Published in final edited form as:

Am J Sports Med. 2018 December ; 46(14): 3486–3494. doi:10.1177/0363546518805091.

Biceps Detachment Preserves Joint Function in a Chronic Massive Rotator Cuff Tear Rat Model

Mengcun Chen^{1,2}, Snehal Shetye¹, Julianne Huegel¹, Corinne N. Riggin¹, Daniel J. Gittings¹, Courtney A. Nuss¹, Stephanie N. Weiss¹, Andrew F. Kuntz¹, and Louis J. Soslowsky¹

¹McKay Orthopaedic Research Laboratory, University of Pennsylvania, Philadelphia, Pennsylvania, USA.

²Department of Orthopaedics, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China.

Abstract

BACKGROUND: Lesions of the long head of the biceps tendon are often associated with massive rotator cuff tears (MRCT) and biceps tenotomy is frequently performed for pain relief and functional reservation. However, the efficacy and safety of biceps tenotomy regarding the effects on the surrounding tissues in chronic MRCT is unclear.

HYPOTHESIS: We hypothesized that biceps tenotomy would result in improved mechanical and histological properties of the intact subscapularis tendon and improved *in vivo* shoulder function, while not compromising glenoid cartilage properties.

STUDY DESIGN: Controlled laboratory study.

METHODS: Right supraspinatus and infraspinatus tendons were detached in 25 male Sprague-Dawley rats, followed by 4 weeks of cage activity to create a chronic MRCT condition. Animals were randomly divided into 2 groups and received either a biceps tenotomy (n=11) or a sham surgery (n=14) and were sacrificed 4 weeks thereafter. Forelimb gait and ground reaction forces were recorded 1 day before the tendon detachment (baseline), 1 day before the surgical intervention (biceps tenotomy or sham), and 3, 7, 10, 14, 21 and 28 days after the intervention to assess *in vivo* shoulder joint function. The subscapularis tendon and glenoid cartilage were randomly allocated for either mechanical testing or histologic assessment after the sacrifice.

RESULTS: Compared to sham group, biceps tenotomy partially restored the *in vivo* shoulder joint function, with several gait and ground reaction force parameters returning closer to pre-injury baseline values at 4 weeks. With biceps tenotomy, mechanical properties of the subscapularis tendons were improved while mechanical properties and histological Mankin score of the glenoid cartilage were not diminished compared to sham group.

CONCLUSION: Biceps tenotomy in the presence of chronic MRCT partially preserves overall shoulder function and potentially restores subscapularis tendon health, without causing detrimental

effects to joint cartilage. This laboratory study adds to the growing literature regarding the protective effects of biceps tenotomy on the shoulder joint in a chronic MRCT model.

CLINICAL RELEVANCE: This study provides important basic science evidence supporting the use of biceps tenotomy in patients with massive rotator cuff tears.

Keywords

Shoulder, rotator cuff; Shoulder, instability; Shoulder, biceps tendon; Shoulder, glenoid labrum

INTRODUCTION

To achieve normal motion and maintain joint stability, multiple musculotendinous units of the shoulder joint must act in synchrony by balancing muscle and external forces in all directions. Transverse force-couple, which is primarily maintained by the subscapularis anteriorly and the infraspinatus and teres minor posteriorly, has been described previously and is a major component to the dynamic stability of the shoulder joint.⁴ In the presence of massive rotator cuff tears (MRCT), where two or more cuff tendons are primarily involved,⁹ the whole joint can be rendered at risk for mechanical instability and subsequent downstream injuries.^{4, 20} A previous study in a rat model of MRCT suggests that the disruption of the transverse force-couple balance due to MRCT (defined as the detachment of supraspinatus and infraspinatus tendons) may lead to joint damage and lesions of the long head of the biceps tendon (LHBT).²⁶ Numerous clinical studies have demonstrated structural damage to the LHBT in the presence of MRCT and have shown a positive correlation between the size of these lesions and the severity of MRCT.^{6, 7, 24}

Lesions of the LHBT are a recognized source of anterior shoulder pain and joint dysfunction, and commonly present in combination with rotator cuff tendon pathology.^{6, 14} After initial observations of the analgesic effect of spontaneous rupture of the LHBT, arthroscopic biceps tenotomy is frequently performed either as a primary operation or in conjunction with other surgical interventions to address shoulder pain and impaired joint function in patients with chronic MRCT.³ Despite studies reporting favorable outcomes after biceps tenotomy in the presence of MRCT,^{3, 17, 30, 37} the effect of this palliative surgery on surrounding joint structures, including the intact rotator cuff tendons and glenoid cartilage, is still controversial.^{15, 16, 18, 36} Cadaveric studies have indicated the role of LHBT as an anterior stabilizer and expressed concerns about the biomechanical consequences of its detachment.^{16, 29} However, animal studies indicated that simultaneous detachment of the LHBT at the time of MRCT initiation resulted in improved shoulder function and a reduction in damage to surrounding joint tissues.³² However, the typical clinical scenario involves LHBT detachment several months or even years after the initial rotator cuff tear. Therefore, the effect of biceps tenotomy on the surrounding tissues in this chronic MRCT scenario remains unknown.

