Characterization of the Proximal Long Head of Biceps Tendon Anatomy Using Magnetic Resonance Imaging

Implications for Biceps Tenodesis

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Background: Biceps tenodesis is a common treatment for proximal long head of biceps (LHB) tendon pathology. To maintain biceps strength and contour and minimize cramping, restoration of muscle-length tension and appropriate positioning of the tenodesis is key. Little is known about the biceps musculotendinous junction (MTJ) anatomy, especially in relation to the overlying pectoralis major tendon (PMT), which is a commonly used landmark for tenodesis positioning.

Purpose: To characterize the in vivo topographic anatomy of the LHB tendon, in particular the MTJ relative to the PMT, using a novel axial proton-density magnetic resonance imaging (MRI) sequence.

Study Design: Descriptive laboratory study.

Methods: In total, 45 patients having a shoulder MRI for symptoms unrelated to their biceps tendon or rotator cuff were prospectively recruited. There were 33 men and 12 women, with a mean age of 37 ± 13 years (range, 18-59 years). All patients underwent routine shoulder MRI scans with an additional axial proton density sequence examining the LHB tendon and its MTJ. Three independent observers reviewed each MRI scan, and measurements were obtained for (1) MTJ length, (2) the distance between the proximal MTJ and the superior border of the PMT (MTJ-S), (3) the distance between the distal MTJ to the inferior border of the PMT, and (4) the width of the PMT.

Results: The average position of the MTJ-S was 5.9 ± 10.8 mm distal to the superior border of the PMT. The mean MTJ length was 32.5 ± 8.3 mm and the width of the PMT was 28.0 ± 7.3 mm. We found no significant correlation between patient age, height, sex, or body mass index and any of the biceps measurements. We observed wide variability of the MTJ-S position and identified 3 distinct types of biceps MTJ: type 1, MTJ-S above the PMT; type 2, MTJ-S between 0 and 10 mm below the superior border of the PMT; and type 3, MTJ-S >10 mm distal to the superior PMT.

Conclusion: In this study, the in vivo anatomy of the LHB tendon is characterized relative to the PMT using a novel MRI sequence. The results demonstrate wide variability in the position of the MTJ relative to the PMT, which can be classified into 3 distinct subtypes or zones relative to the superior border of the PMT. Understanding this potentially allows for accurate and anatomic placement of the biceps tendon for tenodesis.

Clinical Relevance: To our knowledge, this is the first study to radiologically analyze the in vivo topographic anatomy of the LHB tendon and its MTJ. The results of this study provide more detailed understanding of the variability of the biceps MTJ, thus allowing for more accurate placement of the biceps tendon during tenodesis.

Keywords: long head of biceps tendon; biceps tenodesis; musculotendinous junction; anatomy; MRI

Proximal long head of biceps (LHB) tendon pathology is a common cause of anterior shoulder pain and dysfunction.[5,17] Although disease of the LHB can occur in isolation, it is frequently associated with concomitant shoulder pathologies, such as impingement syndrome, rotator cuff tears, and superior labral anterior-posterior lesions.[18] Disease along the length of the LHB tendon can extend from the superior labral insertion to the intra-articular portion and distally to the extra-articular tendon along the bicipital groove and ultimately to the musculotendinous junction (MTJ). Common

The American Journal of Sports Medicine
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DOI: 10.1177/0363546520976630

causes include superior labral anterior-posterior tears, biceps tendinopathy, partial tears, and instability.[18]

Currently, there is no consensus as to the preferred method of treatment for LHB pathology, with both biceps tenotomy and tenodesis being widely used and neither demonstrating clear superiority.[1,12,15] Despite multiple studies comparing the pros and cons of tenotomy versus tenodesis, numerous comparative studies have shown no significant difference in overall functional outcomes or in elbow flexion or supination strength.[1,12,15] However, almost universally, biceps tenotomy is associated with the development of a "Popeye" sign and a cosmetic deformity.[1,12,15] While this may not be of any relevance to a certain subset of the population, such as those who are elderly, obese, and sedentary, there is certainly a proportion of patients who, if given the option, would prefer a biceps tenodesis over a tenotomy to avoid the aforementioned cosmetic deformity and the potential for weakness and cramping.[4] In theory, tenodesis aims to maintain the length-tension relationship of the biceps muscle and therefore potentially minimize muscle wasting and deformity.[5,20]

