (WHO, 2016). Shoulder pain plays a pivotal role in shoulder pathology of the population, especially in athletes and the elderly (Arunkumar *et al.*, 2016). Such cases of pathology of the

LHBBT include tenosynovitis, impingement and tendon instability at the entry site into the BG. The BG, together with the THL, provides stability and promotes smooth functioning of the LHBBT, thereby preventing subluxation during biomechanical movements of the GHJ (Kaur and Gupta, 2015). Factors such as BG morphology and rotator cuff pathologies have been associated with LHBBT disorders as these structures are intricately associated in stability of the LHBBT (Pfahler *et al.*, 1999). The morphometry (i.e. length, width, depth) of the BG may affect the function of its surrounding structures thus leading to various conditions, viz. pulley lesions, tenosynovitis and proximal tears (Kaur and Gupta, 2015).

The present study observed the BG length as 66.64 ± 9.06 mm (right) and 68.31 ± 11.52 mm (left), thereby agreeing with the study by Srimani *et al.* (2016) (Table 2). Studies conducted by Kaur and Gupta (2015) and Arunkumar *et al.* (2016) were observed with considerable smaller BG lengths as compared to the current study (Table 2).

The mean BG width observed in this study agreed with previous studies outlined in Table 2 of similar reported mean BG widths. However, the study by Rajan and Kumar (2016) were reported with smaller mean BG widths as compared to previous studies (Table 2) and the current study.

The mean BG depth was reported in this study as 7.73 ± 1.31 mm (right) and 7.20 ± 1.18 mm (left) and was found to be statistically significant ($p=0.008$). This finding thereby disagrees with previous studies as outlined in Table 2 where smaller BG depths were observed.

In this study, the mean BG width was observed to be slightly larger in male individuals. On the contrary, the mean BG length and depth were increased in female individuals which may be attributed to the unequal sample size of males and females in this study which may have affected the distribution of the mean. According to gender-based differences, males have larger and heavier

bones; however, the results of this study depict otherwise. The biceps brachii muscle is hypertrophied in individuals that are manual laborers (Rasch and Burke, 1974). It has been reported that 90-95% of individuals show dominance of the right hand with the LHBBT of the dominant side presenting with a larger length and width (Vettivel *et al.*, 1992). Consequently, the mean BG length and width were found to be greater on the left sides, suggesting left-handedness. However, the mean BG depth was increased on the right side and presented with a statistically significant p value ($p = 0.008$) which suggests that an increased depth is a common finding on the right side of the BG (Table 1). Although right and left sides were equal in sample size, dry bone humeri were unpaired in this study. Mean BG length, width and depth were observed to be distinctively larger than reported findings by Kaur and Gupta (2015). This could be due to the unequal numbers of male and female, hence this study was not gender-matched. The LHBBT may develop attritional damage due to continuous mechanical stress at anatomically narrow sites beneath the acromion, coracohumeral ligament or the distal BG (Boileau *et al.*, 2004). This degenerative change arises from mechanical strain and impingement of the biceps tendon in the coracoacromial arch during flexion (Boileau *et al.*, 2004). Width can influence the pathology of the biceps tendon as it is ensheathed within the BG where a wider groove allows the tendon to move more freely with lesser chances of damage (Rajani and Man, 2013). According to Cone *et al.* (1983), a BG depicting a width larger than 17.00mm wide is shallow in depth. This may be a predisposing factor to tendon dislocation (Cone *et al.*, 1983). DePalma (2008) further opined that a shallow BG predisposes the GHJ to chronic trauma due to impingement by surrounding structures. Although considerably dated, the radiographic study of Cone *et al.* (1983) concluded that BG depths of 3mm or less were indicative of pathological shoulder conditions. In this study, only 4% of BG mirrored a depth of 3mm or less. While this may suggest that 4% of dry bone

humerii included in this study were subjected to pathological conditions, one should also account for the bone maceration process, during which bone debris is lost. Furthermore, the presence of pathological conditions was not documented in dry bone records. Moreover, the study conducted by Venkatesan *et al.* (2017) recorded that 86% of BG presented with depths that were 3mm or less. The difference between the incidences reported in the current study and that of Venkatesan *et al.* (2017) may be the result of many external factors, viz. geographic location, presence of pathology, occupation of the individual (i.e. hard manual labor vs. desk job) and age of bones in bone storage. Granted that previous studies are yet to document the dimensions of the BG in South African literature, gender and side difference in the BG remain completely unreported.

Conclusion

This study documented larger BG lengths, widths and depths on the right side. Interestingly, the comparison of the BG depth between right and left sides yielded a statistically significant difference which may indicate that increased BG depth is a common finding in the right side of the BG. Female individuals presented with larger BG lengths and depths, while male individuals has larger BG widths. As LHBBT pathology is associated with anterior shoulder conditions and pain, investigation of the BG may provide important information in evaluating individuals with potential abnormality of the LHBBT. The data from this study may be used as a surgical landmark for humeral head replacement in fractures of the proximal humerus and may aid in prosthetic design, position and shape.

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Table 1. Mean dimensional parameters of the BG

Parameters		Mean ± SD of BG Dimensions (mm)		
		Length	Width	Depth
Laterality	Right (n=80)	66.64±9.06	8.98±1.49	7.73±1.31
	Left (n=80)	68.31±11.52	9.27±1.30	7.20±1.18
p-value		0.309	0.189	0.008*
Gender	Male (n=100)	67.44±9.12	9.18±1.45	7.43±1.29
	Female (n=60)	67.53±12.25	9.05±1.31	7.53±1.24
p-value		0.955	0.573	0.622

