Original Article

Biomechanical properties of tenotomy versus biceps knot in a cadaver model

Micah Lissy^{a,b}, Amanda Esquivel^a, Allison Cracchiolo^a, Stephen Lemos^{a,b,*}^a Detroit Medical Center Sports Medicine, United States^b Detroit Medical Center Sports Medicine, Orthopaedic Surgery Sports Medicine Fellowship Program, United States

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ABSTRACT

Background: Biceps tenotomy and biceps tenodesis are the primary methods of treating biceps pathology. This study describes a new technique of tenotomy with the goal of autotenodesis to give the biceps a higher load to failure and decreased chance of a Popeye deformity.

Purpose: The purpose of this study was to evaluate the strength of the “biceps knot”, which is an outlet tenodesis of the biceps tendon and compare the biomechanical properties of this technique to tenotomy.

Methods: Ten matched cadaver shoulder pairs were used. In the tenotomy group, an arthroscopic tenotomy was performed at the labral biceps junction using a narrow angled biter. For the biceps knot group, a self-retrieving suture passing device was used to pass a suture as far lateral as possible. The suture was passed from just distal to the biceps insertion on the superior labrum and tied with a standard non-sliding arthroscopic knot. The humerus and biceps tendon were rigidly fixed to a materials testing machine and cyclically loaded at 10–20 N for 100 cycles at 1 Hz. After cyclic testing, a 2 N preload was placed on the tendon and the tendon was pulled in line with the bicipital groove until failure.

Results: The peak load to failure for the biceps knot was 58.9 N (SEM 8.2 N) and 37.3 N (SEM 4.6 N) for the tenotomy group ($p = 0.046$). The average stiffness for the biceps knot group was 4.2 N/mm (SEM 0.4 N/mm) and 3.2 N/mm (SEM 0.2 N/mm) for the tenotomy group ($p = 0.031$).

Conclusion: Performing the biceps knot is a quick, easy and cost effective alternative to the current tenodesis options available.

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1. Introduction

Biceps tendon pathology is a frequent cause of pain and disability.^{1–5,15} The long head of the biceps tendon (LHBT) is an independent pain generator that is a frequent complaint in patients with shoulder pain.³ There is a “net-like pattern” of sensory and sympathetic neural fibers concentrated at the tendon origin on the glenoid that is a major contributor to pain in the shoulder.² LHBT pathologies have recently become more commonly recognized in association with other pathologies of the shoulder. Ignoring LHBT pathology has been shown to lead to an inferior outcome.⁴

While there is little disagreement that the LHBT generates pain, the function, and consequently biomechanical relevance, of the

tendon in normal shoulder activity remains controversial.^{1,4–6} Biomechanical cadaver studies indicate that the LHBT plays a significant role in stabilizing the glenohumeral joint in all directions of movement.^{1,6} However, the load placed on the biceps in these studies varied significantly, and even exceeded physiologic levels in several studies.^{1,6} Clinical studies using electromyography demonstrate a minimal role for the LHBT in active shoulder stabilization, supporting those who claim it to be a vestigial structure.^{3,6,7} There is no clear answer in the literature as to what the function of the LHBT is and if it is needed at all in a fully functional shoulder.^{2,7,8}

The two most common techniques used to treat LHBT pathology are biceps tenotomy and biceps tenodesis.¹ Tenotomy has been shown to be effective at resolving complaints of pain but can cause a cosmetic deformity commonly referred to as a Popeye deformity from 3 to 70% of the time.^{4,9} A deep muscle ache related to early fatigue in 38% of young active individuals has also been reported.¹⁰ A tenodesis may help to conserve normal anatomy.¹¹ By maintaining the length tendon relationship of the biceps, it less

* Corresponding author at: 28800 Ryan Road Suite 220, Warren, MI 48092, United States. Tel.: +1 586 558 2870; fax: +1 586 558 4651.

E-mail address: selemos@dmc.org (S. Lemos).

frequently causes cosmetic complaints and muscle ache, but can cause bicipital groove pain^{1,6,12} and a tenodesis more technically demanding procedure requiring additional operative time and implants.^{10,13–16}

No consensus has been reached regarding the benefit of tenodesis over tenotomy in the published literature due to variable patient characteristics, methodology, and results.⁸ Given that there has been no proven difference in functional scores or patient satisfaction between the two interventions, an option that is less challenging and avoids complications is desirable.⁶ There is a known phenomenon of autotenodesis that occurs when the long head of the biceps tendon adheres to the bicipital groove after tenotomy.^{6,7} Promoting this process would enable a best of both worlds approach to the treatment of biceps tendon pathology.

The purpose of this study was to evaluate the biomechanical properties of the biceps knot at time zero in a cadaver model and directly compare it to the biceps tenotomy. Our secondary objectives were to describe the arthroscopic biceps knot technique and compare the time required for the two techniques studied.