For biceps tenodesis, an arthroscopic, arthroscopically assisted, or open approach can be performed, and reattachment may be in the suprapectoral or subpectoral region or to the conjoint tendon.[14,16,19,22] Nevertheless, the principle of biceps tenodesis is to excise the diseased portion of the tendon, obtain secure fixation to the humerus along the bicipital groove, and maintain the overall biceps muscle-length tension. Theoretically, undertensioning may cause deformity, fatigue, and cramping pain, whereas overtensioning may contribute to fixation failure and muscular pain.[13,21] In the literature, various tenodesis techniques that attempt to accurately reproduce the native biceps tendon length have been described.[2,3,7,9] However, the large majority of these studies have been performed in cadaveric specimens, and none of them take into consideration the wide variation in anatomy among individuals.

To date, relatively little is known of the topographic anatomy of the LHB tendon, in particular the MTJ and its relationship to the overlying pectoralis major tendon (PMT), which are the most commonly used landmarks for guiding tenodesis position. While previous cadaveric studies have endeavored to characterize this region, the precise location to place the tenodesis and therefore maintain native biceps length in each patient is still debated.[7-9]

Thus, the aim of this study was to perform an in vivo characterization of the LHB tendon and its MTJ relative to the superior and inferior borders of the PMT (sPMT and iPMT, respectively) using a novel magnetic resonance imaging (MRI) scan sequence. We hypothesized that there would be significant variability among individuals in terms of the length of the MTJ (MTJL) and its relationship to the PMT. The abbreviations used this article are defined in Table 1.

TABLE 1
Abbreviations Used in this Article

Abbreviation	Definition
LHB	Long head of biceps
MRI	Magnetic resonance imaging
MTJ	Musculotendinous junction
pMTJ	Proximal aspect of the musculotendinous junction
MTJ-S	Distance between the proximal musculotendinous junction and the superior border of the pectoralis major tendon
MTJ-I	Distance between the distal musculotendinous junction and the inferior border of the pectoralis major tendon
MTJL	Length of the musculotendinous junction
PD	Proton density
PMT	Pectoralis major tendon
iPMT	Inferior border of the pectoralis major tendon
sPMT	Superior border of the pectoralis major tendon
CoV	Coefficient of variability

METHODS

Patients

Patients were recruited in a prospective fashion between April 2018 and September 2018 as they were evaluated in our radiology department using an MRI scan of their shoulder. Patients were included if they were between the ages of 18 and 60 years and their indication for an MRI scan was for determination of shoulder pain or instability. Patients were excluded if they had had previous surgery or substantial trauma to their shoulder, known or suspected proximal biceps tendon pathology, the presence of degenerative changes in the glenohumeral joint, or a rotator cuff tear. Patients were also excluded if they could not place their arm in a standard position for the MRI scan or if there was any obvious patient motion artifact that prevented accurate evaluation. A total of 45 patients were enrolled in this study, with 33 (73%) men and 12 (27%) women. The mean age was 37 ± 13 years (range, 18-59 years). Human ethics/institutional review

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Submitted April 28, 2020; accepted September 1, 2020.
The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

board approval (Avenue Hospital, Ramsay Health HREC, Trial 216) was obtained before commencement of this study, and informed consent was obtained from each patient.