Key: * - statistically significant p-value

Table 2. Summary of mean BG dimensions in the literature reviewed

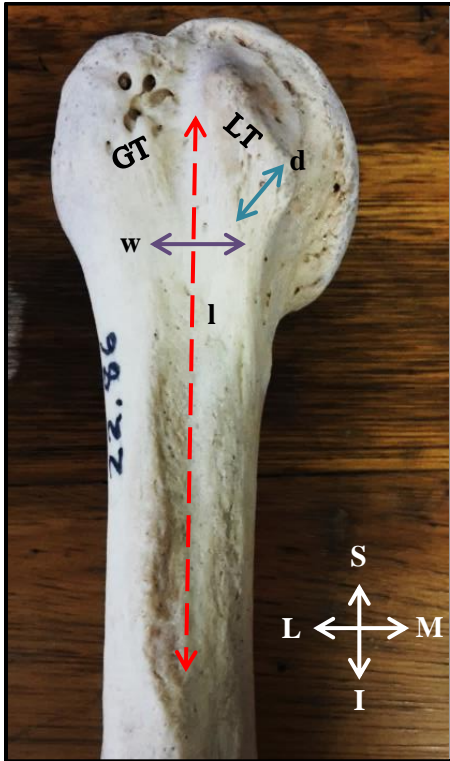
Author (year)	Population	Sample Size (n)	Mean BG Dimensions (mm ± SD)					
			BG Length		BG Width		BG Depth	
			Right	Left	Right	Left	Right	Left
Murlimanju <i>et al.</i> (2012)	India	104	86.00±10.10	83.30±11.50	8.30±2.40	8.70±2.20	4.70±2.00	4.20±1.60
Rajani & Man (2013)	India	101	85.00±0.90	83.00±10.10	9.00±2.10	8.90±1.10	5.00±1.00	6.00±1.00
Kaur & Gupta (2015)	India	100	30.65±3.19	29.64±2.87	8.49±1.45	7.87±1.67	3.83±0.92	3.92±0.86
Arunkumar <i>et al.</i> (2016)	India	98	30.00±2.00	32.00±6.00	8.70±0.10	8.30±0.40	5.00±1.00	6.00±1.00
Rajan & Kumar (2016)	India	100	84.79±5.84	87.33±6.40	6.84±1.01	7.74±1.96	4.21±0.58	5.01±05
Srimani <i>et al.</i> (2016)	India	107	71.59±3.78	70.78±5.04	8.42±0.85	7.70±0.50	4.63±0.38	4.45±0.30
Ashwini & Venkateshu (2017)	India	87	89.94±6.35	88.88±8.11	8.53±1.56	7.96±1.37	6.48±1.13	6.14±1.04
Venkatesan <i>et al.</i> (2017)	India	200	84.40±1.03	78.80±0.82	9.12±1.37	8.86±1.65	4.65±1.04	4.55±1.15
<i>Present Study (2018)</i>	South Africa	164	66.64±9.06	68.31±11.52	8.98±1.49	9.27±1.30	7.73±1.31	7.20±1.18

Table 3. Intra observer Reliability

Descriptive Statistics			Multivariate Analysis: Effect			
Parameter	Dataset	Mean ± Std. Deviation (mm)	Pillai's Trace	Wilk's Lambda	Hotelling's Trace	Roy's Largest Root
BG Length	1	62.20±4.93	0.026	0.974	0.026	0.026
	2	62.15±4.98				
	3	62.28±4.97				
BG Width	1	8.78±0.92	0.000	1.000	0.000	0.000
	2	8.78±0.94				
	3	8.79±0.92				
BG Depth	1	7.65±0.77	0.039*	0.961*	0.040*	0.040*
	2	7.79±0.81				
	3	7.71±0.65				

Key: BG: bicipital groove; *- statistically significant

Figure 1. Antero-lateral view of right dry bone humerus



Key: d- depth; GT- greater tubercle; I- inferior; L- lateral; l- length;
LT- lesser tubercle; M- medial; S- superior; w- width

Chapter 4

As a dynamic stabilizer and flexor of the glenohumeral joint (GHJ), the long head of the biceps brachii tendon (LHBBT) is a common source of anterior shoulder pain. The transverse humeral ligament (THL) has also been reported to play a stabilizing role in the LHBBT. Much emphasis is placed on variations in the length and width of the LHBBT and THL as these parameters is especially important in tendon reattachment and tenodesis.

Therefore, this chapter investigated the morphometry of the LHBBT and THL and the existence of a possible correlation with age.

One manuscript emanated from this chapter:

Title of Manuscript: Long head of biceps brachii tendon and transverse humeral ligament morphometry and their associated pathology

Authors: R Khan, KS Satyapal, N Naidoo, L Lazarus

This manuscript has been submitted to ‘Journal of Orthopaedics’ (Manuscript number: JOO_2019_13) and is currently under review.

Paper 3

Title:

Long head of biceps brachii tendon and transverse humeral ligament morphometry and their associated pathology

Authors:

R Khan¹, KS Satyapal¹, N Naidoo², L Lazarus¹

¹Department of Clinical Anatomy
School of Laboratory Medicine and Medical Sciences
University of Kwa-Zulu Natal
Durban
South Africa

²Department of Basic Medical Sciences
College of Medicine
Mohammed Bin Rashid University of Medicine and Health Sciences
Dubai
United Arab Emirates

Running headline:

Long head of biceps brachii tendon and transverse humeral ligament morphometry

Conflict of interest: None

Correspondence to:

Dr. N Naidoo
Department of Basic Medical Sciences
College of Medicine
Mohammed Bin Rashid University of Medicine and Health Sciences
P. O. Box 505055
Dubai
UAE
Tel: 505 864 363
e-mail: Nerissa.naidoo@mbru.ac.ae or Nerissa.naidoo17@gmail.com

Abstract

As a dynamic stabilizer and flexor of the glenohumeral joint (GHJ), the long head of the biceps brachii tendon (LHBBT) is considered to be a common source of anterior shoulder pain as it is subjected to mechanical stress within the bicipital groove (BG). While the LHBBT is further stabilized by the retinacular activities of the transverse humeral ligament (THL), knowledge detailing variation in the length and width of both these structures is especially important in tendon reattachment and tenodesis. Thus, the aim of this study was to determine the morphometric dimensions of the LHBBT and THL. The LHBBT and THL, obtained from a total of forty cadaveric upper limb specimens (n = 80; Females: 36, Males: 44) were bilaterally dissected and subjected to morphometric evaluation. Findings were recorded as follows: (i) LHBBT length (mm): Right 81.99 ± 21.28 , Left 79.73 ± 17.27 ; Male 79.82 ± 19.66 , Female 82.14 ± 19.03 ; (ii) LHBBT width (mm): Right 4.28 ± 1.31 , Left 4.67 ± 1.43 ; Male 4.35 ± 1.17 , Female 4.63 ± 1.60 ; (iii) THL length (mm): Right 20.91 ± 5.24 , Left 21.19 ± 6.63 ; Male 21.52 ± 5.71 , Female 20.48 ± 5.92 ; (iv) THL width (mm): Right 16.65 ± 6.92 , Left 16.63 ± 7.49 ; Male 16.83 ± 6.65 , Female 16.40 ± 7.84 . With larger LHBBT length observed on the right side and larger LHBBT width observed on the left side; both parameters appeared to be distinctly longer in female individuals. Male individuals are generally present with larger muscle-tendon units; however, this study observed otherwise which may be attributed to the fact that this study was not gender-matched, thus resulting in an undistributed mean. On the contrary, the THL length and width were evidently greater in male individuals, with larger lengths and widths present on the left and right sides respectively. These findings may contribute to South African literature and to clinical knowledge as these parameters are important in the successful outcomes of tenotomy, tenodesis and shoulder-related procedures.

