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Anatomical variations of the biceps brachii insertion: a proposal for a new classification

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Background: *The biceps brachii (BB) muscle is one of the three muscles located in the anterior compartment of the arm. Its insertion consists of two parts. The first part — main tendon — attached in the radial tuberosity and the second part — lacertus fibrosus (LF) — in the fascia of the forearm flexors. The intention of research was to reveal the morphological diversity of the insertion of this muscle. Thanks to the results of this work, have been created a classification of the distal attachment of BB. The results of that research can be used to further develop surgical procedures in the given region.*

Materials and methods: *Eighty (40 left, and 40 right, 42 female, 38 male) upper limbs fixed in 10% formalin solution were examined.*

Results: *We observed three types of the insertion of the BB. Type I was characterised by a single tendon and occurred most frequently in 78.75% of the examined limbs. The second most common type was type II which was characterised by a double tendon and was observed in 13.75% of all the limbs. The last and least common was type III which was characterised by three tendons and occurred in 7.5% of the examined limbs. Additionally, the type of LF was analysed. In 8 (10%) specimens it was absent, i.e. in 2 specimens with type II insertion and 6 specimens with type III (p = 0.0001). Therefore, it may be deduced that type III BB insertion tendon predisposes to LF deficiency.*

Conclusions: *The BB tendon is characterised by high morphological variability. The new classification proposes three types of distal attachment: type I — one tendon; type II — two separated band-shaped tendons; type III — three separated band-shaped tendons. The presence of type III BB tendon predisposes to a lack of LF.* (Folia Morphol 2023; 82, 2: 359–367)

Key words: biceps brachii, biceps brachii tendon, lacertus fibrosus, bicipital aponeurosis, new classification

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INTRODUCTION

The anterior compartment of the arm consists of three muscles: the biceps brachii (BB), brachialis and coracobrachialis muscle. The BB usually consists of two heads: long and short [29]. The short head of the BB, together with the coracobrachialis muscle, originates from the apex of the coracoid process of the scapula, whereas the long head of the BB originates from the supra-glenoid tubercle of the scapula [29]. The proximal tendons belong to long head of BB and short head of BB transform in to muscle tissue that form two muscle bellies. In the distal part, those separated muscle bellies connect together [3, 6, 7].

Insertion of BB consists of two components. One of it is a tendon attached into the radial tuberosity, and the second component being the lacertus fibrosus (LF) which fuses with the fascia of the forearm flexors [6, 7].

The primary functions of the BB are flexion of the elbow and supination of the forearm. In fact, the BB is the prime supinator of the forearm. Since it crosses the glenohumeral joint, it also assists in the shoulder flexion. Depending on the angle of the elbow, the BB performs different actions to cause movements of the upper limb. For example, if the elbow is extended, the BB is a pure elbow flexor until it reaches 90-degree flexion, while at 90 degrees flexion and with the forearm supinated, it produces elbow flexion most efficiently. Also, at 90-degree flexion and with the forearm pronated, the BB becomes the primary forearm supinator [38]. The lacertus fibrosus, on the other hand, has a more complicated function. It is believed that it increases the tension of the main tendon of the BB; it also protects the median nerve and brachial artery running posteriorly [8, 11, 24, 40]. In addition, it plays a significant role in the reinforcement of the antebrachial fascia [24, 38].

The BB is characterised by morphological variability, both in the number of muscle bellies [1, 5, 11, 17, 19, 22, 23], proximal attachments [3, 15, 20, 38, 44], and the variability of its distal attachment, which is much less frequently described in the literature [8, 24, 40].

Studies based on the variability in the types of BB bellies have a significant impact over this research. It could be said whether the number of bellies indicate amount of insertion parts. Also imaging research, e.g. in case of BB insertion rupture/tear, are essential for ongoing research. When imaging, the damaged tendon can be felt superficially (palpation). Examination of the anatomical variant in detail will allow for more accurate imaging studies [2, 17].

The previous studies of the insertion of the BB assess, for example, the arrangement of the distal portion of BB and the points of reference, this serves in research of relationship between heads of BB and its insertion. It would have a potential clinical value to clarify the particular arrangement of the muscle bellies and tendon fibres. May affect the forces exerted on the distal tendon of insertion. Another work, tries to test the tendon footprint. Decreased radial tuberosity height effectively reduces the biceps supination of forearm, thereby limiting the peak supination torque and ability of the biceps to do work [17].