MRI Scan Protocol and Evaluation

Patients were positioned in the MRI scanner in the supine position with the upper extremity by their side, the elbow fully extended, and the forearm placed in neutral rotation. All MRI scans were undertaken using a Siemens 3 Tesla MAGNETOM Vida scanner. Routine sequences of the shoulder were performed using a dedicated shoulder coil. To specifically study the LHB tendon and, in particular, the MTJ and its relationship to the PMT, a novel axial proton-density (PD) sequence was developed. The sequence parameters were as follows: field of view, 180 mm $\times$ 180 mm; matrix, 320 $\times$ 320; TR (repetition time) 4943 milliseconds; and TE (time to echo) 30 milliseconds. The slice thickness was a 2 mm with a 0.2-mm gap between slices. Measurements of the LHB were obtained from this novel axial PD sequence. Specific structures that were identified for analysis on the MRI scan were as follows (Figure 1):

1. sPMT
2. iPMT
3. Proximal aspect of the MTJ (pMTJ)
4. Distal aspect of the MTJ

Three independent observers (A.D.W., A.H.R., E.T.E.) reviewed the axial PD slices of each of the shoulder MRI scans. All reviewers were blinded to the patients' clinical data. One observer was an experienced musculoskeletal radiologist (A.H.R.), 1 was a fellowship-trained shoulder surgeon (E.T.E.), and 1 was a final-year medical student (A.D.W.). Four specific measurements were calculated based on the distance between the axial slices of the above structures (Figure 2):

1. MTJL
2. Width of the PMT
3. Distance between the proximal MTJ and the sPMT (MTJ-S)
4. Distance between the distal MTJ and the iPMT (MTJ-I)

For the MTJ-S calculation, if the pMTJ was proximal to the sPMT, it was given a positive integer. If it was distal to the sPMT, it was given a negative integer. Similarly, for the MTJ-I, if the distal aspect of the MTJ was either distal or proximal to the iPMT, it was denoted as either positive or negative, respectively. If there were any large discrepancies in the measurements among the reviewers, these were re-examined until a consensus result was obtained.

Statistical Methods

Statistical analysis was performed using SPSS Version 20.0 (IBM Corp). Data were described by means, SDs, and ranges. One-way analysis of variance for parametric data and Mann-Whitney testing for nonparametric data were performed to analyze differences among between groups. To determine the correlation between patient variables and measurement, Pearson correlation coefficient analysis was used. $P < .05$ was deemed statistically significant. The coefficient of variability (CoV) was calculated to determine how variable each measurement was around its mean value. The CoV is defined as the ratio of the SD to the absolute value of the mean and expressed as a percentage: CoV = 100 $\times$ SD/mean. The higher the CoV, the greater the variation around the mean.