Key words: long head of biceps brachii tendon; transverse humeral ligament; tendinitis; tenodesis; morphometry

Abbreviations	
BG	Bicipital groove
GHJ	Glenohumeral joint
I	Inferior
L	Lateral
LHBBT	Long head of biceps brachii tendon
M	Medial
P	p-value
<i>r</i>	<i>r</i> correlation co-efficient value
S	Superior
THL	Transverse humeral ligament

Introduction

The annual report of the National Institute for Occupational Health (NIOH) in South Africa has identified musculoskeletal disorders among the most commonly reported illnesses within the working population (NIOH, 2008). Although prevalence of self-reported cases ranges from 16% to 26%, approximately 1% of the adult population consults a medical practitioner on an annual basis with initial complaints of shoulder pain (Brownson *et al.*, 2015). The long head of biceps brachii tendon (LHBBT) together with the THL (transverse humeral ligament) is subject to mechanical stress and has been reported to present with instability of the glenohumeral joint (GHJ) (Werner *et al.*, 2000). The biceps brachii muscle, characterized by the presence of two heads (viz. short head and long head), is a powerful supinator and weak elbow flexor (Chauhan *et al.*, 2013). As a common source of anterior shoulder pain, recent studies have placed emphasis on the role of the tendinous long head of this muscle (Ahrens and Boileau, 2007). The LHBBT, which arises from the supraglenoid tubercle, courses intra-articularly for a short distance through the canal formed by the THL antero-superiorly and the bicipital groove (BG) postero-laterally (Standring *et al.*, 2016). The LHBBT then exits the canal but continues to descend within the BG as it approaches its insertion site at the radial tuberosity (Werner *et al.*, 2000). Although the extra-articular portion of the LHBBT is stabilized by the biceps reflection pulley medially, deviations in the depth and morphology of the BG may subject the LHBBT to mechanical stress and consequent instability (Werner *et al.*, 2000). The tendon is reported to have an approximate width of 5mm-6mm and a length of 90mm (Ahrens and Boileau, 2007; Cucca *et al.*, 2010; Joshi *et al.*, 2014). Although the THL contributes to the stability of the LHBBT within the BG and prevents subluxation; sudden abduction and external rotation of the arm forces the LHBBT against the lesser humeral tubercle medially and the THL superiorly thereby displacing the LHBBT (Jeff *et al.*, 2013; Joshi *et al.*,

2014). Moreover, a torn THL may dislodge the LHBBT from the BG or may allow its free movement, eventually leading to biceps tendinitis (Churgay *et al.*, 2009). Literature outlining the anatomy of the THL remains scarce and for this reason, there is a lack of consensus regarding its morphology and morphometry (Clark *et al.*, 1992; Jost *et al.*, 2000; Werner *et al.*, 2000). Therefore, the aim of this study was to determine the morphometric dimensions of the LHBBT and the THL.

Method and materials

This study comprised of forty cadaveric upper limb specimens (n = 80; Females: 36, Males: 44) obtained from the Discipline of Clinical Anatomy, School of Laboratory Medicine and Medical Sciences, University of KwaZulu-Natal, South Africa. Adherence to institutional policies regarding ethical conduct was maintained (Ethical Clearance Number: BE308/18).

Only adult cadaveric specimens with absence of osteophytic changes and macroscopic pathology and evidence of no previous shoulder surgery were included in this study.

Following standard dissection protocol as outlined in Grant's Dissector by PW Tank (2009), the parameters pertaining to the LHBBT and THL were bilaterally quantified with a digital caliper (Linear Tools 2012, 0-150mm, LIN 86500963) and in accordance with the methods of Snow *et al.* (2013) and Joshi *et al.* (2014), respectively.

Measurements were recorded as follows:

- a) *Length of THL* (mm) (a): measured from the anterior tip of the THL (medial to subscapularis tendon) to the posterior tip of the THL (between the greater and lesser humeral tubercles) (Figure 1A)

- b) *Width of THL* (mm) (b): measured from the greater tubercle to the lesser tubercle of the proximal humerus (Figure 1A)
- c) *Length of LHBBT* (mm) (c): from point of origin (supraglenoid tubercle) to musculo-tendinous junction (Figure 1B)
- d) *Width of LHBBT* (mm) (d): distance between the medial and lateral walls of the BG (Figure 1B)

The statistical analysis was performed using IBM SPSS version 25 (Copyright IBM corporation 1989, 2017, Chicago, Illinois, USA). This also included a comparison of the parameters between gender and laterality. *P* and *r* values less than 0.05 and 0.5, respectively, were statistically significant. The mean values with standard deviations were calculated from the three measurements recorded for each parameter of the THL and LHBBT. Intra observer reliability was determined using the multivariate analysis test of the general linear model (Table 3).

Results

In this study, the mean LHBBT lengths were observed as 81.99 ± 21.28 mm (right) and 79.73 ± 17.27 mm (left) with a p-value of 0.604 recorded for the comparison of the LHBBT length between right and left sides. Male individuals presented with a mean LHBBT length of 79.82 ± 19.66 mm, while the mean LHBBT length in female individuals was recorded as 82.14 ± 19.03 mm with a p-value of 0.594 recorded for comparison of the LHBBT length between male and female individuals (Table 1).

The mean LHBBT widths were found to be 4.28 ± 1.31 mm and 4.67 ± 1.43 mm on the right and left sides, respectively, with a p-value of 0.205 recorded for the comparison of the LHBBT between the right and left sides (Table 1). In addition, the mean LHBBT width was noted as 4.35 ± 1.17 mm

in male individuals, while that of female individuals was 4.63 ± 1.60 mm with a p-value of 0.387 recorded for the comparison of the LHBBT width between males and females (Table 1).

The mean THL length was found to be 20.91 ± 5.24 mm and 21.19 ± 6.36 mm on the right and left sides, respectively, with a p-value of 0.832 recorded for the comparison of THL length between the right and left sides; while that of male and female individuals reflected mean values was 21.52 ± 5.71 mm and 20.48 ± 5.92 mm, respectively, with a p-value of 0.433 recorded for the comparison of THL length between males and females (Table 1). In the present study, the mean THL width was observed as 16.65 ± 6.92 mm and 16.63 ± 7.49 mm on the right and left sides, respectively, with a p-value of 0.989 recorded for the comparison of THL width between the right and left sides. Male individuals presented with a mean THL width of 16.83 ± 6.65 mm, while that of female individuals was recorded as 16.40 ± 7.84 mm with a p-value of 0.797 recorded for comparison of the THL width between males and females (Table 1).

