

Physiologic Long Head Biceps Tendon Excursion Throughout Shoulder Range of Motion

A Cadaveric Study

Joseph D. Lamplot,* MD, Brian E. Ward,[†] MD, Stephen J. O'Brien,[†] MD, Lawrence V. Gulotta,[†] MD, and Samuel A. Taylor,^{†‡} MD

Investigation performed at the Sports Medicine Institute, Hospital for Special Surgery, New York, New York, USA

Background: Restoration of the long head of the biceps tendon (LHBT) length-tension relationship is critical in preserving muscle strength and efficiency when performing biceps tenodesis. While static anatomic landmarks such as the inferior border of the pectoralis major may be used intraoperatively to achieve this, shoulder position may affect the excursion of the biceps tendon and represents another variable to consider.

Purpose/Hypothesis: The purpose of this study was to quantitatively evaluate the normal excursion of LHBT that occurs through a glenohumeral range of motion. We also sought to determine whether elbow position affects LHBT excursion. We hypothesized that LHBT excursion will be affected by glenohumeral flexion and extension, and elbow extension will result in increased excursion at each glenohumeral position compared with a neutral position.

Study Design: Controlled laboratory study.

Methods: A total of 10 fresh-frozen specimens underwent a standard approach for subpectoral biceps tenodesis. The LHBT was identified and tagged with a radiopaque marker within zone 3 of the bicipital tunnel. A total of 3 K-wires were then drilled into the osseous floor: one at the level of the marker in the LHBT, one at 1 cm proximal, and a third 1 cm distal. All 3 K-wires were then cut flush with the anterior humeral cortex. The specimens were next placed into 8 different positions, and the excursion of the LHBT was measured by referencing the K-wires using static fluoroscopic imaging. The results were analyzed using 1-way analysis of variance testing followed by Tukey honestly significant difference testing for pairwise comparison between each individual position and the reference position.

Results: The average total LHBT excursion was 24.4 ± 5.2 mm between the neutral shoulder position and the other shoulder positions tested. The position of the LHBT was significantly different in the reference position compared with each of the other 7 shoulder positions ($P < .001$). Additionally, the 2 positions of shoulder extension had different LHBT excursions when compared with each position of shoulder flexion ($P < .0001$). For each shoulder position tested, the position of the LHBT was not significantly different in elbow flexion compared with extension.

Conclusion: There is approximately 24 mm of LHBT excursion throughout the glenohumeral range of motion, with significantly different amounts of excursion in glenohumeral flexion and extension. Elbow position does not significantly affect LHBT excursion. Positioning the shoulder in extension during biceps tenodesis may overtension the biceps, while positioning the shoulder in flexion may undertension the biceps relative to the neutral position. Further research is needed to identify the optimal shoulder position for biceps tenodesis.

Clinical Relevance: Shoulder positioning is an important consideration in establishing a normal length-tension relationship during biceps tenodesis. When compared with flexed shoulder positions, LHBT excursion significantly differs in positions of extension and in a neutral position.

Keywords: long head of biceps tendon (LHBT); biceps tenodesis; biceps

dilemma.² Tenodesis of the LHBT is a common procedure to address refractory BLC symptoms, including LHBT instability, biceps tendinopathy or tearing, and SLAP tears in some patients, with over 44,000 procedures performed annually and an increasing number of tenodeses performed each year.^{11,14} Recently, indications for this procedure have expanded to include the treatment of SLAP tears and extra-articular bicipital tunnel disease.^{1,6} The bicipital tunnel contains 3 zones and extends from the articular margin of the humeral head to the subpectoral region.¹¹ The goals of biceps tenodesis are to improve shoulder pain and function resulting from BLC disease while minimizing morbidity and maintaining cosmesis. Surgical treatment of BLC disease that extends into the extra-articular bicipital tunnel requires a bicipital tunnel-decompressing tenodesis technique, such as the commonly performed subpectoral biceps tenodesis or subdeltoid transfer of the LHBT to the conjoint tendon.^{10,12,13} An important consideration when performing biceps tenodesis is the restoration and maintenance of the LHBT length-tension relationship, as this is critical in preserving muscle strength and efficiency.⁸ Failure to reestablish this anatomic tensioning may result in cramping, fatigue, and cosmetic (Popeye) deformity of the arm.⁹ Previous studies^{1,10,12} have described various techniques and outcomes of arthroscopic and open biceps tenodesis. While 1 study⁵ reported that static anatomic landmarks alone, such as the inferior border of the pectoralis tendon, may be used intraoperatively to restore an anatomic length-tension relationship, it is likely that shoulder position affects the excursion of the biceps tendon and may represent another variable to consider when attempting to restore this anatomic length-tension relationship. As no study has investigated the physiologic excursion of the LHBT throughout a normal shoulder range of motion, the purpose of this study was to quantitatively evaluate the normal excursion of the LHBT that occurs through a glenohumeral range of motion and the effects of elbow position on LHBT excursion. We also sought to determine whether elbow position affects LHBT excursion. We hypothesized that LHBT excursion would be affected by glenohumeral flexion and extension, and elbow extension would result in increased excursion at each glenohumeral position.