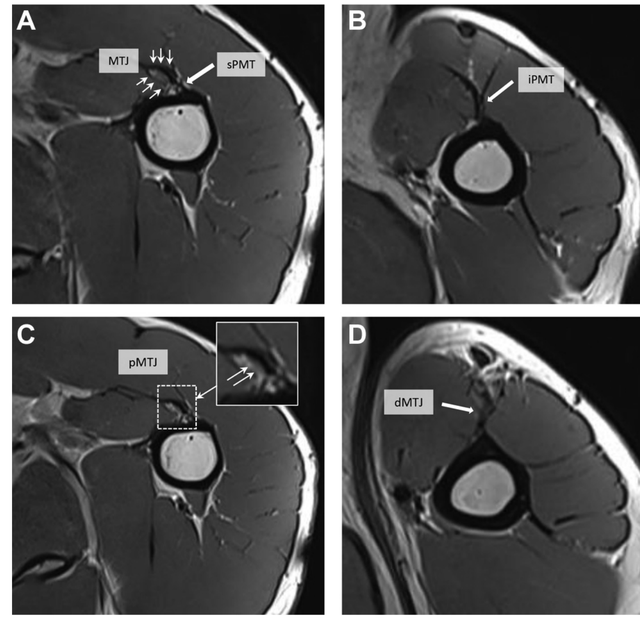

Figure 1. MRI scans of the left shoulder demonstrating the images obtained from the additional axial proton density sequence of the LHB. (A) Identification of the sPMT (thick arrow). The MTJ is identified adjacent to the sPMT, with both the muscle and the tendon of the LHB in view (fine arrows). (B) The iPMT is identified (arrow). (C) The pMTJ is identified as the most proximal slice where the MTJ muscle appears (arrows). (D) The dMTJ is identified as the slice where the LHB tendon disappears and only muscle is seen (arrow). dMTJ, distal aspect of the musculotendinous junction; iPMT, inferior border of the pectoralis major tendon; LHB, long head of biceps tendon; MTJ, musculotendinous juntion; pMTJ, proximal aspect of the musculotendinous junction; sPMT, superior border of the pectoralis major tendon.

RESULTS

The mean MTJL was 32.5 $\pm$ 8.3 mm (range, 15.3-55.7 mm). The average distance of the MTJ-S, which was measured as the most pMTJ to the sPMT, was -5.9 ± 10.8 mm (range, -37.4 to 15.4 mm). The average distance of the MTJ-I, which was from the most distal aspect of the MTJ to the iPMT, was 12.5 $\pm$ 10.5 mm (range, -11.0 to 47.1 mm). The mean width of the PMT was 28.0 $\pm$ 7.3 mm (range, 7.3-41.8 mm). These results are depicted in the schematic in Figure 3 and in Table 2.

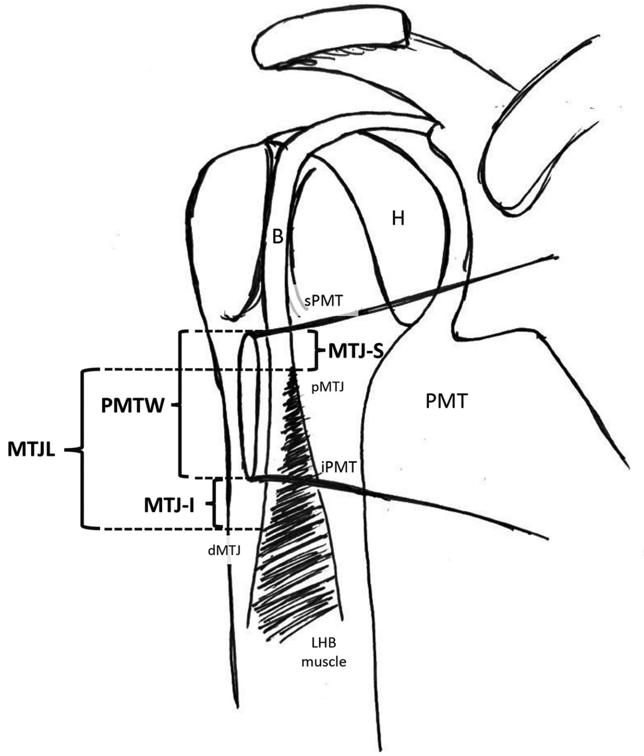

Figure 2. Schematic diagram demonstrating the proximal LHB tendon and its relationship to the PMT and the measurements taken. B, long head of biceps tendon; dMTJ, distal aspect of the musculotendinous junction; H, humeral head. iPMT, inferior border of the pectoralis major tendon; LHB, long head of biceps; MTJ-I, distance between the distal musculotendinous junction and the inferior border of the pectoralis major tendon; MTJL, length of the musculotendinous junction; MTJ-S, distance between the proximal musculotendinous junction and the superior border of the pectoralis major tendon; PMT, pectoralis major tendon; pMTJ, proximal aspect of the musculotendinous junction; PMTW, width of the pectoralis major tendon; sPMT, superior border of the pectoralis major tendon.