2. Materials and methods

Twenty matched fresh frozen cadaver shoulders were used. The shoulder was placed in the beach chair position. The standard posterior viewing portal was established, a diagnostic tour of the shoulder was performed, and the acceptability of the specimen was confirmed. An anterior portal was established at the inferior aspect of the rotator interval by standard practices. An appropriate sized passport flexible cannula (Arthrex, Naples, FL) was placed in the anterior portal. An arthroscopic shaver was used as needed to debride degenerative tissues about the joint to enable visualization. Finally, either the biceps tenotomy or knot procedure was initiated and we began timing the surgical treatment.

The biceps tenotomy group had a standard biceps tenotomy performed arthroscopically just distal to the superior labrum using a narrow angled biter. In the biceps knot group, a self-retrieving Scorpion suture passing device (Arthrex, Naples, FL) was used to pass a Stryker #5 force fiber suture (Stryker, Kalamazoo, MI) from inferior to superior as far lateral as possible. The same suture limb was passed from superior to inferior just distal to the biceps insertion on the superior labrum. Care was taken to leave room to perform the tenotomy without violating either the labrum or the suture. Once it was confirmed that the sutures were passed cleanly, they were tied with a standard non-sliding arthroscopic knot (Fig. 1). The limbs were cut with an arthroscopic knot cutter. The tenotomy was performed just distal to the superior labrum using a narrow biter. The timer was stopped after the completion of the tenotomy in both groups.

Fig. 1. Arthroscopic image of the biceps knot.

Fig. 2. Biomechanical set-up of the cadaveric shoulder.

The soft tissues were dissected away from the humerus distal to the inferior border of the pectoralis major insertion. The most distal aspect of the long head of the biceps tendon was identified and tagged with a suture, taking care not to tension it. Additional soft tissue was removed from the posterior and superior aspect of the shoulder, avoiding all soft tissues overlying the bicipital groove.

The humeri were secured in custom aluminum fixtures and rigidly fixed to the base of an electromechanical materials testing machine (ElectroPuls™ E10000, Instron, Norwood, MA) using a 1 kN load cell. The distal portion of the tendon was identified and secured to the actuator of the materials testing machine by sewing the proximal aspect of the distal biceps tendon to a Dacron rope in a modified Krackow fashion and clamping the tendon-webbing complex (Fig. 2). The Dacron rope has been used previously and has a stiffness of 255 N/mm in order to minimize any effect of the material on the values reported.

First, the specimens were subjected to cyclic loading. The distal end of the tendon was pulled in line with the bicipital groove from proximal to distal from 20 to 60 N for 100 cycles at 1 Hz. If the specimen did not fail during cyclic testing, a 2 N preload was applied and a load to failure test was performed at a rate of 10 mm/s until failure. Force and displacement were recorded by the Instron. Peak-to-peak displacement was considered to be the average difference between the highest and the lowest displacement of the last 3 cycles. The peak load was defined as the load to failure for all specimens. Maximum elongation was considered the displacement measured by the Instron at the peak load. The stiffness was calculated for each specimen after testing by calculating the slope of the line in the linear portion of the force/displacement curve. Average values for each group were determined along with the standard error. Data were compared by a paired, one-tailed Student's *t*-test for significance ($p < 0.05$).

3. Results

The average peak load to failure for the biceps knot group was 58.9 N (SEM 8.2 N) and 37.3 N (SEM 4.6 N) for the tenotomy group. The biceps knot group failed at a significantly higher load ($p = 0.046$) than the tenotomy group (Fig. 3). The average stiffness for the biceps knot group was 4.2 N/mm (SEM 0.4 N/mm) and 3.2 N/mm (SEM 0.2 N/mm) for the tenotomy group (Fig. 4) ($p = 0.031$).

The maximum elongation for the biceps knot was 17.9 mm (SEM 2.5 mm) and 13.2 mm (SEM 1.1 mm) for the tenotomy group ($p = 0.10$). The average peak-to-peak displacement for the biceps

Fig. 3. Comparison of load to failure of the two procedures.

Fig. 4. Comparison of stiffness among the two procedures.

knot group was 1.1 mm (SEM 0.1 mm) and 1.9 mm (SEM 0.2 mm) for the tenotomy group (Fig. 4) and this difference was significant ($p = 0.016$).

The average time it took to complete the tenotomy was 40.6 s (SEM 12 s). The average time for the biceps knot procedure was 806.5 s (SEM 130 s). This length of time was significant when compared with the tenotomy ($p = 0.0002$).

4. Discussion

The purpose of this study was to evaluate the biomechanical properties of the biceps knot at time zero in a cadaver model and directly compare it to the biceps tenotomy. We also compared the time required for the two techniques studied. We found that the biceps knot had a significantly higher load to failure and stiffness and significantly less elongation during cyclic testing compared with the tenotomy. It took approximately 13 min longer to complete the biceps knot technique.