METHODS

The study was approved by the Hospital for Special Surgery Institutional Review Board. A total of 10 fresh-frozen forequarter specimens with no known history of shoulder

pathology or surgery and no evidence of prior surgery or abnormalities on inspection were acquired from a national tissue bank. Arthroscopy was first performed on each specimen to confirm an intact LHBT, superior labrum, biceps anchor, and rotator cuff. A 10-cm incision was made from the axilla extending down the anterior upper arm. Deep dissection remained the same as a standard subpectoral biceps tenodesis approach, leaving the pectoralis major and latissimus dorsi tendons fully intact. Blunt dissection was performed through the subcutaneous tissue, and the inferior edge of the pectoralis tendon was identified. The LHBT was identified immediately deep to the pectoralis tendon. A circular radiopaque marker was attached to the LHBT at the anterior musculotendinous junction using a suture. Next, with the shoulder in 0° of abduction and 0° of forward flexion with the elbow flexed to 90°, three 0.062 K-wires were then drilled into the bicipital tunnel osseous floor: one at the level of the marker in the LHBT, one at 1 cm proximal, and a third 1 cm distal. A caliper was used to measure and confirm the distances between the wires. The K-wires were then cut flush with the anterior humeral cortex, taking care to retract and avoid injury to soft tissues during K-wire insertion and cutting (Figure 1).

The specimens were then brought into 4 different shoulder positions: 30° of extension, 0° of forward flexion (neutral), 45° of forward flexion, and 90° of forward flexion. Each of these shoulder positions was evaluated both with the elbow flexed to 90° and with the elbow in full extension, except for the neutral position, where a measurement was made with the elbow flexed to 90° only. A fifth shoulder position was performed in 90° of forward flexion and 45° of abduction, with the elbow flexed to 90°. Therefore, a total of 8 upper extremity positions were tested. These positions were selected because they allowed us to assess a wide range of shoulder and elbow motion while also representing specific positions that the shoulder may be placed in when performing a biceps tenodesis procedure. An anteroposterior radiograph of the upper humerus was taken with each specimen in each position (Figure 2).

For each position, the excursion of the biceps tendon was measured and recorded using a digital radiographic ruler within the picture archiving and communication system of our institution (Sectra). For each specimen, the location of the radiopaque marker with the shoulder in neutral flexion and the elbow flexed to 90° was used as a reference position from which all other measurements were made. To determine LHBT excursion in each shoulder position tested, the distance between the existing anatomic landmark (biceps musculotendinous junction) and K-wire was measured and

†Address correspondence to Samuel A. Taylor, MD, 535 E. 70th Street, New York, New York 10021, USA (email: taylors@hss.edu).

*Emory University, Department of Orthopaedics, Atlanta, Georgia, USA.

‡Sports Medicine Institute, Hospital for Special Surgery, New York, New York, USA.

Final revision submitted April 14, 2020; accepted April 27, 2020.

