



Re-visiting the brachialis muscle: morphology, morphometry, gender diversity, and innervation

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Abstract

Purpose The brachialis (BM) is a complex muscle with a long-running controversy regarding its morphology and innervation. The primary objective of this study was to elucidate the detailed gross morphology of BM in an adult Sri Lankan population.

Method Cadaveric upper limbs ($n=240$) were examined for the proximal and distal attachments, length, width, thickness of BM, and innervations by the musculocutaneous (MCN) and radial nerve (RN).

Results In all cases, the BM consisted of two heads: superficial head (SHB) and deep head (DHB). Proximally SHB and DHB originated from the lateral, anterior, and medial aspects of the middle and distal thirds of the shaft of the humerus and inserted onto the coronoid process and the tuberosity of ulna, respectively, as two separate entities. Statistically significant ($P<0.05$) gender differences were observed between the mean values (mm) of muscle length (male: 188.03 ± 10.54 ; female: 166.14 ± 7.97), width (male: 26.57 ± 4.80 ; female: 25.28 ± 4.67), thickness (male: 10.73 ± 1.74 ; female: 9.74 ± 1.28), and tendon length (male: 44.44 ± 7.73 ; female: 33.40 ± 5.09). In all cases, MCN innervated the BM, while the model site of piercing was in the middle third of the muscle. The incidence of RN contribution to BM was 83.33% and in the vast majority it pierced the inferior third of the BM.

Conclusion Present study provides a comprehensive anatomical overview of the BM. An in-depth knowledge of the anatomy of BM may aid in comprehending functional characteristics, enhance the accuracy of imaging modalities, and provide new insight to the current surgical approaches around the elbow joint which in turn will invariably minimize the potential complications encountered during clinical procedures.

Keywords Brachialis · Morphometric variations · Gender · Musculocutaneous nerve · Radial nerve · Innervation variations

Introduction

The brachialis (BM) is a fusiform muscle which together with the biceps brachii and coracobrachialis comprises the anterior compartment of the arm. It lies beneath the biceps brachii and contributes to the floor of the cubital fossa. It has been characteristically described as originating from the anterior surface of the distal half of the humerus clasping the insertion of deltoid tendon. The broad muscle belly proceeds distally across the anterior surface of the elbow joint to be inserted into the tuberosity of the ulna and coronoid process by way of a thick converging tendon [25, 28]. The BM is one

of the rare muscles of the body with only one movement related function—a pure flexor. The BM is not only the prime mover of the elbow flexion but also primarily responsible for sustaining the forearm in flexed position [17]. Moreover, it is the largest force contributor (47%) to the flexion torque, whereas the biceps brachii contributes only 34% [13]. It flexes the elbow regardless of forearm position in supination or pronation. When the forearm is extended the BM undergoes eccentric contraction, thus producing a steady movement [17].

It is a peculiar muscle with dual innervations from the musculocutaneous (MCN), the nerve of the flexor compartment and the radial nerve (RN), the nerve of the extensor compartment of the arm [23, 25, 28]. However, the incidence, nature of innervations and the functional significance of the radial nerve contribution is not precisely known. A large body of evidence supports morphological variations of

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the BM and its dual innervations. The constancy of the RN supply is reported to vary from 30.43 to 100% in different populations [2, 8, 12, 16, 20, 26]. All these variations add to the complexity of the BM and also should be considered in radio-diagnostic, orthopedic, reconstructive, or surgical procedures in the upper limb.

From a morphological and surgical stand point of view, explicit knowledge of the BM and its innervations would facilitate its potential role in anterior surgical approach to the distal humerus [11], muscle transfer to restore finger flexion in brachial plexus and forearm injuries [1, 7, 24], tendon transfer to reconstruct annular ligament of the elbow joint [18], reinnervation procedures to restore elbow flexion [30], and motor nerve blocks [3].

Despite its significance little is known concerning the precise anatomical details of the BM in Sri Lankans, inhabitants of the south Asian country. Hence, this study was undertaken to elucidate the detailed gross morphology, morphometry, gender differences of the BM and its innervations in an adult Sri Lankan population. The primary objective of this study was to elucidate the detailed gross morphology of BM. The secondary objectives were to evaluate gender differences of the morphometrical parameters of BM and variations in the pattern of its innervation by MCN and RN.

Materials and methods

This study was carried out on a total of 120 apparently healthy human cadavers (60 males and 60 females) that was utilized for the routine gross anatomy dissections in the Department of Anatomy, University of Ruhuna, Sri Lanka. Upper limbs with any physical deformities or trauma were excluded from the study. The age of the cadavers varied between 58 and 72 years.