The following *r* and p-values were recorded for the correlation of age with morphometric parameters of the LHBBT and THL (Table 2):

- | | | |
|-------|------------------------------|---------------------------------------|
| i) | Age vs. THL length | (<i>r</i> = 0.076; p-value = 0.504) |
| ii) | Age vs. THL width | (<i>r</i> = 0.274; p-value = 0.014) |
| iii) | Age vs. LHBBT length | (<i>r</i> = 0.254; p-value = 0.023) |
| iv) | Age vs. LHBBT width | (<i>r</i> = -0.113; p-value = 0.319) |
| v) | LHBBT width vs. THL length | (<i>r</i> = -0.147; p-value = 0.192) |
| vi) | LHBBT width vs. THL width | (<i>r</i> = -0.239; p-value = 0.033) |
| vii) | LHBBT width vs. LHBBT length | (<i>r</i> = -0.093; p-value = 0.412) |
| viii) | LHBBT length vs. THL length | (<i>r</i> = 0.284; p-value = 0.011) |

- ix) LHBBT length vs. THL width ($r = 0.436$; $p\text{-value} = 0.000$)
- x) THL width vs. THL length ($r = 0.379$; $p\text{-value} = 0.001$)

Only one parameter, viz. LHBBT length, yielded statistically significant p-values for different effects of the multivariate analysis (Table 3). The descriptive statistics also indicated that the mean value, deduced from the third set of measurements, is dissimilar to the mean values of the first and second sets of measurements. This discrepancy in readings may be due to presence of one or more outliers in the respective dataset. The difference in readings was further confirmed by the statistically significant p-value of 0.003, indicating the reduced reliability of the values recorded for this LHBBT parameter. As the biostatistician verified the accuracy of the sample size, the reduced reliability may be due to investigator fatigue.

The remaining parameters (viz. THL width, THL length and LHBBT width) did not yield any statistically significant differences, thus indicating optimum intra-observer reliability of the respective values as similar readings were recorded for all these parameters (Table 3).

Discussion

The LHBBT is a common origin site of anterior shoulder pain (Walch *et al.*, 1999; Ahrens and Boileau, 2007). Pathology of the LHBBT is often associated with rotator cuff disease and instability of the GHJ as it is intricately associated with the GHJ and the rotator cuff muscles (Urita *et al.*, 2016). Biomechanical movements of the arm resulting in sudden abduction and external rotation, forces the LHBBT medially against the lesser tubercle of the humerus and superiorly against the THL (Joshi *et al.*, 2014). The THL contributes to the stability of the LHBBT within the BG and prevents subluxation (Jeff *et al.*, 2013). In athletes, especially those participating in overhead throwing activities, the GHJ and LHBBT undergo large amounts of stress due to greater

biceps activity (Hsu *et al.*, 2008). This study, therefore, aimed to investigate the morphometric parameters of the LHBBT and THL.

Biceps tendinitis is a musculoskeletal disorder of the LHBBT (Churgay *et al.*, 2009). Inflammation of the LHBBT is defined as primary tendinitis and secondary tendinitis when it is in the BG or in the presence of rotator cuff tears, respectively (Churgay *et al.*, 2009). Primary tendinitis occurs in 5% of reported cases of biceps tendinitis, with secondary tendinitis accounting for the remaining 95% (Churgay *et al.*, 2009). Variation in the length and width of the LHBBT and THL has become an area of renewed interest as these factors play a key role in tendon reattachment and tenotomy (Mazocca *et al.*, 2007). According to Ropper *et al.* (2014), hypertrophic biceps brachii muscles and larger LHBBT were commonly observed in individuals involved in manual labor. Furthermore, 90-95% of these individuals demonstrated right-hand dominance (Ropper *et al.*, 2014). In the current study, the LHBBT mean length was found to be larger on the right side and distinctively greater in female individuals. The mean LHBBT lengths recorded in this study correlated with the findings of Joshi *et al.* (2014). However, the mean LHBBT length reported by Gothelf *et al.* (2008) and Cucca *et al.* (2010) were lower than those of the present study. Greater mean LHBBT widths were observed on the left side and were markedly higher in female individuals (Table 1). Although the mean LHBBT width documented by Drolet *et al.* (2016) was similar to that of the current study; the mean values of Cucca *et al.* (2010) and Joshi *et al.* (2014) were characteristically larger.

The LHBBT width may influence pathology of the LHBBT as the tendon is ensheathed within the BG by the THL (Rockwood *et al.*, 2004). The presence of a wider groove may allow the LHBBT to move more freely, thereby decreasing the chances of damage or injury (Karistinos and Poulos, 2007). In other cases, the THL covering the LHBBT may rupture causing the tendon to slide back

and forth in the BG or slip out of the groove subsequently leading to biceps tendinitis (Karistinos and Poulos, 2007). However, the presence of a narrow BG may predispose an athlete to tendinitis (Pfahler *et al.*, 1999). This degeneration may be seen on imaging resources (viz. CT scans, MRI, radiographs) and is noted to correlate with pathology of the LHBBT (Pfahler *et al.*, 1999). With regards to the right and left side, the mean THL length and width recorded by Snow *et al.* (2013) and Chidambram *et al.* (2015) were lower than those of the current study. This may be due to the difference in the sample sizes of previous studies. Ethnicity and population-specific differences may also account for the difference in magnitude of the THL length and width (Karistinos and Poulos, 2007). The mean THL length and width observed in this study was found to be larger in male individuals. This finding alluded to gender-based differences generally depicted by the size of muscle-tendon units in males and the presence of light-weighted bones in females (Karistinos and Poulos, 2007). This study also correlated age with the relevant morphometric parameters (i.e. lengths and widths of the LHBBT and THL). Only one of the four negative correlations yielded a statistically significant p-value (i.e. LHBBT width vs. THL width) (Table 2). Similarly, statistically significant differences were observed for five out of the six positive weak correlations (i.e. Age vs. THL width; Age vs. LHBBT length; LHBBT width vs. LHBBT length, LHBBT length vs. THL width; THL width vs. THL length) (Table 2). It may be postulated that the negative weak correlation shared between the width of the LHBBT and the THL may be due to body build, nutritional status, diet and the effects of training (Mazzocca *et al.*, 2007). Biceps tenotomy and tenodesis have been identified as quick, easy and cost-effective procedures for the management of pathological conditions of the LHBBT when present with lesions of the rotator cuff muscles and the biceps labral complex (Elser *et al.*, 2011). While the functional role of the LHBBT is not clearly understood, the LHBBT is well accepted as a source of shoulder pain (Hanyspiak *et al.*, 2015).