One or more of the authors has declared the following potential conflict of interest or source of funding: J.D.L. has received educational support from Elite Orthopedics. B.E.W. has received educational support from Smith & Nephew. S.J.O. has received speaking fees from Smith & Nephew and hospitality payments from Exactech. L.V.G. has received consulting fees from Exactech and Zimmer Biomet and hospitality payments from Smith & Nephew; and has stock/stock options in Responsive Arthroscopy. S.A.T. has received educational support from Arthrex and Smith & Nephew, consulting fees from DePuy, honoraria from Encore Medical, and hospitality payments from Exactech. 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.

Ethical approval for this study was obtained from the Hospital for Special Surgery (study No. 2016-0071-CR4).

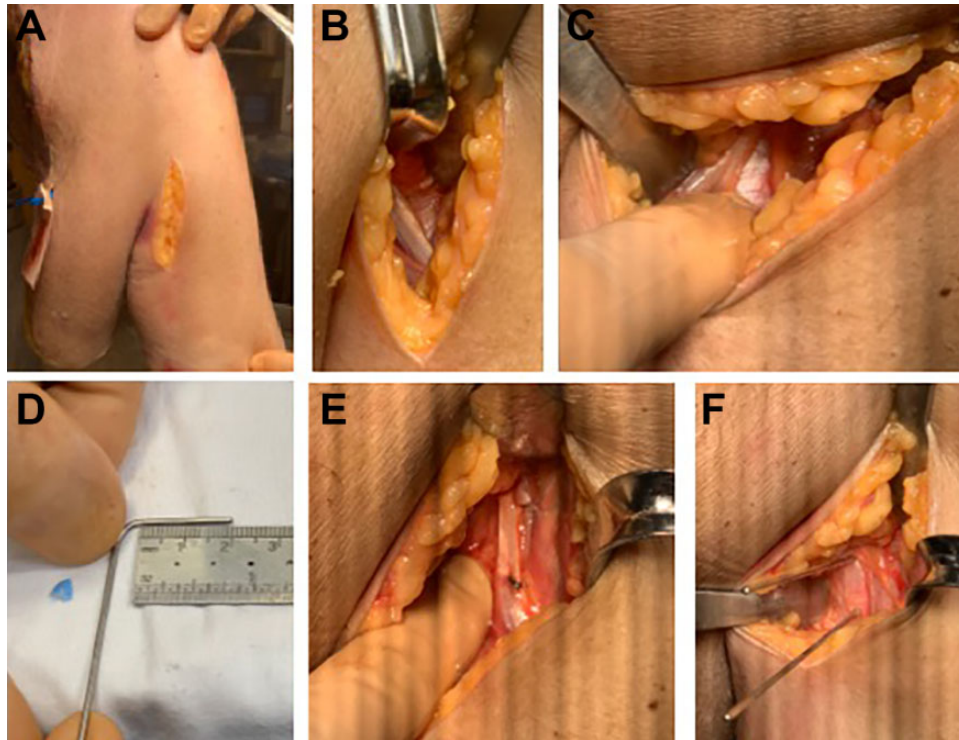


Figure 1. Specimen preparation. (A) Incision made from the axilla down the anterior upper arm. (B) Deep dissection with superior retraction of intact pectoralis major demonstrates the LHBt within the bicipital groove. (C) LHBt retracted medially to visualize the floor of the bicipital groove for placement radiopaque marker and K-wires. (D) A K-wire was bent such that it measured 2 cm in length from its end to the bend; this was used to place 3 K-wires at 1 cm apart from one another. The distance between each was verified after K-wire placement. (E) A radiographic marker secured at the biceps musculotendinous junction using a suture. (F) Two K-wires are visualized within the bicipital groove before being cut flush to the anterior cortex of the humerus. LHBt, long head of the biceps tendon.



Figure 2. Fluoroscopic image demonstrating 3 K-wires and circular radiopaque marker sutured to biceps tendon.

compared with this reference position. Movement of the circular radiopaque marker proximally relative to the K-wires was considered positive (proximal) excursion,

while movement distally was considered negative (distal) excursion (Figure 3).

Total LHBt excursion throughout the range of motion tested was determined for each specimen tested, and an average of all specimens was calculated to determine the overall mean LHBt excursion.

The results were then analyzed for significance using a 1-way analysis of variance (ANOVA) test followed by Tukey honestly significant difference (HSD) test for pairwise comparison between each individual position and the reference position. Statistical significance was defined as *P* values of .05 or lower. All analyses were conducted using Excel (Microsoft Corp).