Dissections of the upper limbs ($n = 240$) were performed according to the Romanes [23]. Skin, subcutaneous fat, and superficial fascia of the upper limb were dissected and the full length of the BM was exposed from its proximal to distal attachment. The BM was carefully examined for its proximal and distal attachments and morphological characteristics. The MCN was identified on the medial surface of the BM, as it descends through the interval between biceps brachii and BM. The RN was explored from the spiral groove of the humerus, its course from posterior to anterior compartment of the arm and then in between the BM and brachioradialis muscles. A detailed dissection was performed to determine if there are primary branches from the main trunks of the MCN and RN to the BM and if so, their numbers, direction, and pattern of distribution within the muscle. Furthermore, primary branch or its secondary branches were tracked as far as possible into the muscle by teasing the muscle fibers away from the nerve twigs.

The following parameters: length, width, thickness of the BM, and length of the tendon external to the muscle belly were recorded independently on both sides in males and females. The length of the muscle was defined as the maximum distance from the most proximal attachment to the most distal attachment. The width and thickness of the muscle were defined as the maximum diameters in the coronal and sagittal planes, respectively. Furthermore, the BM was divided into cross section and re-measured to verify the maximum thickness and width. The anatomical cross-sectional area (ACSA) of the BM was calculated according to the method described by Hanson et al. [10]. The length of the BM was divided into three equal segments and the sites of MCN and RN piercing the muscle (motor points) were recorded in relation with the superior, middle, or inferior thirds of the muscle.

All the above measurements were obtained using a flexible steel measuring tape and a digital sliding caliper (Mitutoyo, Japan) capable of measuring to the nearest 0.01 mm. Each measurement was repeated thrice and the mean was taken for further analysis. Furthermore, the measurements were recorded by the same investigator to minimize the inter-observer errors in methodology. Results were expressed as mean \pm SD and analyzed using the Statistical Package for Social Sciences (SPSS), 15th version. A comparison of mean values between sides and genders was performed using the *t* test. *P* value < 0.05 was considered statistically significant.

Results

In all the specimens studied, BM was present as a fusiform muscle which consisted of two heads: a superficial head (SHB) and a deep head (DHB). The SHB was larger, anterior, and proximal to the DHB (Fig. 1a). The proximal attachment of SHB encircled the medial, anterior (Fig. 1b) and lateral surfaces (Fig. 1c) of the middle third of the shaft of the humerus partially clasping the insertion of deltoid muscle with two angular processes (Fig. 1b, c). The middle fibers of the SHB had a straight vertical course, while the lateral and medial fibers extended slightly infero-medial and infero-lateral direction proximo-distally. The DHB was a relatively smaller, oblique, fan-shaped muscle with a broad proximal attachment that spanned across the lateral supra condylar ridge (Fig. 2a), anterior and medial surfaces (Fig. 2b) of the distal third of the shaft of the humerus. Its muscle fibers had an oblique course in the antero-inferior direction. The infero-lateral fibers were more obliquely positioned relative to the superio-medial fibers (Fig. 2a). Few muscle strands from the deep surface of the DHB extended to the anterior surface of the capsule of the elbow joint (Fig. 2c).