The intraarticular, extrasynovial portion of the LHBT passes through a soft tissue sling on its path out of the joint. Adjacent structures such as the coracohumeral ligament, superior glenohumeral ligament, joint capsule and the tendons of the supraspinatus, and subscapularis muscles all contribute to form the biceps reflection pulley.^{1,6,17} These structures merge distally with the falciform ligament, a tendinous expansion from the sternocostal head of the pectoralis major tendon that sandwiches the long head of the biceps tendon.¹⁸ Collectively, these components form the roof of the bicipital groove and prevent subluxation of the tendon.¹ They are often referred to as the “transverse humeral ligament”¹⁷ or the “intertubercular transverse ligament”.¹⁸ In the groove itself is the vinculum, providing nutrition to the tendon. In the healthy shoulder, the above static and dynamic structures

resist distal excursion of a tenotomized tendon.⁴ In the pathologic shoulder, there is often hypertrophy of the intraarticular long head of the biceps tendon, stenosis of the soft tissue sling, and scarring or adhesions from local inflammation that further aid in resisting distal migration.^{19,20}

Autotenodesis is the adherence of the biceps tendon to the bicipital groove. Kim et al. demonstrated that autotenodesis occurs both clinically and histologically in healthy rabbit shoulders after tenotomy.^{4,11} Karataglis et al. used ultrasound to confirm that 82.7% of tenotomized long head of the biceps tendons remained in the bicipital groove at 2 years.⁵ Furthermore, only 5.8% of the tenotomies migrated far enough distally to create a Popeye deformity. This indicates that even a minimal increase in resistance to biceps excursion could be expected to improve clinical outcomes.

Scheibel et al. grouped tenodesis techniques into three categories: soft tissue techniques, osseous techniques, and intraosseous techniques.^{12,21} We describe a fourth category in this paper, the outlet tenodesis. By enlarging the intraarticular end of the LHBT, we obstruct its passage through the soft tissue sling and bicipital groove, thereby indirectly tenodesing the LHBT. The biceps knot uses no implantable hardware and took an average of just over 13 min to complete. Bradbury et al. also described an outlet tenodesis technique, but he included a piece of the superior labrum with the biceps release.²¹

Our results show the average peak load to failure for the tenotomy group to be 37.3 N (SEM 4.6 N). In a review of two biomechanical studies, Hsu et al. found the average load to failure for tenotomies to be 81.6 N.⁸ Ahmad et al. reported an average load to failure of 33 N in tenotomies ($n = 7$) while Wolf et al. reported an average of 110 N.¹ Our numbers are more closely aligned with those found by Ahmad. It is possible that these discrepancies could be due to differences in testing procedures. The biceps knot had an average peak load to failure of 58.9 N (SEM 8.2 N). While this value is significantly higher than the tenotomy group, it is lower than reported values for tenodesis. In the same study, Hsu found the average load to failure for tenodesis to be 233.5 N.⁸

The physiological requirements of the biceps tendon have been examined. Pereira et al. estimated that 52 N is the force necessary through the elbow to maintain the arm flexed to 90° against gravity.¹⁸ This value doubles to approximately 110 N to lift a 1 kg weight.²² Upon isolating the LHBT, a maximum load of 40.32 N has been predicted by Elser et al. by extrapolation from the cross-sectional area of the tendon itself.¹ Rodesky et al. estimated that 130–160 N is the maximum force possible for the LHBT, given the cross-sectional area of the long head of the biceps muscle belly.²³ Given these values, current tenodesis treatment options may allow for a higher peak load than necessary. Simultaneously, up to 25% can present with a Popeye deformity after tenodesis leading some authors to conclude that the quality of the tendon tissue is more important than the strength of fixation.¹²

Limitations of the study include those inherent in all cadaveric studies. This study only provides data on the peak-to-peak elongation, load to failure, stiffness, and displacement at time zero and cannot account for any effect of healing. The technique described relies on both dynamic and static components of restraint across the bicipital groove. No measures were taken to recreate tension in the subscapularis, supraspinatus, or pectoralis major tendons, possibly underestimating the clinical effect.

5. Conclusion

The biceps knot technique had a significantly higher load to failure and stiffness when compared with the tenotomy in this time zero cadaveric study. It also had a significantly smaller peak-to-peak elongation compared with the tenotomy, indicating that at

low loads this repair moved less inside the bicipital groove. Performing the biceps knot is a quick, simple, and economical alternative to the current tenodesis options available. With postoperative activity restriction, it has sufficient fixation strength to resist displacement with motion against gravity at the elbow. Further study including clinical correlation is indicated.

Author contributions

Lissy – testing, writing; Esquivel – testing, data processing, writing; Cracchiolo – testing, data processing, writing; Lemos – PI, idea conception, writing/editing.

Conflicts of interest

The authors have none to declare.

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