As a result of the analysis of the available studies on the distal attachment of the BB muscle, there were no measurements such as width, length, thickness according to direct type of insertion: one band, two bands, three bands. Also there was lack information about any correlation between the type of insertion and the superficial LF layer shown in results of measurement as width, length, thickness. Whether there are relationships between the type of trailer and gender or body side? Will any of the types show clearly different dimensions (width, thickness, length) from the others? This study remedies these gaps.

The BB muscle is exposed to frequent overloads. This leads to consecutive micro-injuries, which in turn trigger inflammation and subsequent biceps tendinopathy. A significant occurrence of loads on this muscle may be indicated by the fact that the rupture of the tendon of the head of a long biceps can happen at any age. Many sports aimed at using the strength of the upper limbs lead to a significant load on the work of the BB muscle. In the first place may be one-handed disciplines such as badminton, arm wrestling and two-handed such as ice hockey, tennis. In second place were sports involving throwing, e.g. American football, baseball [15, 20, 38]. Distal tendon ruptures are diagnosed less frequently [26].

Injury to the distal BB tendon is very common in the fourth to sixth decade of life. It usually occurs in the dominant arm of men [25, 27]. The most common cause of such damage is a sudden exertion of an eccentric force on the supinated forearm at the moment when the BB muscle is tense or partially tense [27, 28]. In addition, the irregularity of the radial tuberosity can lead to damage to the attachment of the distal biceps muscle [39].

Examination and anatomical classification of this area due to the multiplicity of damage and the subsequent necessity to perform insertion reconstruction treatments will help in better preparation for the repair plan [28, 39].

The main objective of this study is to provide the measurements that were mentioned in the previous paragraphs and answer the questions. This information could potentially assist in detecting a predisposition to developing tendon injury, if such a relationship were established. Also the purpose of the present study was to characterise the possible variations in the morphology of the distal attachments of the BB and to draw relevant conclusions with regard to an accurate classification of the area that can be useful for improved evaluation of imaging and for planning surgical procedures in the region.

The hypothesis was that there would be variation in the distal BB morphology and that a classification system could be developed. The clinical importance of BB muscle gives us motivation to carry out this research with an aim to determine variation of BB insertion.

MATERIALS AND METHODS

An electronic digital calliper was used for all measurements (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan), and each measurement was performed twice with an accuracy of up to 0.1 mm. The Bioethics Committee of the Medical University of Lodz (resolution RNN/1337/20/KE) approved the study protocol. All methods and techniques used during carrying out the research were in accordance with the protocol approved above. The cadavers belonged to the Department of Anatomical Dissection and Donation of the Medical University of Lodz, Poland.

Eighty (40 left, and 40 right; 42 female, 38 male) upper limbs fixed in 10% formalin solution were examined. The mean age of the cadavers at death was 77.9 years (standard deviation [SD] = 22.5) (53–95) (Central European population). The cadavers were the property of the Department of Anatomical Dissection and Donation, Medical University of Lodz, Poland, having been obtained as donation to the university anatomy programme. Any upper limbs with evidence of surgical intervention in the dissected area were excluded. All dissection procedures in the shoulder and arm area were performed in accordance with a pre-established protocol [30, 31, 33–36, 45, 46].

Dissection began with the removal of the skin and superficial fascia from the area of the shoulder and anterior and medial side of the arm and the anterior side of the forearm. The next stage included visualisation of the lateral, medial and posterior cords of the brachial plexus, and visualisation of both BB, coracobrachialis, and brachialis muscles. Then, the site of the lacerum was carefully checked. After checking and measuring the lacerum, the muscles of the anterior forearm group were delaminated to locate and check as well as to measure the tendons and examine their insertion. Next, all the structures were thoroughly cleaned [32, 38, 41].

Upon dissection, the following morphological features of the BB were assessed:
- the morphology of the BB lacerum:
  - (proximal) width and thickness at the beginning at the point of detachment from the terminal tendon line;
  - (distal) width and thickness at the end of lacertum fibrosum, the type of BB insertion (indicated by number of tendons);
- morphometric measurements of the BB:
  - (distal) width and thickness at the point of attachment to radial tuberosity;
  - length from attachment radial tuberosity till start of muscle belly.