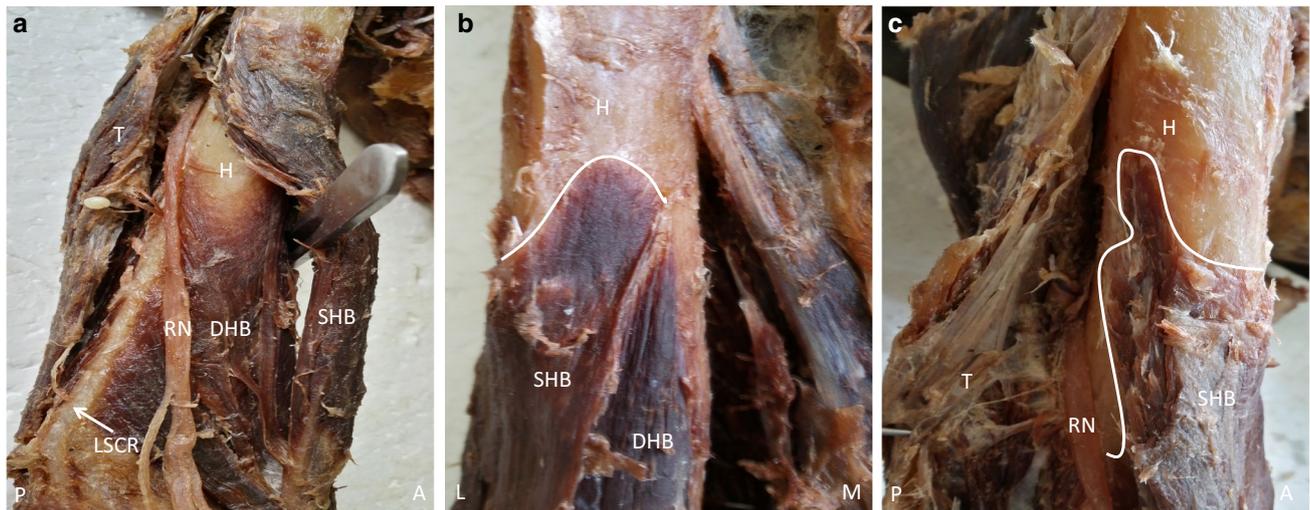


Fig. 1 **a** Lateral view of a right upper limb showing two heads of the BM: SHB and DHB. All superficial muscles are removed to visualize the BM. A scalpel handle is passed in between SHB and DHB. Communicating slips of muscle fibers are seen to extend between deep surface of the SHB and anterior surface of the DHB (arrow heads). The RN with its circuitous relationship to the humerus is seen to emerge from the posterior surface of the shaft of the humerus and proceeds downwards over the DHB antero-laterally. There was no contribution from the RN to DHB. **b** Anterior view of a right upper limb showing the origin of SHB from anterior and medial surface of the shaft of the humerus. All superficial muscles are removed to

visualize the BM. The SHB is anterior and proximal to the DHB. The white solid line shows the upper anterior and medial margins of the proximal attachment of SHB. **c** Lateral view of a right upper limb showing the origin of SHB from the lateral surface of the shaft of the humerus. All superficial muscles are removed to visualize the BM. The white solid line shows the upper lateral margin of the proximal attachment of SHB. The RN can be seen winding around the humeral shaft as the triceps is reflected posteriorly. *A* anterior, *DHB* deep head of brachialis, *H* shaft of the humerus, *L* lateral, *LSCR* lateral supracondylar ridge, *M* medial, *P* posterior, *RN* radial nerve, *SHB* superficial head of brachialis, *T* triceps brachii