Shoulder pain resulting from biceps tendinitis has been successfully treated with arthroscopic biceps tenotomy or tenodesis and many techniques require the extra-articular portion of the LHBBT within the BG to be visualized morphometrically (Hanyspiak *et al.*, 2015). Therefore, morphometric parameters outlining the structures of the LHBBT and THL may provide useful reference data required for the design and development of prosthesis, successful operative outcomes and may lead to an overall improvement in the healthcare system (Walch *et al.*, 1999; Boileau *et al.*, 2002; Mazzocca *et al.*, 2003). Since this study did not account for body build (*viz.* height, humeral length, weight) and lifestyle factors (*viz.* smoking, exercise and diet), it is recommended that future studies incorporate these factors for effective translation in clinical practice.

Conclusion

Although both parameters of the LHBBT were markedly greater in female individuals in this study, the LHBBT length was found to be larger on the right side and the LHBBT width was found to be larger on the left side. While male individuals presented with larger THL morphometric parameters, the THL length and width were notably greater on the left and right sides, respectively. This study noted that female individuals displayed larger LHBBT parameters, a finding that should be considered during surgical and prosthetic procedures. The results of this study may contribute to South African literature and enrich clinical knowledge as these parameters are important in tenotomy, tenodesis and other shoulder-related procedures.

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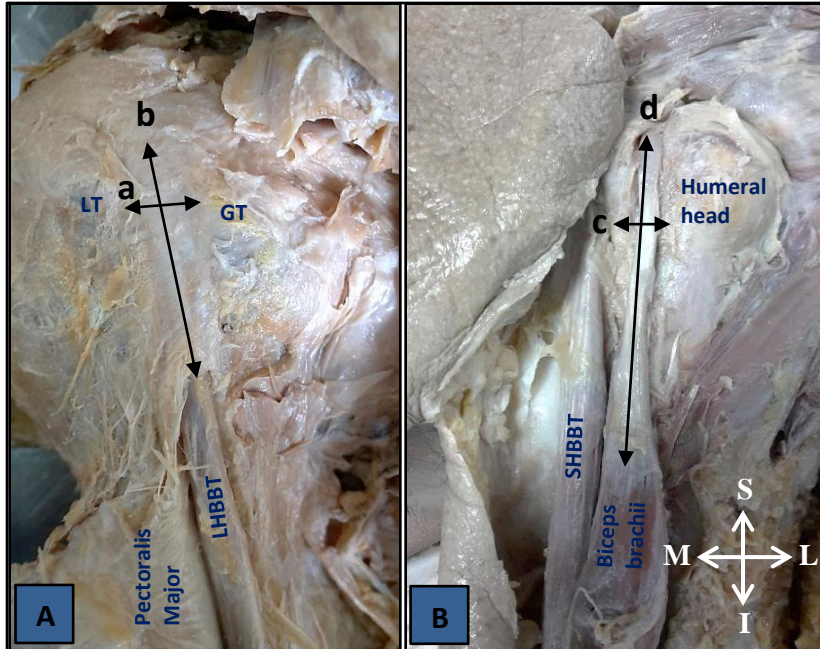
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Figure Legends

Figure 1. Anterior view of right shoulder: (A) Length and width of THL, (B) Length and width of LHBBT



Key: a- THL width; b- THL length; c- LHBBT width; d- LHBBT length; GT- greater tubercle; I- inferior; L- lateral; LHBBT- long head of biceps brachii tendon; LT- lesser tubercle; M- medial; S- superior; SHBBT- short head of biceps brachii tendon

Table 1. Morphometric parameters of the LHBBT and THL

Parameters		Morphometry: Mean ± SD (mm)			
		LHBBT length	LHBBT width	THL length	THL width
Laterality	Right (n=40)	81.99±21.28	4.28±1.31	20.91±5.24	16.65±6.92
	Left (n=40)	79.73±17.27	4.67±1.43	21.19±6.36	16.63±7.49
p-value		0.604	0.205	0.832	0.989
Gender	Male (n=44)	79.82±19.66	4.35±1.17	21.52±5.71	16.83±6.65
	Female (n=36)	82.14±19.03	4.63±1.60	20.48±5.92	16.40±7.84
p-value		0.594	0.387	0.433	0.797

Table 2. Pearson Product Moment Correlation Co-efficient(r) test of parameters in this study

Parameters	Age		LHBBT width		LHBBT length		THL width		THL length	
	<i>r</i>	P	<i>r</i>	p	<i>r</i>	P	R	P	<i>r</i>	p
THL length	0.076	0.504	-0.147	0.192	0.284	0.011*	0.379	0.001*	1	
THL width	0.274	0.014*	-0.239	0.033*	0.436	0.000*	1			
LHBBT length	0.254	0.023*	-0.093	0.412	1					
LHBBT width	-0.113	0.319	1							
Age	1									

*statistically significant p-value

Table 3. Intra observer Reliability

Descriptive Statistics			Multivariate Analysis: Effect			
Parameter	Dataset	Mean \pm Std. Deviation (mm)	Pillai's Trace	Wilk's Lambda	Hotelling's Trace	Roy's Largest Root
THL Width	1	13.42 \pm 2.58	0.036	0.964	0.037	0.037
	2	13.50 \pm 2.60				
	3	13.43 \pm 2.60				
THL Length	1	19.53 \pm 2.55	0.009	0.991	0.009	0.009
	2	19.74 \pm 2.90				
	3	19.61 \pm 2.82				
LHBBT Width	1	5.28 \pm 1.27	0.030	0.970	0.031	0.031
	2	5.38 \pm 1.33				
	3	5.18 \pm 1.12				
LHBBT Length	1	80.39 \pm 21.17	0.136*	0.864*	0.157*	0.157*
	2	79.96 \pm 20.62				
	3	74.75 \pm 21.25				

Key: LHBBT: long head of biceps brachii tendon; THL: transverse humeral ligament; *- statistically significant

Chapter 5

Synthesis

This cross-sectional study investigated the anthropometric parameters of the glenohumeral joint (GHJ) with emphasis on the scapula, bicipital groove (BG), long head of biceps brachii tendon (LHBBT) and the transverse humeral ligament (THL) in a select South African population

Subset (i): Dry bone evaluation of the scapula and humerus

a) An anthropometric evaluation of the scapula with emphasis on the coracoid process and glenoid fossa in a South African population

Degenerative diseases and instability of the GHJ in the athletes, young adults and the elderly are considered to be the leading causes of shoulder pain (Sahni and Narang, 2014).