RESULTS

The mean excursion of the LHBt from the reference position at each shoulder position is summarized in Figure 4 and Table 1.

Throughout the range of motion tested, there was a mean excursion of 24.4 ± 5.2 mm. One-way ANOVA testing demonstrated a significant between-group difference in LHBt excursion (*F*-statistic 43.5; *P* < .0001). Post hoc Tukey HSD tests demonstrated a significant difference in the excursion

of the LHBT between the reference position and each of the 7 shoulder positions ($P < .001$; range, 2.6×10^{-6} to 3.2×10^{-6}). Additionally, the 2 positions of shoulder extension had significantly different LHBT excursions when compared with each position of shoulder flexion ($P < .0001$; range,

2.0×10^{-4} to 1.3×10^{-7}). The positions of shoulder flexion did not have significant differences in LHBT excursion when compared with one another ($P > .28$). There was no difference in LHBT excursion with elbow extension compared with that with elbow flexion at each shoulder position ($P > .41$).

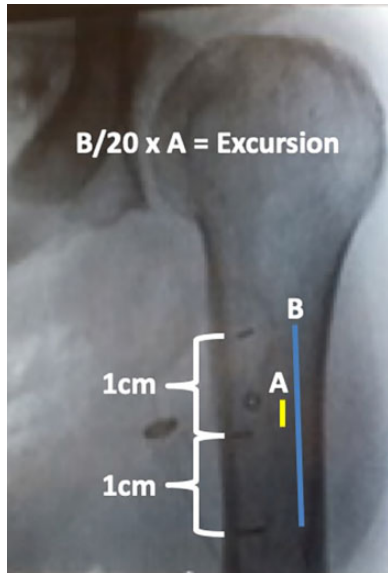


Figure 3. A radiograph with 3 K-wires embedded in the proximal humerus and a radiopaque circular marker attached to the biceps musculotendinous junction over the central K-wire. Radiographs taken in the tested arm positions were then used to measure excursion in millimeters. The measured distance between the most superior and inferior K-wires (B) and the measured distance of the LHBT marker from the central K-wire (A) were calculated. $B/20 \times A = \text{excursion (mm)}$.

DISCUSSION

In this study, we demonstrated that there is approximately 24 mm of normal excursion of the LHBT throughout the tested range of shoulder motion. In each shoulder position tested, in varying degrees of glenohumeral flexion and extension, the position of the LHBT was significantly different compared with the neutral shoulder position. Furthermore, the excursion occurring with glenohumeral extension was found to be significantly different from each position of shoulder flexion. Elbow position did not appear to have a significant impact on LHBT excursion. These findings are important because the shoulder position affects the length-tension relationship of the LHBT, which needs to be reestablished in the setting of biceps tenodesis.

The intention of a biceps tenodesis is to reestablish the resting tension of the LHBT and avoid undertensioning, which can lead to cramping, cosmetic deformity, and possibly weakness.^{4,9,10} As we demonstrated that the LHBT has a significant amount of tendon excursion throughout shoulder range of motion, tethering the biceps while in a suboptimal glenohumeral position may limit the range of motion. This is consistent with the findings of McGahan et al⁷ who reported that LHBT tenodesis in 0° of abduction and maximum internal rotation results in a loss of glenohumeral external rotation. Similarly, performing a tenodesis in a glenohumeral position, which results in LHBT laxity relative to the native length-tension relationship, may result in cosmetic deformity and cramping. A recent study by Tao