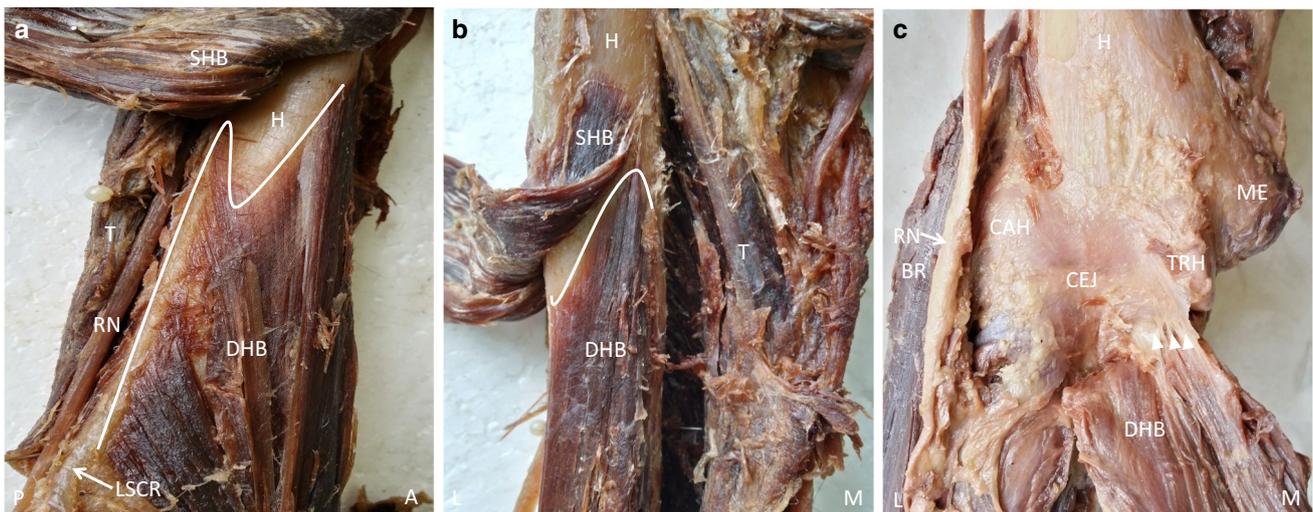


Fig. 2 **a** Anterior view of a right upper limb showing the origin of DHB. The SHB is reflected superiorly and laterally to visualize the origin of DHB. The white solid line shows the upper anterior and medial margins of the proximal attachment of DHB. **b** Lateral view of a right upper limb showing the origin of DHB from lateral side of the shaft of the humerus. The SHB is reflected superiorly to visualize the origin of DHB. The white solid line shows the upper lateral margin of the origin of DHB. The RN is displaced posteriorly behind the lateral epicondyle. The infero-lateral fibers of the DHB were more obliquely positioned (asterisk) relative to the superio-medial

fibers. **c** Anterior view of a right elbow joint showing slips from the deep surface of DHB to the anterior surface of the capsule of elbow joint (arrow heads). The BM is entirely separated from its origin and reflected anteriorly to visualize the deep surface of the DHB and capsule of the elbow joint. *A* anterior, *BR* brachioradialis, *CAH* capitulum of humerus, *CEJ* capsule of elbow joint, *DHB* deep head of brachialis, *H* shaft of the humerus, *L* lateral, *LSCR* lateral supracondylar ridge, *M* medial, *ME* medial epicondyle, *P* posterior, *RN* radial nerve, *SHB* superficial head of brachialis, *T* triceps brachii, *TRH* trochlear of humerus

The SHB and DHB were loosely adherent and easily separable from each other particularly along the lateral side of the distal third of the humerus (Fig. 3a). However, distally the tendon of the SHB was more tightly adherent to the DHB and its aponeurosis. Communicating slips of muscle were also observed between the two heads (Fig. 1a). The muscle belly of the SHB proceeded inferiorly crossing the anterior surface of the elbow joint and converged to form a thick circular tendon that inserted onto the tuberosity of ulna (Fig. 3a, b). The DHB formed a musculo-aponeurotic insertion onto the anterior surface of the coronoid process of ulna. The distal attachment of the DHB to the coronoid process was broader, medial and proximal to that of the SHB (Fig. 3a, b).

In all 240 specimens studied MCN innervated the BM (100%) irrespective of RN contribution. In all cases, only one primary motor branch (100%) emerged from the main trunk of the MCN and innervated the SHB from its medial aspect (Fig. 4a). This branch to BM was the third motor branch from the MCN, which was preceded by branches to coracobrachialis and biceps brachii muscles. The MCN primary branch to BM divided into variable number of secondary branches (2–4) before piercing the SHB. All MCN branches to BM had a descending course (100%) towards the muscle (Fig. 4a). The distribution of MCN branches had a

superficial to deep course with in the SHB and some of its nerve twigs emerged from the deep surface of the SHB to reach and pierce the anterior surface of the DHB. There were no muscular branches from the MCN that supplied directly to the DHB.

Out of 240 upper limbs, in 191 upper limbs (83.33%), RN innervated the BM. The RN descended between the BM and brachioradialis muscles and innervated the DHB through its lateral aspect (Fig. 4a, b). There was no contribution directly from RN to the SHB. The number of primary branches from the RN to DHB varied from 2 to 3 [two branches in 78.01% and three branches in 21.99% (Fig. 4a, b)]. The RN branches to DHB either had a relatively transverse (77.83%) or descending (22.17%) course towards the muscle.

The MCN pierced the BM in its superior and middle thirds in 12.5% and 87.50% of the study subjects, respectively, while none of the branches pierced the inferior third of the muscle. On the other hand, the RN pierced the BM in its middle and inferior thirds in 17.38% and 82.62% of the study subjects, respectively, while none of the branches pierced the superior third of the muscle (Table 1).

The results of the various anatomical dimensions of the BM according to the gender are shown in Table 2. Statistically significant ($P < 0.05$) gender differences were observed between the mean values of muscle length, width, thickness,