Therefore, the objective of this study was to define the impact of surgical detachment of the LHBT as a potential palliative treatment in a chronic MRCT rat model. We hypothesized that biceps tenotomy would result in improved mechanical and histological properties of the

intact subscapularis tendon and improved *in vivo* shoulder function without compromising glenoid cartilage properties.

MATERIALS AND METHODS

Animals and Study Design

Supraspinatus and infraspinatus (S+I) tendons were detached in right forelimbs of 28 male Sprague-Dawley rats (464±24g; IACUC approved) followed by 4 weeks of cage activity to create a model of chronic MRCT.^{2, 23, 32} These animals with chronic MRCT were randomly divided into two groups that received either a surgical biceps tenotomy (BT, n=14) or a sham surgery (SS n=14) on the right shoulder (Fig. 1). *In vivo* functional tests were performed using a customized quantitative ambulation device followed by animal sacrifice for *ex vivo* analysis.^{32, 33} For histology (n=4 in each group), tissues were immediately dissected and fixed in formalin. The remaining animals were designated for mechanical testing and stored intact at -20 °C until the day of testing. Three rats from the BT group assigned for mechanical testing were observed to have an intact biceps tendon on the day of testing and were excluded from further analysis resulting in a final study sample size of 25. (BT, n=11 and SS, n=14).

Quantitative Ambulation

In vivo shoulder joint function was assessed by recording forelimb gait and ground reaction forces on an instrumented walkway 1 day before the supraspinatus and infraspinatus detachment (pre-injury baseline, Pre), as well as 1 day before (Pre-I), and 3, 7, 10, 14, 21 and 28 days after the biceps tenotomy/sham intervention as previously described.²⁷ Data was collected for both the injured and contralateral limbs. Kinetic data including medial/lateral, braking/propulsion, and vertical ground reaction forces, and kinematic data including stride length (longitudinal distance between two-steps of a specific paw), stride width (Averaged distance between two front paws while the animal is walking) and stride speed (Stride length/time) were determined for each walk. Parameters were averaged across walks (n=3–4) at each time point for each animal and normalized to body weight, and the change in force from baseline was calculated.

Mechanical Testing

Tendon Mechanics—Specimens were thawed, and the humerus was dissected to isolate the subscapularis tendon. Tendon testing was then performed as previously described.³¹ Briefly, stain lines were placed on the upper and lower bands of the subscapularis tendon (at insertion and mid-substance) to locally track regional optical strain. Tendon cross-sectional area was measured using a custom laser device.⁸ The humerus was embedded in a holding fixture using polymethylmethacrylate, the tendons were gripped with cyanoacrylate annealed sand paper, and the specimen was immersed in phosphate-buffered saline (PBS) at 37°C. The tensile testing protocol was as follows: (1) Preload to 0.08 N, (2) Preconditioning - 10 triangular waves from 0.1N to 0.5 N at a rate of 1% strain/second, (3) Stress-relaxation at 6% strain for 300 seconds, and (4) Ramp-to-failure at 0.3% strain/second. Stiffness was calculated as the slope of the linear region of the load-displacement curve from ramp-to-

failure data and region-specific modulus (insertion and mid-substance) was calculated as the slope of the linear region of the stress-strain curve.

Cartilage Mechanics—The glenoid was prepared for cartilage mechanical testing as previously described²⁵ by sharply detaching the long head of the biceps at its insertion on the superior rim of the glenoid (SS group only) and was preserved by wrapping in PBS-soaked gauze and frozen (−20 °C).

For cartilage thickness measurement,²⁵ each scapula was thawed and immersed in PBS containing protease inhibitors (5 mM benzamidine hydrochloride, 1 mM phenylmethylsulfonyl fluoride, 1 M N-ethylmaleimide) at room temperature. Specimens were scanned at 0.1-mm increments using a 45-MHz ultrasound probe (VisualSonics, Inc, Toronto, Ontario, Canada) in plane with the scapula. Captured B-mode images of each scan were segmented by manually selecting the cartilage and bony surfaces of the glenoid. The three-dimensional positions of these surfaces were reconstructed and used to determine cartilage thickness. Each thickness map was divided into five regions (center, posterior-superior, posterior-inferior, anterior-superior and anterior-inferior) and mean cartilage thickness was computed for each region. After ultrasound scanning, specimens were wrapped in soft tissue and frozen (−20 °C) until mechanical testing.