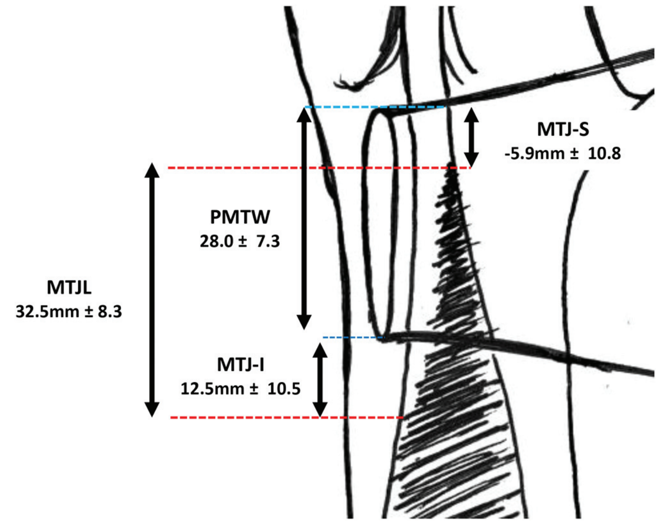

Figure 3. Schematic diagram summarizing the results of the measurements obtained. Measurement made in millimeters (mm). MTJ-I, distance between the distal musculotendinous junction and the inferior border of the pectoralis major tendon; MTJL, length of the musculotendinous junction; MTJ-S, distance between the proximal musculotendinous junction and the superior border of the pectoralis major tendon; PMTW, width of the pectoralis major tendon.

TABLE 2
Mean Values of Musculotendinous Junction Measurements According to Patient Age, Sex, and BMI[a]

	MTJL	MTJ-S	MTJ-I
All patients (n = 45)	32.5 ± 8.3	–5.9 ± 10.8	12.5 ± 10.5
Age <45 y (n = 30)	33.1 ± 9.0	–4.2 ± 9.8	11.9 ± 10.6
Age ≥45 y (n = 15)	31.2 ± 6.8	–9.2 ± 12.1	13.6 ± 10.4
Male (n = 33)	31.7 ± 8.4	–7.0 ± 11.1	12.6 ± 10.5
Female (n = 12)	34.6 ± 8.2	–2.9 ± 9.5	12.2 ± 10.9
BMI <25 (n = 24)	34.2 ± 10.3	–7.6 ± 21.8	13.8 ± 12.6
BMI ≥25 (n = 21)	31.8 ± 12.4	–2.0 ± 6.6	17.0 ± 16.5

[a]Data are presented as mean ± SD. Measurements in millimeters (mm). No significant difference was observed between any of the subcategories (Mann-Whitney *U* test). BMI, body mass index; MTJ-I, distance between the distal musculotendinous junction and the inferior border of the pectoralis major tendon; MTJL, length of the musculotendinous junction; MTJ-S, distance between the proximal musculotendinous junction and the superior border of the pectoralis major tendon.

The CoV, which determined how variable each measurement was around its mean value, MTJL was 25.5%; MTJ-S was 183%; and MTJ-I was 84%. From these results, we found that there was most variability in the value for the MTJ-S, that is, the position of the pMTJ. On further analysis of the data, we were able to classify the types of biceps MTJ anatomy based on the position of the pMTJ relative to the sPMT (MTJ-S) (Figure 4).

Type 1: At or above the sPMT
Type 2: Between 0 and 10 mm distal to the sPMT
Type 3: >10 mm distal to the sPMT

In our series, 15 patients each were in 1 of these 3 categories. The mean MTJ-S for patients in the type 1 group was + 4.1 ± 5.1 mm (range, 0-15.4 mm); the type 2 group, −4.7 ± 3.2 mm (range, −0.1 to −9.5 mm); and the type 3 group, −18.1 ± 8.6 (range, −11.0 to −37.4). We found that there was a significant difference between the groups in terms of the MTJL, with the type 1 group having a greater MTJL, followed by the type 2 and then type 3 groups (40.7 ± 8.1 vs 29.5 ± 4.7 vs 27.0 ± 5.6; $P < .00001$) (Table 3).