In the present study, the mean CL was larger on the right side which corroborated the findings of Fathi *et al.* (2017) and Verma *et al.* (2017), while the mean CW and CGD appeared to be higher on the left side which confirmed the earlier report of Coskun *et al.* (2006) but differed from that of Kavita *et al.* (2013). From these findings, dominance was observed on both right and left sides and this could be indicative of the bilateral use of handedness in physical activities or to the fact that there is an equal distribution of right-handed and left-handed individuals within the population (Ropper *et al.*, 2014). Studies have stated that the glenoid shape, notch type, length and width of the glenoid fossa provides literature on the glenoid fossa that aid in the stability of the GHJ (Coskun *et al.*, 2006; Kavita *et al.*, 2013; Mahto and Omar, 2015). All three shapes of the glenoid fossa were found to be more prevalent in males. Type 3 (oval) glenoid fossa shape was observed to be the most predominant on both the right and left sides, which corroborate with the studies of

Mamatha *et al.* (2011) and Gupta *et al.* (2015). Glenoid fossa Type 1 (inverted comma) and Type 2 (pear) were reported as the least prevalent shape on the left and right sides, respectively, the latter of which differed from the literature reviewed (Mamatha *et al.*, 2011; Dhinsda and Singh, 2014; Chhabra *et al.*, 2015; El-Din *et al.*, 2015; Gupta *et al.*, 2015; Hassanein, 2015).

According to Jung *et al.* (2012), the presence of a distinct notch on the glenoid fossa prevents attachment of the glenoid labrum to the glenoid rim. Although glenoid notch Type 3 (double notch) was absent, Types 1 (without a notch) and 2 (with one notch) were noted to present with a higher prevalence in males. With regards to laterality, Type 1 (without a notch) and Type 2 (one notch) were predominant on the left and right sides, respectively. While this finding was dissimilar to the reported values of Coskun *et al.* (2006) and Hassanein (2015), the difference recorded for the comparison between laterality and notch yield may suggest that notch type 1 (without a notch) and 2 (with one notch) is a common finding in the right and left sides of the glenoid fossa ($p = 0.019$). In this study, the mean VD, HD1 and HD2 were increased on the right side and in male individuals. The presence of increased values on the right side corroborated the findings of previous studies (Mamatha *et al.*, 2011; Dhinsda and Singh, 2014, Mahto and Omar, 2015, Gupta *et al.*, 2015; Hassanein, 2015).

As the increase in prevalence of degenerative shoulder disease and traumatic injuries in the elderly and young adults, respectively, demands more focus, the provision of accurate and reliable diagnostic data that reflects with demographic relevance, may be beneficial to the healthcare system due to the apparent lack in shoulder-related literature in South Africa.

b) Dimensional analysis of the bicipital groove in a South African population

The morphology of the BG has been observed to present with significant variability which is considered to affect the THL and the biomechanics of the LHBBT (Karistinos and Poulos, 2007).

The mean BG width was observed as slightly larger in males. The mean BG length and depth however increased in female individuals and this may be due to the unequal number of males and females in this study which ultimately affected the distribution of the mean. According to gender-based differences, males have larger and heavier bones; however, results from this study disagreed with this finding (Ropper *et al.*, 2014). According to Ropper *et al.* (2014), hypertrophic biceps brachii muscles and larger LHBBT were commonly observed in individuals involved in manual labor. Furthermore, 90-95% of these individuals demonstrated right-hand dominance (Vettivel *et al.*, 1992). The mean BG length and width were found to be greater on the left side thereby indicating left-handedness while the mean BG depth was observed to be larger on the right side and presented with a statistically significant difference ($p = 0.008$). Although right and left sides were equal in sample size, dry bone humeri were unpaired in this study. The mean BG length, width and depth in this study were observed to be distinctively larger than that reported by Kaur and Gupta (2015) and may be due to the unequal numbers of male and female, hence this study was not gender-matched. The mean BG depth on the right and left sides were greater than of those reported in previous studies (Murlimanju *et al.*, 2011; Rajani and Man, 2013; Kaur and Gupta, 2015; Arunkumar *et al.*, 2016; Rajan and Kumar, 2016; Srimani *et al.*, 2016; Ashwini and Venkateshu, 2017; Venkatesan *et al.*, 2017). However, mean BG width on the right was larger than the studies by Murlimanju *et al.* (2012); Kaur and Gupta (2015); Rajan and Kumar (2016); Srimani *et al.* (2016) and Ashwini and Venkateshu (2017), but smaller than that reported by Rajani and Man (2013) and Venkatesan *et al.* (2017). Width can influence the pathology of the LHBBT

as it is ensheathed within the BG where a wider groove allows the tendon to move more freely with lesser chances of damage, whilst a narrow groove with confined movement results causing abrasion or tearing of the LHBBT (Rajani and Man, 2013). On both right and left sides, the mean BG length was larger than the findings of Kaur and Gupta (2015) and Arunkumar *et al.* (2016), but smaller than that reported by Murlimanju *et al.* (2012); Rajani and Man (2013); Rajan and Kumar (2016), Srimani *et al.* (2016); Ashwini and Venkateshu (2017) and Venkatesan *et al.* (2017).

Since biceps tendinitis is associated with decreased biceps activity and pain, investigation of the BG may provide useful data to evaluate individuals with potential abnormality of the biceps tendon. It may also be used as a landmark for humeral head replacement in the treatment of proximal humerus fractures.

Subset (ii): Cadaveric dissection of the long head of biceps brachii tendon and transverse humeral ligament

c) Long head of biceps brachii tendon and transverse humeral ligament morphometry and their associated pathology

The THL contributes to the stability of the LHBBT within the BG and prevents subluxation of the LHBBT (Jeff *et al.*, 2013; Joshi *et al.*, 2014). However, a torn THL may dislodge the LHBBT from the BG or may allow free movement of it, eventually leading to biceps tendinitis (Churgay, 2009).

While the LHBBT length and width were greater on the right and left sides, respectively; both parameters appeared to be distinctly longer in females. Male individuals are generally present with larger muscle-tendon units; however, this study observed otherwise which attributed to the fact that this study was not gender-matched, thus resulting in an undistributed mean. The mean LHBBT

lengths recorded in this study correlated with the findings of Joshi *et al.* (2014). However, the mean LHBBT length reported by Cucca *et al.* (2010) and Gothelf *et al.* (2008) were lower than those of the present study. The mean LHBBT widths were observed to be larger on the left side and were markedly higher in female individuals. Although the mean LHBBT width documented by Drolet *et al.* (2016) was similar to that of the current study; the mean values documented by Cucca *et al.* (2010) and Joshi *et al.* (2014) were distinctively larger. With regards to the right and left sides, the mean THL lengths and widths recorded by Snow *et al.* (2013) and Chidambram *et al.* (2015) were lower than those of the current study. This may be due to the difference in sample sizes of previous studies when compared to this study. Additional possible limitations could be the result of ethnicity and population differences. The mean THL length and width observed in this study was found to be larger in males. This finding concurs that the size of muscle-tendon units in males are larger as compared to females who display light-weighted bones.