The procedure of BB dissection was performed in accordance with the following principles:
- when clearing the BB, attention should be paid to the presence of its accessory heads;
- when checking the BB, the distal part should be carefully studied for the presence of coracobrachialis longus muscle and for the relationships between the median nerve and musculocutaneous nerve.

Ethical approval and consent to participate

The Bioethics Committee of the Medical University of Lodz (resolution RNN/1337/20/KE) approved the study protocol. The cadavers belonged to the Department of Anatomical Dissection and Donation of the Medical University of Lodz, Poland. Informed consents were obtained from all participants before they died.

Statistical analysis

A χ^2 test were used to compare differences in insertion types between genders, sides of the body. The Shapiro-Wilk test was used to check the normality of the data. The Manny-Whitney test and the Wilcoxon test were used to compare data on gender and sides of the body. In order to compare data on

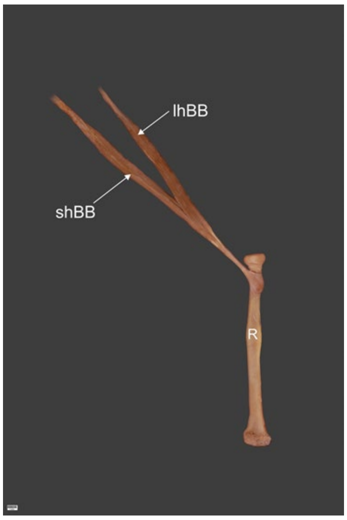

Figure 1. Type I of biceps brachii insertion; shBB — short head of the biceps brachii; lhBB — long head of the biceps brachii; R — radius bone.

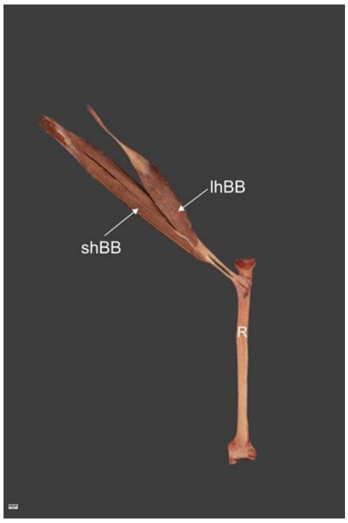

Figure 2. Type II of the biceps brachii insertion; shBB — short head of the biceps brachii; lhBB — long head of the biceps brachii; R — radius bone.

measurements of the indicated types of insertion, we used the Mann-Whitney test and the Kruskal-Wallis test with the appropriate *post hoc* test.

For analysis, Statistica 13.1 was employed. We considered that p-value lower than 0.05 was statistically significant. In addition, Bonferroni correction was used for multiple comparisons.

RESULTS

Anatomic study

In all 80 limbs, the BB insertion was present and suitable for morphological analysis. Based on a morphological analysis, the following types of BB insertion were differentiated:
- type I — was characterised by a single tendon and insertion into the radial tuberosity of the radius. This type was found in 63 upper limbs (78.75%) (34 females, 29 males; 32 right and 31 left) (Fig. 1);
- type II — was characterized by a double tendon and insertion into the radial tuberosity of the radius. This type was observed in 11 limbs (13.75%) (2 females, 9 males; 5 right and 6 left) (Fig. 2);
- type III — was characterised by a triple tendon and insertion into the radial tuberosity. This type was recognised in 6 upper limbs (7.5%) (6 females, 0 males; 3 right and 3 left) (Fig. 3).

Type II was significantly more common in males, whereas type III in females ($p = 0.0013$). There was no significant difference in the frequency of type occurrence between side of the body (p = 09479).

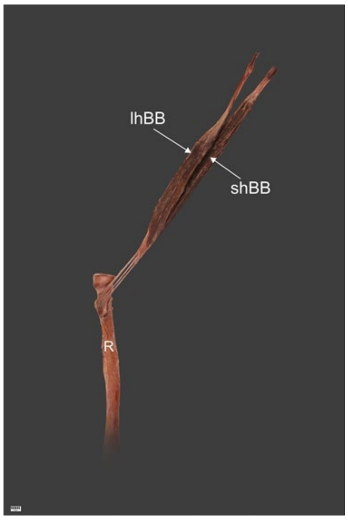

Figure 3. Type III of biceps brachii insertion; shBB — short head of the biceps brachii; lhBB — long head of the biceps brachii; R — radius bone.