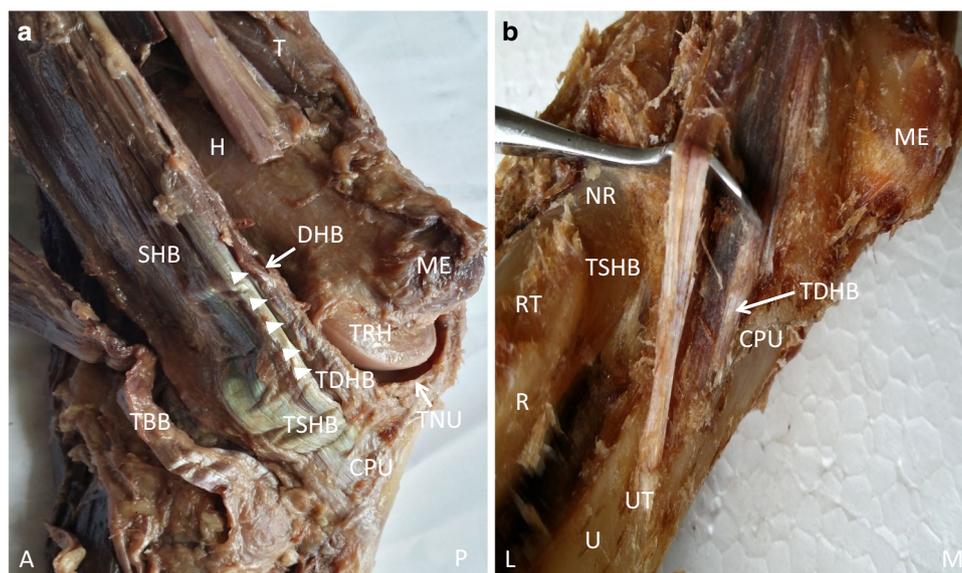


Fig. 3 **a** Medial view of a right upper limb showing insertions of the SHB and DHB in relation to the surrounding anatomy of the elbow region. The flexor muscles of the forearm are dissected from the common flexor origin/ME to visualize the insertion of the BM. The elbow joint capsule is cut opened into the joint cavity. The TSHB and TDHB are clearly seen as two separate entities (arrow heads). **b** Medial view of a right upper limb showing insertions of the SHB and DHB to the ulna. All the superficial structures are removed to visualize the precise insertion of the SHB and DHB. A scalpel handle is passed in between the TSHB and TDHB. The TSHB is seen as a thick

and rounded structure which inserts more onto the ulnar tuberosity whereas the TDHB is broader and musculo-aponeurotic and inserts more proximally onto the coronoid process of ulna. *A* anterior, *CPU* coronoid process of ulna, *DHB* deep head of brachialis, *H* shaft of the humerus, *L* lateral, *M* medial, *ME* medial epicondyle, *NR* Neck of the radius, *P* posterior, *R* radius, *RT* radial tuberosity, *T* triceps brachii, *TBB* tendon of biceps brachii, *TDHB* tendon of DHB, *TNU* trochlear notch of ulna, *TRH* trochlear of humerus, *TSHB* tendon of SHB, *U* ulna, *UT* ulna tuberosity

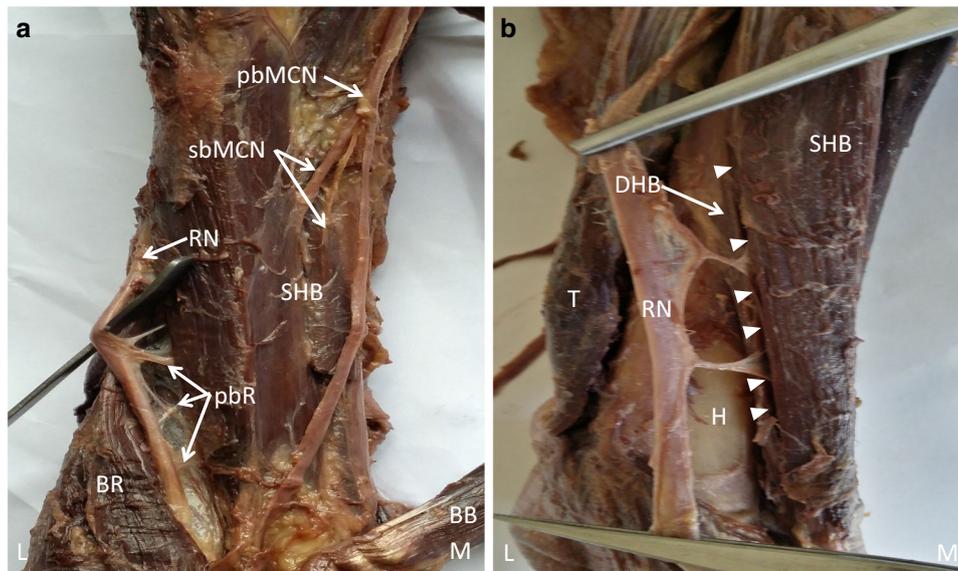


Fig. 4 **a** Anterior view of a right upper limb showing the dual innervations of BM. The BB is incised and reflected medially to visualize the superficial aspect of BM. The RN is lifted anteriorly for clear visualization of its branches. The MCN innervates the muscle through one primary branch which subdivides into two secondary branches that pierces the SHB from its medial side. The RN gives off three primary branches that enter the DHB from its lateral side. **b** Lateral view of a right upper limb showing the RN innervations to BM. The RN is