These findings may contribute to South African literature and may enhance currently available clinical knowledge as these parameters are important for the successful outcomes of tenotomy, tenodesis and other shoulder-related procedures. Furthermore, it may prove useful in detecting and preventing LHBBT and its associated pathology.

Table 5. Answers to research questions pertaining to this study

Subset/Chapter	Research Questions
Subset (i) Chapter 2: Investigation of the coracoid process and glenoid fossa	1) Shape: 1 (27.44%); Shape 2 (29.26%); Shape 3 (43.30%) Notch: Type 1 (9.15%); Type 2 (90.85%); Type 3 (0%) 2) CL: $41.62 \pm 4.81\text{mm}$ CW: $13.73 \pm 6.90\text{mm}$ 3) VD: $35.06 \pm 3.07\text{mm}$ HD1: $18.00 \pm 3.07\text{mm}$ HD2: 24.05 ± 2.76 4) CGD: $27.78 \pm 5.94\text{mm}$
Subset (i) Chapter 3: Investigation of the bicipital groove	5) Length: $67.48 \pm 10.29\text{mm}$ Width: $9.13 \pm 1.40\text{mm}$ Depth: $7.47 \pm 1025\text{mm}$
Subset (ii) Chapter 4: Investigation of the LHBBT and THL	6) Length: $80.86 \pm 19.28\text{mm}$ Width: $4.48 \pm 1.57\text{mm}$ 7) Length: $21.05 \pm 5.80\text{mm}$ Width: $16.64 \pm 7.21\text{mm}$

Caveats in this study

This study did not account for dry bone scapulae and humerii that are bilateral components belonging to the same individual which may promote effective translation in clinical practice.

It is also suggested that inter-observer reliability indices be considered to further reduce standard errors in measurement and observation. Investigation of the GHJ should also be conducted on imaging resources, viz. x-rays and CT scans, as these tools are the first line of diagnosis in clinical practice.

Although South Africa is a nation rich in ethnic diversity, ethnicity was not taken into consideration in this study. Therefore, it is recommended that further studies incorporate a sample size representative of the South African population which may provide reference data on prosthesis

designs of variation which exist in the different ethnic groups of the population. However, this study may contribute to reducing the paucity of shoulder-related literature in South Africa and moreover in the Southern Hemisphere.

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Emanation of Publications and Conference Presentations

(i) Manuscripts Submitted for Publication

1. An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population

R Khan, KS Satyapal, N Naidoo, L Lazarus

This manuscript has been submitted to 'Folia Morphologica' (Manuscript number: #62596) and is currently under review.

2. Dimensional analysis of the bicipital groove in a South African population

R Khan, KS Satyapal, N Naidoo, L Lazarus

This manuscript has been submitted to 'International Journal of Morphology' (Manuscript number: IJM 012-19) and is currently under review.

3. Long head of biceps brachii tendon and transverse humeral ligament morphometry and their associated pathology

R Khan, KS Satyapal, N Naidoo, L Lazarus

This manuscript has been submitted to 'Journal of Orthopaedics' (Manuscript number: JOO_2019_13) and is currently under review.

(ii) Conferences

Papers delivered at conferences

1) An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population

R Khan, KS Satyapal, N Naidoo, L Lazarus

Poster Presentation

Anatomical Society of Southern Africa 2018, Muldersdrift, Gauteng, South Africa

23 April - 26 April 2018

2) An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population

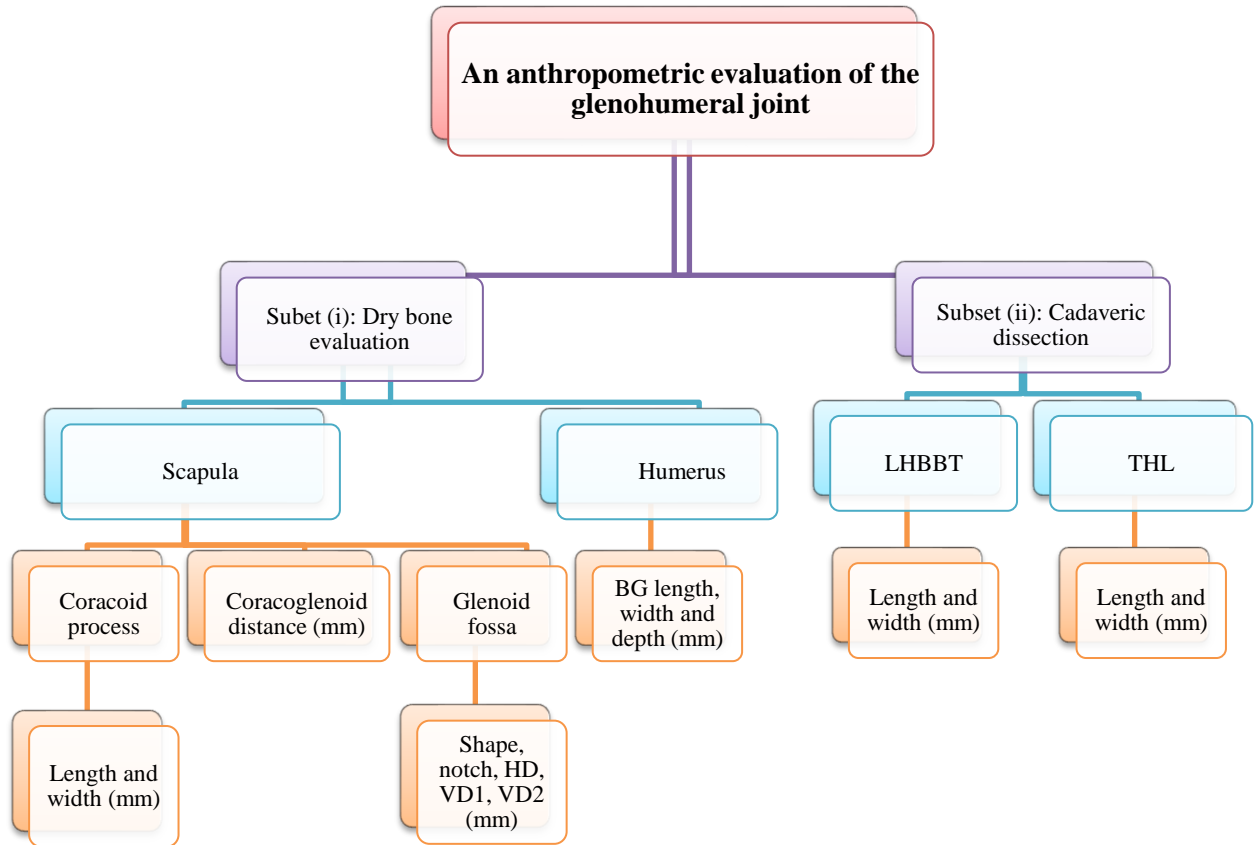
R Khan, KS Satyapal, N Naidoo, L Lazarus