Cartilage thickness for indentation testing was determined by identifying the indentation location on each thickness map. Each scapula was thawed and immersed in PBS containing a protease inhibitor cocktail at room temperature. Utilizing a 0.5-mm-diameter, nonporous spherical indenter, cartilage indentation testing was performed.²⁵ Briefly, a preload (0.005 N) was followed by stepwise stress relaxation tests (8- μ m ramp at 2 μ m/seconds followed by a 300-second hold). The scapula was repositioned for each localized region such that the indenter tip was perpendicular to the cartilage surface. Equilibrium elastic modulus was calculated, as described by Hayes et al,¹⁰ at 20% indentation and assuming a Poisson's ratio of $\nu = 0.30$.

Histology

Subscapularis samples were left intact as bone-tendon-muscle units and glenoid samples were detached from the rest of the scapula at the scapular neck. Tendon samples were paraffin processed and longitudinal sections (7 μ m) were collected. The width of the glenoid cartilage (short axis of the oval glenoid cartilage) was measured before sectioning and used for calculation of the anterior (20–40% of the width), central (40–60% of the width) or posterior plane (60–80% of the width) while the glenoid cartilage was sectioned along the short axis of the oval glenoid cartilage. Subscapularis tendon sections were stained with hematoxylin and eosin and images were graded by three blinded investigators for cell density (scale: 1=less and 3=more dense) and cell shape (scale: 1=spindle and 3=round). Cartilage sections were stained using safranin O, fast green, and iron hematoxylin, imaged in five regions (center, posterior-superior, posterior-inferior, anterior-superior and anterior-inferior) corresponding to the indentation locations, and graded using a modified Mankin score, which incorporates scores for cellularity, structure and matrix staining.²⁵ Due to the presence of an intact tidemark in all images, scoring for this category was removed. Three

blinded investigators performed the cartilage histology scoring. Cartilage cell density was also quantified using the bioquantification software system (Bioquant Osteo II; BIOQUANT Image Analysis Corp, Nashville, TN, USA).

Statistics

Ambulation data was assessed using a two-way ANOVA with multiple imputations (for ~13% of missing data).⁵ Tissue mechanics and cartilage thickness were assessed using two-tailed t-tests. For tendon histology and cartilage scoring, median grades were compared between groups using a Mann-Whitney test. Significance was set at $p = 0.05$.

RESULTS

Quantitative Ambulation

Kinetic Results (Figure 2A):

Early post-intervention period (3d-10d after the intervention): Lower medial/lateral forces were observed in the BT group 7d after the intervention when compared with pre-intervention values, however, there were no differences between groups. Decreased propulsion, braking, and vertical ground reaction forces were also observed in the BT group during this period. Decreased braking force and stance time were observed during this period in the SS group, along with higher propulsion force than the BT group.

Late post-intervention period (2w-4w after the intervention): Lower medial/lateral forces were observed in the BT group during this period when compared with pre-intervention values without any differences between groups. Furthermore, higher rate of loading were observed in the BT group than in the SS group.

Kinematic Results (Figure 2B):

Early post-intervention period (3d-10d after the intervention): The affected limb had decreased stride length in the BT group while there were no differences between the two groups.

Late post-intervention period (2w-4w after the intervention): A significant increase of contralateral limb stride length was observed at 4 weeks in the SS group while lateral stride width was higher in the SS group than the BT group.

Tendon Properties

Tendon mechanics: Decreased stress relaxation (Fig 3A) and increased tendon stiffness (Fig 3B), along with a decrease in insertion site modulus (Fig 3C), were exhibited in the lower band of the subscapularis tendon in the BT group compared to the SS group with no changes in mid-substance modulus (Fig. 3D). No changes in any mechanical parameters were identified in the upper band (Fig. 3A–D).

Tendon histology:

No differences in cell density (cellularity) or morphology were observed in either band between the two groups (Table 1).

Cartilage Properties

Cartilage Mechanics: No differences were observed between groups for equilibrium elastic modulus (Fig 4A) or cartilage thickness (Fig 4B) in any of the regions.

Cartilage histology: An increase in cell quantitative density was observed in posterior-inferior region in the BT group (Fig. 5), while there were no differences in modified Mankin score grading between groups in any regions (Table 2).