lifted anteriorly for clear visualization of its branches. The RN gives off two primary branches which are seen to enter the plane in between the SHB and DHB to innervate the DHB (arrow heads). *BB* biceps brachii, *BR* brachioradialis, *DHB* deep head of brachialis, *H* shaft of the humerus, *L* lateral, *M* medial, *MCN* musculocutaneous nerve, *pbMCN* primary branch of MCN, *pbRN* primary branch of RN, *RN* radial nerve, *sbMCN* secondary branch of MCN, *SHB* superficial head of brachialis, *T* triceps brachii

Table 1 Incidence and entry point of musculocutaneous nerve and radial nerve supply to the brachialis muscle (BM)

Innervation	Incidence (%)	Site of penetration of BM		
		Superior 1/3 (%)	Middle 1/3 (%)	Inferior 1/3 (%)
Musculocutaneous nerve	100	12.5	87.5	0
Radial nerve	83.33	0	17.38	82.62

Table 2 Gender-based anatomical dimensions of the BM

Gender	Male	Female
Total number	60	60
Length of BM (mm)	188.03 ± 10.54*	166.14 ± 7.97
Width of BM (mm)	26.57 ± 4.80*	25.28 ± 4.67
Thickness of BM (mm)	10.73 ± 1.74*	9.74 ± 1.28
ACSA of BM (mm ²)	220.97 ± 38.67*	201.95 ± 46.95
Tendon length of BM (mm)	44.44 ± 7.73*	33.40 ± 5.09

Data are expressed as mean ± standard deviation

ACSA anatomical cross-sectional area, *BM* brachialis muscle

*($P < 0.05$)

and ACSA. All the above parameters were greater in males than in females. A comparison of the dimensions of BM between the right and left sides according to the gender is shown in Table 3. Bilateral variations of the above parameters were present in both genders demonstrating a bilateral

asymmetry. However, side differences were not statistically significant.

Discussion

The present study documents valuable novel information pertaining to the morphology, morphometry, innervation, and gender dimorphism of BM muscle in an adult group of Sri Lankan population. Population-specific anatomical dimensions of the BM and detailed analysis of its relationship with the MCN and RN will invariably facilitate diagnostic, reconstructive, and surgical interventions of the upper limb.

Standard anatomy texts appear to provide inconsistent descriptions regarding the anatomy of BM. For instance, the BM is stated as an occasionally doubled muscle that arises from the anterior surface of the distal half [28] or lower two-thirds [25] of humerus with a tendinous [28] or

Table 3 Side-based anatomical dimensions of the BM

Gender	Male		Female	
	Left	Right	Right	Left
Length (mm)	187.11 ± 10.54	188.94 ± 11.45	164.12 ± 10.60	168.17 ± 4.20
Thickness (mm)	10.25 ± 1.44	11.20 ± 2.02	9.54 ± 1.29	9.93 ± 1.35
Width (mm)	26.88 ± 5.43	26.26 ± 4.58	26.21 ± 5.60	26.55 ± 4.05
ACSA (mm ²)	214.73 ± 41.83	227.21 ± 38.03	206.78 ± 38.32	197.11 ± 57.65
Tendon length (mm)	42.67 ± 7.51	46.20 ± 8.22	33.88 ± 5.53	32.92 ± 5.09

Data are expressed as mean ± standard deviation

ACSA anatomical cross-sectional area, BM brachialis muscle

*($P < 0.05$)

musculo-tendinous [25] insertion either solely into the coronoid process of ulna [23] or coronoid process and tuberosity of ulna [17, 25, 28]. The nature of RN supply to the BM is described as motor [28] or sensory [23] to the muscle [28] or lateral part of the muscle [25]. In view of these inconsistent and vague descriptions, the significance of analyzing the detailed morphology of BM cannot be underestimated. This study provides evidence that the BM clearly consists of two heads with distinct proximal and distal attachments. Proximally SHB and DHB originated from the lateral, anterior, and medial aspects of the middle and distal thirds of the shaft of the humerus and inserted onto the coronoid process and the tuberosity of ulna, respectively, as two separate entities. The morphology and attachments of the muscle observed in our study correspond well with those described by Leonallo et al. [14].