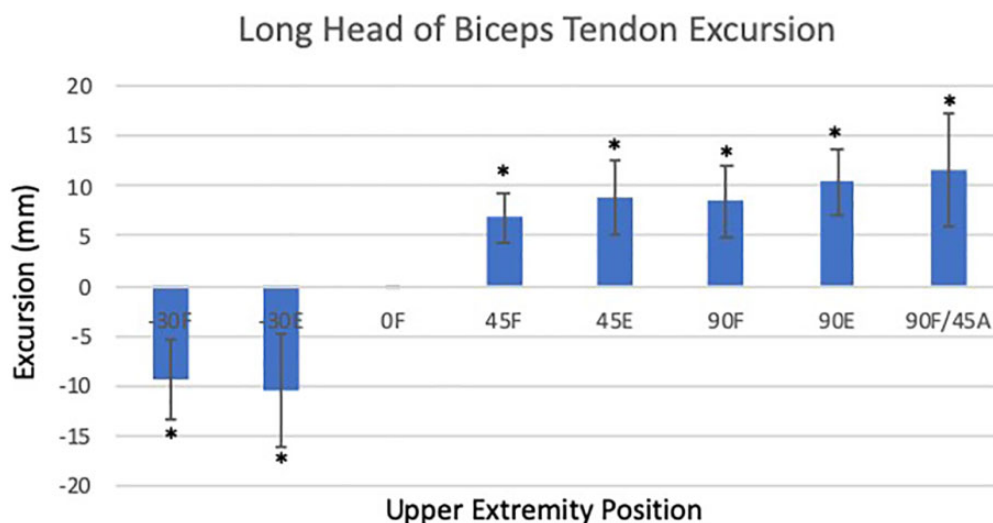


Figure 4. Long head of biceps tendon excursion at each tested shoulder and elbow position. The number beneath each bar refers to the degrees of glenohumeral flexion. * $P \leq .001$ compared with 0°F (neutral shoulder position). A, glenohumeral abduction; E, elbow extension; F, elbow flexion.

TABLE 1
Mean LHBT Excursion at Each Upper Extremity Position Tested^a

Upper Extremity Position	Mean LHBT Excursion, mm	SD, mm	<i>P</i> (Relative to 0°F)	<i>P</i> (Relative to -30°E)	<i>P</i> (Relative to -30°F)
-30°F	-9.4	3.9	1.2×10^{-5}	—	0.61
-30°E	-10.3	5.6	2.6×10^{-4}	0.61	—
0°F	0.0	0.0	—	1.2×10^{-5}	2.0×10^{-4}
45°F	6.9	2.5	1.2×10^{-5}	4.2×10^{-6}	3.3×10^{-5}
45°E	8.9	3.7	3.5×10^{-5}	1.6×10^{-7}	5.9×10^{-6}
90°F	8.5	3.6	3.9×10^{-5}	2.6×10^{-6}	6.5×10^{-5}
90°E	10.4	3.2	3.2×10^{-6}	1.3×10^{-7}	2.6×10^{-6}
90°F/45°A	11.6	5.7	1.2×10^{-4}	1.1×10^{-5}	1.8×10^{-5}

^aA, glenohumeral abduction; E, elbow fully extended; F, elbow flexed to 90°; —, not calculated. Values in bold indicate statistical significance ($P < .05$).

et al¹⁰ demonstrated that fixation of the LHBT to the rotator interval with the shoulder in 0° of abduction and 0° of forward flexion maintained the native length-tension relationship of the LHBT. While further investigation is necessary, the combined findings of McGahan et al, Tao et al, and our study suggest that 0° of forward flexion and 0° of abduction may represent a position that closely re-creates the native length-tension relationship. We currently utilize a neutral glenohumeral position in approximately 90° of elbow flexion. This is because glenohumeral extension to 30° was shown to lead to significantly more biceps excursion than a neutral position, and this increased excursion would likely overtension the LHBT if tenodesed in this position. Similarly, each position of glenohumeral flexion led to a significantly different amount of biceps excursion than the neutral position, and this difference in excursion would likely undertension the LHBT if tenodesed in this position. LHBT excursion did not differ with 45° and 90° of shoulder flexion, possibly because the LHBT experiences less tension in glenohumeral flexion than extension. However, further research is necessary to determine the optimal position of the shoulder during biceps tenodesis.

Appropriate tensioning of the biceps tendon is a critical step to success during biceps tenodesis, regardless of the specific technique used.⁴ While biceps tenotomy alone may be considered for low-demand patients, it can result in a relatively high rate of cosmetic deformity and has been associated with biceps cramping/spasm, shoulder pain, and weakness, which may be in part because of the procedure's inability to restore the anatomic length-tension relationship of the biceps. This may be particularly relevant in tenodesis techniques that result in undertensioning of the biceps.