Additionally, the type of LF was analysed (Fig. 4). In 8 specimens it was absent (10%; 8 females, 0 males, $p = 0.2686$; 4 right and 4 left; in 2 specimens with type II insertion and 6 specimens with type III, $p = 0.0001$).

Comparison of morphological data between genders and side of the body is presented in Table 1. Table 2 demonstrates data on insertion types.

According to a post-hoc analysis, the length of tendon I in type I and III is almost equal and its higher than in type II, while tendon I width was greater in type I than in types II and III.

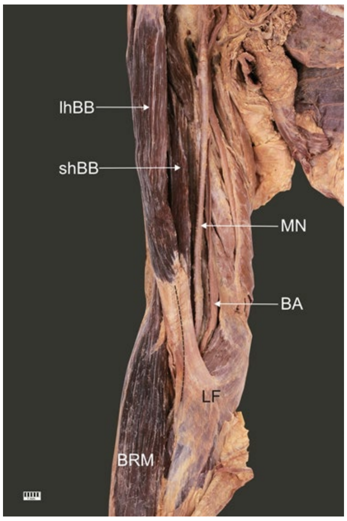

Figure 4. Lacertus fibrosus; ihBB — long head of the biceps brachii; shBB — short head of the biceps brachii; MN — median nerve; BA — brachial artery; BRM — brachioradialis muscle; LF — lacertus fibrosus.

DISCUSSION

The BB muscle probably arises from a common premuscle mass with coraccbrachialis, and brachialis. All three muscles in very early stages are intimately fused together. The origins of the long and short head of the BB at this early prenatal life are close to each other, and later growth of the scapula will separate them. The distal insertion of the common muscle mass varies at the later time than the proximal [6, 7].

In most cases the distal BB tendon is described as easily divided into two components; an anterior layer linked to the short head, and a posterior layer linked to the long head [7].

The key value of the work is presentation of a new systematic classification of the distal BB insertion based on anatomical dissection. It should be emphasized that this is the first classification of this type that is necessary for orthopaedists and surgeons operating in this area. It can also be useful for physiotherapists when planning rehabilitation procedures and radiologist for imaging analysis [6, 7].

Many studies are focused on the measurement of the tendon and lacertus fibrosus [11, 40]. Eames et al. [13] and also Snoeck et al. [40] observed that LF superficial layer was present in all tested limbs. In the present study, the absence of LF superficial layer was observed in 10%.

In the present study, we have noticed that LF originates both from the long and short head of BB, extends over the pronator teres and connects to the fascia of the forearm, as described earlier by other researchers [3, 6, 7, 40]. The finding that the short and long head in the myotendinous junction was the origin of the LFs was crucial as it identified LF as an important landmark that allows identification of the short head of the tendon and, therefore, correct orientation of the entire distal biceps' tendon during surgical repair [40].

Table 1. Morphometric parameters according to gender and side of the body

Parameter	Sex		P value	Side of the body		P value
	Females	Males		Right	Left	
Tendon I length	66.08 (12.08)	65.92 (12.30)	0.7396	66.08 (12.09)	65.93 (12.28)	0.9037
Tendon I width	7.83 (3.94)	6.04 (225)	0.0313	7.01 (3,38)	6.94 (3.36)	0.2736
Tendon I thickness	2.52 (0.65)	2.54 (0.67)	0.9539	2.54 (0.67)	2.52 (0.65)	0.8945
Tendon II length	59.92 (9.74)	55.78 (2.76)	0.0922	58.22 (7.26)	57.29 (7.29)	0.4008
Tendon II width	2.53 (0.55)	3.98 (0.58)	0.0012	3.32 (1.09)	3.27 (0.83)	0.7353
Tendon II thickness	1.78 (0.20)	2.33 (0.38)	0.0006	2.06 (0.45)	2.09 (0.40)	0.8886
Tendon III length	66.46 (3.21)			66.37 (3.59)	66.55 (3.58)	1.0000
Tendon III width	1.91 (0.30)			1.76 (0.22)	2.06 (0.33)	0.1088
Tendon III thickness	1.39 (0.12)			1.35 (0.12)	1.43 (0.11)	0.1088
Lacertus fibrosus length	38.58 (8.76)	36.83 (10.19)	0.4272	37.49 (9.63)	37.91 (9.45)	0.0218
Lacertus fibrosus width proximal	7.62 (3.98)	6.41 (3.27)	0.2281	6.93 (3.64)	7.10 (3.74)	0.3419
Lacertus fibrosus thickness proximal	1.15 (0.63)	1.11 (0.41)	0.9551	1.13 (0.53)	1.12 (0.54)	0.5043
Lacertus fibrosus width distal	12.39 (6.80)	12.26 (10.05)	0.3054	12.59 (8.83)	12.07 (8.32)	0.9249
Lacertus fibrosus thickness distal	1.67 (0.70)	1.58 (0.40)	0.7269	1.60 (0.55)	1.64 (0.60)	0.3339