It is proposed that the existence of two morphologically distinct heads of the BM to exert different functions: the more proximal insertion of the DHB on the coronoid process of ulna having a role in initiation of the flexion, while more distal insertion of the SHB onto the ulna tuberosity exerting a greater power in maintaining the flexed position of the elbow [14]. In addition, the DHB acting together with the anconeus as a muscular sling stabilizes the forearm against rotation [14]. In surgical reconstruction of the BM tendon ruptures, enhanced elbow kinematics have been observed when reinsertion of the SHB further distal to its original insertion site on the ulna [9]. The tendon of the SHB serves as a potential graft source for reconstruction of the annular ligament of the elbow [18]. Such clinical scenarios demand a detailed morphology and morphometry of the tendon for harvesting the precise length of the graft tendon at the correct location for a better clinical outcome. Muscular fibers were shown to extend directly between the deep aspect of the DHB and the capsule of the elbow joint. These have been designated as articularis cubitus or capsularis subbrachialis are thought to prevent capsular impingement during elbow flexion [14]. Our results, though purely observational, are consistent with the above finding. It is likely that surgical procedures of the elbow joint such as elbow arthroplasty

might involve these capsular fibers. Therefore, a comprehensive knowledge of BM and its association with the joint capsule may be utilized for effective reconstructive surgical procedures of the elbow joint.

While the MCN supply is universally accepted, the nature of the RN innervation to BM remains a long-running controversy. The prevalence of RN contribution to the BM is well documented in the literature and shows a wide variation of 30.43–100% among different populations [2, 8, 12, 16, 20, 26]. This study, where the incidences of MCN and RN contribution to BM are 100% and 83.33%, respectively, further reinforces the above findings. Variations in the incidences of RN contribution to the muscle concerned may reflect ethnic differences [16]. Developmentally, this apparent contradiction in its innervations by both the MCN and RN is postulated to occur as a result of fusion of dorsal (extensor) and ventral (flexor) muscular primordia [5]. In those BM that are solely innervated by MCN (16.67%), only the ventral muscular primordia contribute to the development of the muscle.

From a clinical standpoint of view, in vivo ultrasound imaging has demonstrated that the BM, including its muscle belly and tendon is clearly discernable as two separate entities. The ultrasound imaging also has the potential to distinguish isolated lesions such as avulsions with bony detachments involving the DHB and tendinopathy with loss of normal fibrillar structure [27]. Furthermore, MRI studies have spectacularly delineated the territories of dual innervations of the BM, specifically demonstrating that RN and MCN neuropathies causing denervation of the infero-lateral segment and medial segment of the BM, respectively, while combined lesions resulting in a complete denervation of the muscle [7].

According to the overall shape, the BM is classified as a fusiform muscle, and thus, its force generating axis extends in a straight line between the attachment points [17]. Such muscles can be measured by the anatomical cross-sectional area (ACSA). It is generally believed that the size of a muscle reflects its strength [28]. The maximum contraction force generated by a muscle is related to its physiological cross-sectional area (PCSA). In muscles, whose pennation angle

is zero degrees, the ACSA corresponds to the PCSA. The fiber pennation angle of BM has been reported to be zero degrees [15], and consequently, its PCSA and ACSA must be identical. Evidence supports that moment across a joint generated by associated muscles is related to architectural parameters of the muscle such as fascicle length, width, pennation angle, and cross-sectional area. It has been demonstrated that following cerebro-vascular accidents, the parietic BM tends to acquire a shorter fascicle length accompanied by a larger pennation angle [15]. Clearly, such architectural changes of the BM are not in favour of its force generating potential. This study documents a significant gender difference in all the anatomical dimensions including ACSA of the BM. Accordingly, it implies that changes in the size and presumably the strength of the contractile force generated by the BM is gender specific. Therefore, knowledge of the normal architectural dimensions of BM will invariably facilitate to identify muscle deformations, evaluate functional improvement of paretic muscles following clinical intervention, and understand the mechanisms that underlie rehabilitation procedures [15].