Subpectoral biceps tenodesis is a common technique used to treat refractory BLC symptoms, including LHBT instability, biceps tendinopathy or tearing, and SLAP tears in some patients.^{1,6,14} While previous studies have attempted to determine the relationship of static anatomic landmarks in the shoulder in an attempt to guide proper biceps tensioning in the setting of tenodesis, the excursion of the LHBT and individual anatomic variability in these landmarks make restoration of anatomic tensioning using landmarks alone difficult. Tao et al¹⁰ and David and Schildhorn³ reported techniques for achieving anatomic tensioning of the biceps

when performing open subpectoral biceps tenodesis by maintaining the anatomic length and tension of the tendon after release from the glenoid labrum. Both groups of authors alluded to the difficulty of maintaining anatomic tensioning when performing a biceps tenodesis using anatomic landmarks alone as a guide. Our finding that, on average, the LHBT has 24 mm of excursion throughout the range of shoulder motion tested supports the notion that relying on anatomic landmarks alone as a guide to reestablishing this length-tension relationship may be inadequate, as the relationship between static landmarks changes based on arm glenohumeral position. As such, the use of anatomic landmarks as well as the position of the upper extremity should be considered to optimize the LHBT length-tension relationship.

Only 1 prior study⁷ investigated the excursion of the LHBT. McGahan et al⁷ sought to determine the effects of an in situ biceps tenodesis on glenohumeral joint range of motion, reporting an average LHBT excursion of 19.4 ± 5.4 mm of the LHBT with range of motion in the scapular plane and a significant decrease in shoulder external rotation when tenodesis was performed in 0° of abduction and maximum internal rotation. Before tenodesis, the authors assessed LHBT excursion in scapular plane abduction only. Furthermore, the biomechanical testing setup consisted of a potted humerus without an elbow joint. In contrast, our study aimed to answer the specific question of how much LHBT excursion occurs throughout a normal arc of shoulder motion and to assess how elbow flexion affects LHBT excursion. Our biomechanical setup consisted of the entire forelimbs, including the scapula and the distal extremity, thereby leaving the proximal origin and distal insertion of the biceps intact. Furthermore, we assessed LHBT excursion with the shoulder in varying degrees of flexion and with the elbow either in a flexed or extended position. These shoulder and elbow positions better simulate possible positions of the shoulder and elbow at the time of biceps tenodesis surgery and may thereby help to guide optimal shoulder and elbow positioning at the time of surgery.

There are several limitations to our study. First, as cadavers were utilized, the specimens had no muscle tone and were only able to be taken through a passive range of motion. While these factors may have affected the results,

patients undergoing biceps tenodesis often are under general anesthesia with or without a paralytic, with minimal resting tone. Laterality was not distinguished, and biceps tenodesis was not performed. Second, our findings make no specific suggestion as to what the optimal shoulder and elbow position is for biceps tenodesis but instead provide the amount of LHBT excursion that occurs at various shoulder positions relative to a neutral shoulder position (the resting position of the arm in vivo). Additionally, we did not place the marker at the inferior border of the pectoralis tendon, something that has been suggested as a landmark for reestablishing an anatomic length-tension relationship, which may have increased the ability of our findings to be more easily translated to the clinical setting.^{3,10} The specimens tested did not have pathologic LHBT, and it remains unknown how LHBT pathology affects its excursion. Aside from a neutral (0°) position of glenohumeral abduction, only 1 other position of abduction was tested, as LHBT excursion through a range of scapular plane abduction has previously been described and did not affect LHBT in our study.⁷ We did not test with neutral glenohumeral position with the elbow in extension, and while this would have been additive, it should be noted that elbow position did not significantly affect tendon excursion ($P > .41$ in all of the other glenohumeral positions tested). This may be because of the ability of the muscular portion of the long head biceps to accommodate distally. Proximally, the course of the LHBT runs over the circumference of the humeral head; as a result, glenohumeral position has a greater effect on tendon excursion than elbow position. This would also help explain why glenohumeral extension appears to have a greater effect than flexion. Finally, while we did demonstrate significant differences in LHBT excursion at all shoulder positions, the clinical impact of these differences remains unknown. Although a clear difference in LHBT excursion was observed when comparing the neutral position to each position of flexion and extension, and also when comparing each position of extension with each position of flexion, excursion did not differ significantly at 45° and 90° of flexion. Despite these limitations, our findings do suggest that shoulder position at the time of tenodesis fixation clearly affects the resting anatomic length-tension relationship and should be considered, in addition to static landmarks.