With respect to patient age, we found no significant difference in any of the measurements for patients younger than or older than 45 years. Furthermore, no significant difference was seen between men and women or with respect to body mass index (>25 or <25) or hand dominance (Table 2). There was poor correlation between age and the MTJL and

TABLE 3
Classification of the MTJ-S Position Into 3 Types[a]

	Type 1 (n = 15)	Type 2 (n = 15)	Type 3 (n = 15)	*P* Value
MTJ-S	+4.1 ± 5.1	−4.7 ± 3.2	−18.1 ± 8.6	
MTJ-I	10.6 ± 9.8	8.6 ± 5.2	16.2 ± 10.4	
MTJL	40.7 ± 8.1	29.5 ± 4.7	27.0 ± 5.6	.00001

[a]Data are presented as mean ± SD. Measurements in millimeters (mm). Statistical significance is observed in the MTJLs between the different types (1-way analysis of variance). Type 1, at or above the sPMT; type 2, between 0 and 10 mm below the sPMT; type 3, >10 mm distal to the sPMT. MTJ-I, distance between the distal musculotendinous junction and the inferior border of the pectoralis major tendon; MTJL, musculotendinous junction length; MTJ-S, distance between the proximal musculotendinous junction and the superior border of the pectoralis major tendon; sPMT, superior border of the pectoralis major tendon.

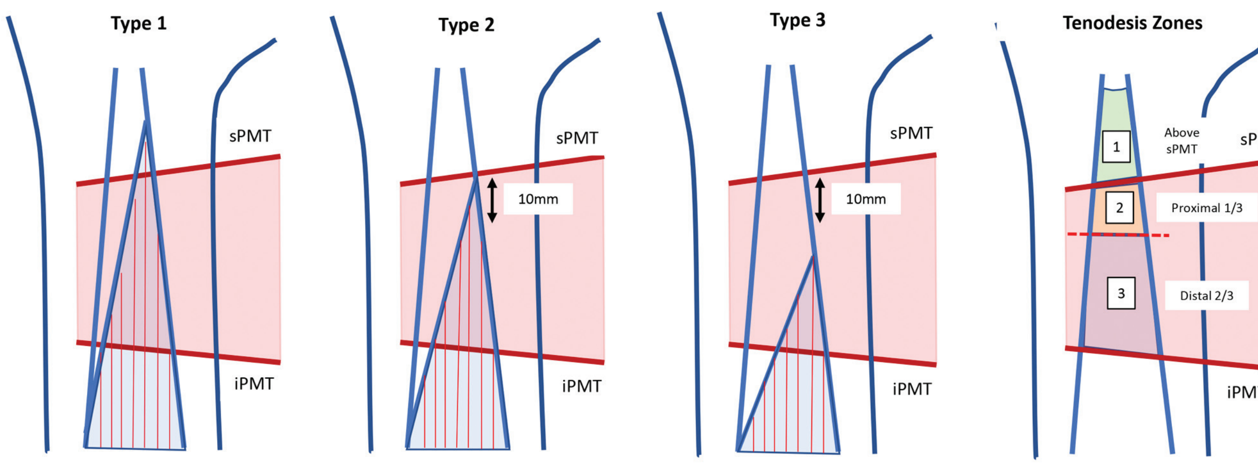

Figure 4. Schematic diagram depicting the 3 types of pMTJ positions observed and the tenodesis zones. Type 1, at or above the sPMT; type 2, between 0 and 10 mm distal to the sPMT; type 3, >10 mm distal to the sPMT. Zone 1, above the sPMT; zone 2, proximal one-third of the PMT; zone 3, distal two-thirds of the PMT. PMT, pectoralis major tendon; pMTJ, proximal border of the pectoralis major tendon; sPMT, superior border of the pectoralis major tendon.