While all the BM were innervated by the MCN (100%), in 16.67%, it was the sole contributor. In accordance with our results, several studies have reported that in the large majority of cases, MCN contributed a single primary motor branch to the BM: 100% [8], 95.8% [30], 92% [6], 73.91% [20] and 72.1% [19], and 100% (this study). The branching pattern of MCN was thought to influence the number of heads of BM [29]. Several studies have quantified the anatomical aspects of the BM innervations in relation to the length of the muscle. In our study, the data were expressed as a percentage with regard to the length of the BM to avoid errors caused by anthropometric differences [19]. The model site of MCN piercing was at the middle third of the BM in 85% [16] and 87.50% (this study), while the large majority of RN pierced the inferior third of the muscle: 84% [26], 83% [16], and 82.62% (this study). The majority of RN branches to BM had a transverse course: 100% [26], 75% [8], and 77.83% (this study). Indeed, the MCN and RN entered the BM at variable levels in different study populations. Therefore, data concerning the level of penetration of these nerves into the BM will shed light on surgical procedures, thus avoiding or minimizing motor nerve injuries.

BM is regarded as the key muscle for controlling flexion spasticity [3]. Particularly, in stroke survivors, the spasticity of elbow flexors not only contributes to the typical upper limb posture in hemiplegia, but also limits the rehabilitation attempts to improve function [15]. In such instances, motor point block of the BM is considered to be a better treatment option than blocking the main trunk of the MCN nerve, as it avoids undesirable complications associated with the latter. Furthermore, BM is the major flexor of the elbow that also has no role in supination.

As such, motor point blocking of the BM will reduce the spasticity of elbow flexion without affecting the ability to supinate [4, 20]. Therefore, knowledge regarding the precise location of motor point, the location, where the motor branch entered the muscle, will invariably facilitates more accurate approach to the BM motor point blocks.

With the advent of nerve, muscle, and tendon transfer procedures, substantial progress has been achieved in restoration of normal muscle function in patients suffering from muscle impairments. Brachial plexus injuries cause functional deficits in the upper extremity necessitating complex and daunting task of reconstruction procedures directed towards the restoration of elbow flexion. In such instances, nerve transfers is considered as an attractive option, as it allows prompt reinnervation of the motor end plate thus enabling to restore the original musculo-tendinous dynamics. Advances in double fascicle transfers, in which redundant motor fascicles of the median nerve has been used to reinnervate the BM, have yielded excellent functional outcomes [22]. Therefore, the significance of understanding and defining the internal topography of BM innervations cannot be underestimated. In other instances, when the primary nerve repair is not technically feasible to restore the elbow flexion, a myriad of muscle and tendon transfers has been used with a varying degree of success. The brachialis muscle-to-flexor digitorum profundus and flexor pollicis longus transfer are an effective option to restore digital flexion and prehensile function of patients with lower trunk brachial plexus palsy or forearm injury [1, 7, 24]. The detailed neurotopographical information of the BM also provides insight to the surgical exposure of the distal humerus. Dual innervations with MCN from the lateral side and RN from the medial side, the midline of the BM represents an internervous plane. The standard anterior approach to the surgical exposure of the humerus that involves midline splitting of the BM is based on this principle [11]. According to the results of this study, in 16.67%, whose BM is solely innervated by MCN, the anterior approach to the humerus would result in denervating the lateral half of the BM, while in splitting, the muscle mass between BM and brachioradialis, the risk of denervating the lateral segment of BM would be as high as 83.33%.

Limitations of the study

The current study was performed on formalin-fixed 240 adult cadaveric upper limbs. Thus, the embalming process may have an impact on the morphometrical parameters of the BM. This is one of the main limitations of the study. Furthermore, power analysis has not been conducted to assess the sufficiency of the sample size to reach a conclusion.

Conclusion

The present study provides evidence that the BM clearly consists of two heads with distinct proximal and distal attachments. Proximally SHB and DHB originated from the lateral, anterior, and medial aspects of the middle and distal third of the shaft of the humerus and inserted onto the coronoid process and the tuberosity of ulna, respectively, as two separate entities. While all BM were innervated by MCN (100%), in 16.67%, it was the sole contributor. RN contribution to BM was 83.33%. The vast majority of MCN and RN pierced the middle and inferior thirds of the muscle, respectively. Precise anatomical knowledge of the BM will be imperative in radio-diagnostic and modern surgical procedures around the elbow joint, which in turn will invariably minimize the potential complications encountered during clinical procedures.

Author contributions II: contributions to concept/design, acquisition of data, data analysis/interpretation, drafting of the manuscript, critical revision of the manuscript, and approval of the article. BGN: contributions to concept/design, critical revision of the manuscript, and approval of the article. SMU: acquisition of data, data analysis/interpretation, and drafting of the manuscript. KNP: acquisition of data and data analysis/interpretation.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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