CONCLUSION

We demonstrated that approximately 24 mm of LHBT excursion occurs throughout the shoulder range of motion tested. Relative to neutral glenohumeral position, the position of the LHBT significantly differs with glenohumeral flexion and extension. Elbow position does not appear to

affect LHBT excursion. These findings are important because they suggest that restoration of an anatomic length-tension relationship at the time of biceps tenodesis depends not only on referencing static anatomic landmark(s) but should also consider shoulder position. Future studies should incorporate our findings and those of previous studies in order to determine the optimal shoulder position and anatomic landmarks to establish an anatomic length-tension relationship during biceps tenodesis.

REFERENCES

- Boileau P, Parratte S, Chuinard C, Roussanne Y, Shia D, Bicknell R. Arthroscopic treatment of isolated type II SLAP lesions: biceps tenodesis as an alternative to reinsertion. *Am J Sports Med.* 2009;37(5):929-936.
- Calcei JG, Boddapati V, Altchek DW, Camp CL, Dines JS. Diagnosis and treatment of injuries to the biceps and superior labral complex in overhead athletes. *Curr Rev Musculoskelet Med.* 2018;11(1):63-71.
- David TS, Schildhorn JC. Arthroscopic suprapectoral tenodesis of the long head biceps: reproducing an anatomic length-tension relationship. *Arthrosc Tech.* 2012;1(1):e127-e132.
- Denard PJ, Dai X, Hanypsiak BT, Burkhart SS. Anatomy of the biceps tendon: implications for restoring physiological length-tension relationship during biceps tenodesis with interference screw fixation. *Arthroscopy.* 2012;28(10):1352-1358.
- LaFrance R, Madsen W, Yaseen Z, Giordano B, Maloney M, Voloshin I. Relevant anatomic landmarks and measurements for biceps tenodesis. *Am J Sports Med.* 2013;41(6):1395-1399.
- McCormick F, Nwachukwu BU, Solomon D, et al. The efficacy of biceps tenodesis in the treatment of failed superior labral anterior posterior repairs. *Am J Sports Med.* 2014;42(4):820-825.
- McGahan PJ, Patel H, Dickinson E, Leasure J, Montgomery W 3rd. The effect of biceps adhesions on glenohumeral range of motion: a cadaveric study. *J Shoulder Elbow Surg.* 2013;22(5):658-665.
- Rassier DE, MacIntosh BR, Herzog W. Length dependence of active force production in skeletal muscle. *J Appl Physiol (1985).* 1999;86(5):1445-1457.
- Slenker NR, Lawson K, Ciccotti MG, Dodson CC, Cohen SB. Biceps tenotomy versus tenodesis: clinical outcomes. *Arthroscopy.* 2012;28(4):576-582.
- Tao MA, Calcei JG, Taylor SA. Biceps tenodesis: anatomic tensioning. *Arthrosc Tech.* 2017;6(4):e1125-e1129.
- Taylor SA, Fabricant PD, Bansal M, et al. The anatomy and histology of the bicipital tunnel of the shoulder. *J Shoulder Elbow Surg.* 2015;24(4):511-519.
- Taylor SA, Newman AM, Dawson C, et al. The "3-pack" examination is critical for comprehensive evaluation of the biceps-labrum complex and the bicipital tunnel: a prospective study. *Arthroscopy.* 2017;33(1):28-38.
- Taylor SA, Ramkumar PN, Fabricant PD, et al. The clinical impact of bicipital tunnel decompression during long head of the biceps tendon surgery: a systematic review and meta-analysis. *Arthroscopy.* 2016;32(6):1155-1164.
- Werner BC, Brockmeier SF, Gwathmey FW. Trends in long head biceps tenodesis. *Am J Sports Med.* 2015;43(3):570-578.