TABLE 4
Correlation Between Age and Height With MTJL and MTJ-S[a]

	MTJL		MTJ-S	
	Correlation (*r*)	*P* Value	Correlation (*r*)	*P* Value
Patient age	−0.209	.276	−0.332	.078
Patient height	−0.0531	.78	−0.2421	.206

[a]No significant difference was observed between any of the subcategories (Pearson correlation coefficient). MTJL, musculotendinous junction length; MTJ-S, distance between the proximal musculotendinous junction and the superior border of the pectoralis major tendon.

pMTJ measurements ($r = -0.209$; $P = .276$ and $r = -0.332$; $P = .078$, respectively). No significant correlation was found between patient height and the MTJL and pMTJ measurements ($r = -0.0531$; $P = .78$ and $r = -0.2421$; $P = .206$, respectively) (Table 4).

DISCUSSION

In our present study, the aim was to characterize the in vivo anatomy of the MTJ of the LHB tendon using a novel PD MRI sequence. While previous cadaveric studies have examined this area in detail, we believed that an in vivo study would be more representative of the normal population of patients who would be evaluated for the treatment of shoulder pathology with respect to age, sex, hand dominance, height, and body mass index. The inherent limitations of using cadaveric specimens are that they are often of elderly subjects and the sample size is frequently limited. Furthermore, the natural tension of the biceps muscle and the LHB tendon is potentially altered. This invariably may affect the determinations of various measurements of the longitudinal anatomy of the LHB. Hussain et al[7] examined 43 embalmed shoulder specimens and stated that one of their limitations was that the potential "chemical preservation and desiccation of the samples may have led to variations not noted with fresh frozen shoulders." Nevertheless, that study, in addition to other previously conducted cadaveric studies by Denard et al[3] and Jarrett et al[8] using fresh-frozen specimens, has provided further understanding of the LHB tendon and has guided, up to this point, how to best restore biceps muscle-length tension during tenodesis.

Biceps tenodesis has been shown to provide reliable and durable results for the management of proximal LHB tendon pathologies.[18] Despite the numerous surgical techniques that have been described, no one method has demonstrated a clear advantage over the others because of the lack of level 1 or level 2 comparative studies. Since the first description of a biceps tenodesis by Gilcreest[6] in 1925, there has been substantial evolution in the technique, with wide variations having been described in the literature. Presently, biceps tenodesis can be performed either proximally or distally in the bicipital groove, with a variety of fixation methods and via open, arthroscopic, or arthroscopically assisted approaches.[14,19,20,22] Regardless of the technique, successful tenodesis relies on secure fixation of the tendon to either soft tissue or bone and maintaining, as accurately as possible, the native biceps muscle-length tension relationship. By keeping the appropriate tension, this most reliably restores the form and contour of the biceps muscle, preserves biceps strength, and minimizes the risk of fixation failure due to overtensioning or cramping from muscle shortening.[3,13]

However, to position the biceps tendon in its anatomic position after it has been tenotomized and mobilized requires understanding of the relationship of the biceps tendon and/or the MTJ to its surrounding structures. As such, several authors have advocated for subpectoral tenodesis over suprapectoral tenodesis, as this technique places the MTJ of the biceps under the PMT, where it naturally lies.[11,16,20] Therefore, in theory, this gives more control and accuracy of the placement of the tendon as compared with suprapectoral tenodesis, where the positioning along the bicipital groove can be variable.[11,16,20] Nonetheless, the exact position to place the tenodesis is still unclear, as no clinical studies that have assessed varying tenodesis positions with clinical outcomes have been performed. Previous authors have recommended placing the subpectoral tenodesis "beneath" or at the " inferior border" of the PMT.[16,20] Jarrett et al[8] demonstrated that the average distance of the MTJ of the LHB was 2.2 cm (95% CI, 1.16, 3.14) distal to the sPMT and hence suggested the tenodesis be placed more proximally, closer to the sPMT. Similar findings were reported by Kovack et al,[10] who showed in a cadaveric study that the MTJ was on average 2.38 cm distal to the sPMT.