Poster Presentation

66th National Conference of the Anatomical Society of India, Rishikesh, India

11 November - 14 November 2018

Appendix A: Research Overview



Key: BG- bicipital groove; HD1- horizontal diameter 1; HD2- horizontal diameter 2; LHBBT- long head of biceps brachii tendon; mm- millimeters; THL- transverse humeral ligament; VD- vertical diameter

Appendix B



UNIVERSITY OF
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RESEARCH OFFICE
Biomedical Research Ethics Administration
Westville Campus, Govan Mbeki Building
Private Bag 9, 54001
Durban
4003
KwaZulu-Natal, SOUTH AFRICA
Tel: 27 31 260-7609 - Fax: 27 31 260-4609
Email: BRECS@ukzn.ac.za

Website: <http://www.ukzn.ac.za/Research-Ethics/BiomedicalResearchEthics.aspx>

22 June 2018

Ms R Khan (213516600)
School of Laboratory Medicine and Medical Sciences
College of Health Sciences
Raeesakhan8665@gmail.com

Dear Ms Khan

Protocol: An anthropometric evaluation of the gleno-humeral joint in a South African population.
Degree: MMed
BREC Ref No: BE308/18

PROVISIONAL APPROVAL

A sub-committee of the Biomedical Research Ethics Committee has considered your application received on 15 May 2018.

The study is given **PROVISIONAL APPROVAL** subject to the response to the following queries:

1. Please provide further justification for this research.
2. Please submit Gatekeeper permission.

Please could each query be responded to separately e.g. BREC Query 1; (List the query) and below the query state the Answer to Query 1. A tabulated response is not acceptable.
Please email your response to brec@ukzn.ac.za.

All changes to the text must be highlighted and the relevant pages of the research application form resubmitted. Only one copy of the responses and amended pages needs to be submitted. Only when full ethical approval is given, may the study begin. Full ethics approval has not been given at this stage.

PLEASE NOTE: Provisional approval is valid for 6 months only should we not hear from you during this time the study will be closed and reapplication will need to be made.

Your acceptance of this approval denotes your compliance with South African National Research Ethics Guidelines (2015), South African National Good Clinical Practice Guidelines (2006) (if applicable) and with UKZN BREC ethics requirements as contained in the UKZN BREC Terms of

Appendix C



01 August 2018

Ms R Khan (213516600)
School of Laboratory Medicine and Medical Sciences
College of Health Sciences
Raeesakhan8665@gmail.com

Protocol: An anthropometric evaluation of the gleno-humeral joint in a South African population.
Degree: MMed
BREC Ref No: BE308/18

EXPEDITED APPLICATION; APPROVAL LETTER

A sub-committee of the Biomedical Research Ethics Committee has considered and noted your application received on 15 May 2018.

The study was provisionally approved pending appropriate responses to queries raised. Your response received on 28 June 2018 to BREC letter dated 22 June 2018 have been noted by a sub-committee of the Biomedical Research Ethics Committee. The conditions have now been met and the study is given full ethics approval and may begin as from 01 August 2018. Please ensure that site permissions are obtained and forwarded to BREC for approval before commencing research at a site.

This approval is valid for one year from 01 August 2018. To ensure uninterrupted approval of this study beyond the approval expiry date, an application for recertification must be submitted to BREC on the appropriate BREC form 2-3 months before the expiry date.

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

Your acceptance of this approval denotes your compliance with South African National Research Ethics Guidelines (2015), South African National Good Clinical Practice Guidelines (2006) (if applicable) and with UKZN BREC ethics requirements as contained in the UKZN BREC Terms of Reference and Standard Operating Procedures, all available at <http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx>.

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

The sub-committee's decision will be noted by a full Committee at its next meeting taking place on 14 August 2018.

We wish you well with this study. We would appreciate receiving copies of all publications arising out of this study.

Yours sincerely

Prof. D. Wassenaar
Deputy Chair: Biomedical Research Ethics Committee

Co-ordinator/Release administrator: research@ukzn.ac.za
Supervisor: research@ukzn.ac.za
Co-Supervisor: research@ukzn.ac.za

Biomedical Research Ethics Committee

Professor V Rambritch (Chair)

Westville Campus, Govan Mbeki Building

Postal Address: Private Bag 624001, Durban 4000

Telephone: +27 (0) 31 281 2428 Fax/mobile: +27 (0) 31 280 4569 Email: brec@ukzn.ac.za

Website: <http://www.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx>



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Appendix D



TRREE

Zertifikat Certificat Certificado Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants



Clinical Trials Centre
The University of Hong Kong

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Raeesa Khan

a complété avec succès - has successfully completed

Introduction to Research Ethics

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

February 27, 2016
CID - AricaN76Z



Professeur Dominique Sprumont
Coordinateur TRREE Coordinator



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[REV - 20170310]

Appendix E



Zertifikat
Certificat

Certificado
Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants



Certificat de formation - Training Certificate
Ce document atteste que - this document certifies that

Raeesa Khan

a complété avec succès - has successfully completed
Research Ethics Evaluation

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

February 27, 2016
CED - MelpKafC



Professeur Dominique Sprumont
Coordinateur TRREE Coordinator



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Swiss Academy of Medical Science (SAMES/ASSM/SAMW) (www.sames.ch) - Commission for Research Partnerships with Developing Countries (www.krpe.ch)

[R.0V - 20170310]

Appendix F

Turnitin Originality Report

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Masters By Raeesa Khan

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Appendix G

Data Sheets

Table 6: Data sheet for dry scapula specimens

Specimen no.	Gender	Side	Shape of glenoid	Notch type of glenoid	VD of glenoid (mm)	HD1 of glenoid (mm)	HD2 of glenoid (mm)	CL(mm)	CW (mm)	CGD (mm)
01										
02										
03										
04										

Key: CGD: coracoglenoid distance; CL: coracoid length; CW: coracoid width; HD1: horizontal diameter 1; HD2:

horizontal diameter 2; VD: vertical diameter

Table 7: Data sheet for dry humerus specimens

Specimen no.	Gender	side	BG length (mm)	BG width (mm)	BG depth (mm)
01					
02					
03					
04					

Key: BG: bicipital groove

Table 8: Data sheet for cadaveric dissection of LHBBT and THL

Specimen no.	Gender	Side	THL Length (mm)	THL width (mm)	LHBBT length (mm)	LHBBT width (mm)
01						
02						
03						
04						

Key: THL: transverse humeral ligament; LHBBT: long head of biceps brachii tendon