Table 2. Morphometric parameters according to insertion types

Parameter	Insertion types			P value
	I	II	III	
Tendon I length	68.76 (11.72)	51.83 (5.30)	63.09 (3.27)	0.0001
Tendon I width	7.93 (3.10)	3.91 (1.24)	2.60 (0.10)	0.0001
Tendon I thickness	2.62 (0.65)	2.23 (0.72)	2.09 (0.12)	0.001
Tendon II length		53.77 (5.12)	65.00 (3.04)	0.0011
Tendon II width		3.87 (0.58)	2.24 (0.19)	0.0011
Tendon II thickness		2.18 (0.48)	1.87 (0.10)	0.0392
Tendon III length			66.46 (3.21)	
Tendon III width			1.91 (0.30)	
Tendon III thickness			1.39 (0.12)	
Lacertus fibrosus length	39.07 (9.05)	28.09 (6.61)		0.0003
Lacertus fibrosus width proximal	7.17 (3.88)	5.96 (1.16)		0.8782
Lacertus fibrosus thickness proximal	1.13 (0.56)	1.13 (0.15)		0.7143
Lacertus fibrosus width distal	12.90 (8.91)	8.33 (2.97)		0.3852
Lacertus fibrosus thickness distal	1.60 (0.57)	1.79 (0.55)		0.4641

Athwal et al. [2] describe that the short head of biceps brachii is the starting point of LF. On the other hand, Dirim et al. [12] describe formation of the LF by combining superficial tendon-type fibres arising from both heads of the biceps muscle of the arm. In presented research LF was described same as Dirim did.

The most thorough examination was carried out by Eames et al. [13] who pointed out that LF is formed by the combination of three layers. The long head from its radial side forms the first and thickest layer. The second layer is the middle layer. It is formed by the combination of aponeurosis and a short head. It has the form of loose tissue [13]. The third layer starts as in the case of the first layer only deeper. In addition, it is strengthened by a superficial layer of aponeurosis [13].

Compare presented research to the work of Snoeck et al, the measurement of the LF length was made as a central dimension (according to the manuscript of Snoeck et al. [40]) and it appear no significant statistical differences. Lacertus fibrosus did not show significant variations related to gender, Same result occurred in research of Forthman et al. [16].

Unfortunately width and thickness are unable to be compared. Measuring equipment and measurement procedures may have differed between studies. Most research on the distal part of the BB is limited to performing narrowed morphometric measurements of the tendon as well as describing the LF and the relationship between the BB and LF tendons [8, 11, 13, 21, 26].

Athwal et al. [2] described that it is possible to "separate" the tendon fibres belonging to the short or long head of BB. They specified two attachment sites on the radial tuberosity of the radius. The superior aspect is occupied by the long head of BB and the inferior aspect is occupied by the short head of BB [2]. Also Forthman et al. [16] examined radial tuberosity for the extent of insertion of biceps brachii. The biceps tendon footprint lies over the apex of the tuberosity, with the geometric centre of the tendon inserting in less pronation [2].

Unlike Athwal et al. [2], we did not observe the possibility of "separating" tendons from each other. We strongly believe that the division into the superior and inferior aspect of insertion of the short and long head of BB is not exceptionally reliable, due to the fact that subsequent tests should be based on the possibility of checking the distal attachment, e.g. for BB with three, four and e.g. five heads.