In our study, we found that, on average, the most pMTJ (MTJ-S) was 5.9 $\pm$ 10.8 mm distal to the sPMT (Figure 3). This contrasts with the findings of Jarrett et al,[8] Denard et al,[3] Kovack et al,[10] and Hussain et al,[7] who reported that the pMTJ was on average 22.0 mm, 24.5 mm, 23.8 mm, and 57 mm distal to the sPMT. This may be explained by the mean age of the patients included in each of the studies. In our study, the mean age of the patients was 37.3 years, whereas in the previously performed cadaveric studies, the average age ranged from 57 to 84 years.[3,7,8,10] One could argue that with advancing age, biceps muscle bulk invariably decreases, hence affecting the nature of the biceps MTJ and subsequently its position relative to the sPMT. As such, having a younger population in our study may explain why the MTJ was more proximal relative to that reported in previous cadaveric studies. In our study, although we did not show significant correlation between patient age and the MTJ-S, the correlation coefficient was $r = -0.332$, with a trend toward significance ($P = .078$), thus suggesting that with increasing age, the MTJ-S becomes more distal relative to the sPMT.

It has been our experience that intraoperative identification of the pMTJ is a key landmark to place the ends of the sutures that insert adjacent to the bicipital groove. An interesting finding from our study was the variation in the position of the MTJ. We were able to identify 3 distinct types of MTJ positions relative to the sPMT. This indicates that not all biceps tendons are alike, and this may be for a variety of reasons, such as overall muscle bulk or normal variation in anatomy. Nonetheless, this brings into question the "one-size-fits-all" approach to biceps tenodesis. It may be, in fact, that for optimum results, the position of the tenodesis should be varied according to the individual's anatomy. The use of an MRI scan has the benefit of preoperatively determining the patient's native biceps tendon position, which can potentially be used intraoperatively as a guide to place the tenodesis relative to the PMT. As the mean width of the PMT in our study was 28.0 $\pm$ 7.3 mm, we could divide the pMTJ position into 3 zones for tenodesis placement: zone 1, above the sPMT; zone 2, proximal one-third of the PMT (between 0 and 10 mm below the sPMT); and zone 3, distal two-thirds of the PMT (>10 mm below the PMT) (Figure 4).

There have been various techniques described to assist in maintaining the native position of the biceps tendon during tenodesis.[2,3,21] However, many of these require additional surgical steps, which may be cumbersome and do not take into consideration the changing position of the patient's arm throughout the procedure. In contrast, an MRI scan determines the relative location of the MTJ-S with the elbow fully extended and the biceps maximally stretched. Therefore, when performing the tenodesis, one can be confident that the tenodesis is not overtensioned if placed in a similar location.

One of the potential limitations of our study is that the MRI scan protocol that we developed had a slice thickness of 2 mm and a gap distance of 0.2 mm. We found that this combination provided the optimum resolution and detail to identify the necessary structures, such as the borders of the PMT and the MTJ, without excessive interference with adjacent slices (cross-talk). However, in theory, a thinner slice thickness would provide greater spatial resolution to differentiate between adjacent structures and also longitudinally allow for more accurate measurements of the structures. Another limitation of this study is the assumption that the position of the MTJ relative to the PMT is static through shoulder movements and elbow flexion and extension. In this study, we only measured the position of the biceps tendon with the shoulder in 0° of abduction and in neutral rotation and the elbow full extended. This most likely simulates the maximal excursion of the biceps tendon, and, as a result, the resting position may be more proximal as the elbow flexes. Indeed, further studies need to be performed to evaluate this.

CONCLUSION

In this study, we characterized the in vivo anatomy of the MTJ of the LHB tendon using a novel PD MRI sequence. We found that the mean position of the MTJ-S was 5.9 $\pm$ 10.8 mm distal to the sPMT, the mean MTJL was 32.5 $\pm$ 8.3 mm, and the PMT width was 28.0 $\pm$ 7.3 mm. However, our findings demonstrated that there is wide variability in the position of the MTJ relative to the PMT, which can be classified into 3 distinct subtypes or zones, relative to the sPMT. Understanding this potentially allows for more accurate and anatomic placement of the biceps tendon during tenodesis.

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