In the present study we observed three types of BB tendon insertions. Therefore we proposed a 3-folded classification. Type I is characterised by a single tendon and occurred most frequently (in 78.75%) in the examined limbs. This type was commonly described by many other researchers [2, 5, 6, 12]. The second most common type is type II which was characterised by a double tendon and was observed in 13.75% of all the limbs. Also this type was already mentioned in other researches [23, 25]. The last and rarest one was type III which was characterised by three tendons and occurred in 7.5% of the examined limbs. Apart from the information about its rare occurrence, no one has described this type before.

Additionally, the type of LF was analysed. Therefore, it may be deduced that type III BB insertion tendon predisposes to LF deficiency. No one ever before described such comparison. Statistical differences were also observed in the study, e.g. the length of tendon I in type I and III is almost equal and its higher than in type II, while tendon I width was greater in type I than in types II and III. Thus, it can be speculated that type I BB tendon insertions are least likely to be affected by rupture or fiberisation as compared to types II and III.

Knowledge of the anatomical variant of BB insertion will allow for a more accurate diagnostic examination of the case [11–13, 27]. Such as:

- tendon rapture (can be complete or partial);
- disinsertion of the tendon (tendon detachment from its insertion may be partial or complete);
- tendinopathy (it causes loss of the fibrillar aspect of the tendon, the structure of which appears disorganised and accompanied by diffuse, heterogeneous thickening);
- enthesopathy (associated with hypoechoic swelling that involves one or all of the tendons that) insert on the radial tuberosity;
- bursitis (distention and inflammation of the tendon bursa, which allows the tendon to roll around radial tuberosity);
- peritendinopathy (chronic pain have tendon sheath effusions that are not associated with tendon anomalies).

Unfortunately, we do not have information about side of limb domination, it would be interesting comparison. However, an anatomical comparison of left to right also seems valid. We assume in advance that men exhibit a greater muscle mass of the BB muscle, so it is interesting which type will be dominant depending on gender. It could be assumed that it will be the most durable type.

Women have naturally smaller muscle tissue, so it can be assumed that the muscle naturally causes less stress on the insertion, so a softer (weaker) attachment is enough for effective work. So it appears that type III is the weakest among those three.

An important piece of information for better planning of surgical procedures for repairing the raptures of the distal attachment of the BB tendon is knowledge of its size and location. Skilfully idling the course and orientation of this attachment will support surgeons in determining the size of the partial tear in the thickness of this tendon and indicating the associated muscles. Nowadays, surgical procedures to repair the detachment of the biceps tendon are performed on a daily basis. Tendon fracture repair procedures are performed using the technique of one incision (usually suture anchors are used here) or the technique of two cuts [42, 43].

Broken tendons are subject to several treatment techniques: one cut technique (use of seam anchors), two-cut technique (using bone tunnels), biotendinosis screw for fixation and endobuttons [4, 9, 10, 18, 28, 42, 43]. Different methods of double incision (standard and modified) are characterised by a different dimension of showing the ulnar periosteum. The Morrey technique (muscle splitting technique) reduces the possibility of synostosis [14, 37]. It turned out that against the induction of nerve palsy (radial or lateral antebrachial cutaneous nerve) nor the heterotopic ossification does not protect the anterior small incision of the cubital fossa with the execution of muscle splitting technique [43].

Limitations of the study

Our research is not without its limitations. In the first place, it would be necessary to indicate the non-uniform nature of the classification, which is influenced by morphological details, such as shape or surface of the insertion. In the second place, we should mention that as the results of anatomical research we are able to present a jumble of inconsistencies and the continuation of this work should be studies checking the probable value of using ultrasound and magnetic resonance imaging to image and map the area that has been studied in our work. Performing a biomechanical test of each type of tendon would allow to confirm the indication of which of the types is stronger and whether the differences in the range of morphometric measurements are significant. The study also lacked indications of tendon belonging to muscle heads in type 2 and type 3. Another weakness of these studies is the failure to assess the deep LF layers. Despite the indicated limitations, this work brings with it knowledge that allows for a more accurate definition of search in this area of research/treatment. It also indicates a uniform classification and nomenclature, helping in the work of future researchers or surgeons moving in this region.

CONCLUSIONS

The BB tendon is characterised by high morphological and topographical variability. Its insertion can be affected by different types of lesions, some of which are frequently misdiagnosed on the basis of the clinical examination. Therefore it seems very important to develop the new BB insertion classification. It proposes three types of distal attachment (I–III). Additionally, an equally important piece of information is lack of lacertus fibrosus in presence of type III BB tendon.

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