DISCUSSION

Lesions of the LHBT are often associated with MRCT and may be responsible for shoulder pain and dysfunction.^{6, 30} Surgical biceps tenotomy is currently a treatment option either in conjunction with cuff repair, or even as a primary operation when repair is impossible. However, little is known regarding the effect of the detachment of the LHBT on surrounding joint structures in this common procedure.^{3, 17, 30, 37} Previous studies indicated that simultaneous detachment of the LHBT in the presence of supraspinatus and infraspinatus detachment resulted in improved shoulder function and less joint damage,³² however, the current study investigated the role of biceps tenotomy in a more clinically relevant chronic MRCT scenario. We hypothesized that the detachment of the long head of the biceps tendon would (1) improve shoulder function and (2) improve mechanical and histologic properties of the subscapularis tendon and (3) would not damage mechanical and histologic properties of the glenoid cartilage.

The altered gait patterns in the contralateral limbs in the SS possibly indicate a compensatory response to an increase in transverse force-couple imbalance. In contrast, although there were some changes during the early post-intervention period in the BT group, no alterations in these parameters remained significant at the final 4-week time compared to the pre-intervention value. Similarly, although the ground reaction force analysis showed inferior kinetic properties in both groups at the early post-intervention time period, no alterations in these parameters remained significant at 4 weeks post intervention. These differences during the early post intervention period may due to the surgical intervention and acute inflammation. However, rate of loading was closer to baseline in the BT group at 3 week post-intervention and medial-lateral force was better as compared to the Pre-I values at late post-intervention time points in the BT group. These improvements in kinematic and kinetic parameters in the BT group during the late post-intervention period may indicate improved stability of the shoulder during locomotion and/or relief of pain after the biceps tenotomy. Overall, these *in vivo* kinetic and kinematic measures indicate a more favorable outcome in *in vivo* function for the BT group. The results are further supported by most clinical studies in which significant functional improvements were reported utilizing biceps tenotomy in the presence of supraspinatus and infraspinatus cuff tears.^{3, 17, 30}

For mechanics of the subscapularis tendon, the increase in overall lower band tendon stiffness and decrease in stress relaxation in the BT group can be attributed to a rebalance of the transverse force couple as previously reported,^{11, 26, 32} which has been shown to be critical to joint health and function.^{11, 22} In the absence of biceps tenotomy, the unbalanced posteriorly directed force of the biceps tendon on the humeral head could decrease loading to the subscapularis tendon, resulting in reduced stiffness of the lower band. Furthermore, the decrease in insertion site modulus of the lower band in the BT group also indicates a return toward baseline subscapularis material properties (unpublished data).

An increase in cell density was noted in PI region of the glenoid cartilage in the BT group, which may indicate a more metabolically active state, however, there were no differences in cartilage thickness or equilibrium elastic modulus between the two groups for any of the regions. In addition, modified Mankin score was not different between groups for any of the regions. Previous studies identified compromised mechanical properties of the glenoid cartilage during disruption of the transverse force balance in a MRCT model, probably as a result of increased humeral head translations and decreased joint stability.²⁶ However, our results suggest that the additional detachment of LHBT in the presence of chronic MRCT does not exacerbate cartilage properties, at least at early stages, which is in accordance with previous animal studies and clinical outcomes.^{3, 30, 32, 35}

Several cadaveric biomechanical analyses have indicated that LHBT acts as an anterior stabilizer of the glenohumeral joint, with its role increasing as shoulder stability decreases, such as in the presence of MRCT.^{1, 12, 13, 16, 21, 29} Some concern has been expressed regarding the biomechanical consequences of the detachment of LHBT, such as increased glenohumeral migration. Such effects may outweigh the pain relieving effects of this procedure on shoulders with MRCT, supporting the preservation of the biceps tendon.^{16, 29} However, cadaveric studies cannot simulate the complicated spatiotemporal loading patterns of a shoulder joint during activities of daily living. Clinical studies published to date have not arrived at a consensus regarding use of biceps tenotomy to alleviate joint pain and improve shoulder stability. In one study, significantly greater proximal migration of the humeral head was observed in patients with MRCT without contraction of biceps, and depression of the humeral head with the biceps intact¹⁶. Additional studies have shown that patients with MRCT have decreased acromiohumeral distance after biceps tenotomy or tenodesis.^{3, 35} Conversely, some studies have recommended biceps tenotomy as a palliative surgery and achieved favorable treatment outcomes in reparable or irreparable MRCTs.^{3, 30, 35} In these studies, superior migration of the humeral head has generally not been observed on postoperative radiographs after biceps tenotomy.³⁵ Furthermore, the acromiohumeral narrowing observed after biceps tenotomy was equivalent to that seen after simple arthroscopic joint debridement and less than that seen after acromioplasty.³ Currently, there is a lack of evidence confirming the direct causal relationship between humeral migration and glenohumeral arthritis in the long-term. Besides, rotator cuff tear arthropathy is a relatively uncommon endpoint for rotator cuff tears patients.²⁰ In addition, clinically, an arthroscopic biceps tenotomy would only be performed on patients with a potentially functional shoulder without glenohumeral arthritis,³ which may render the concern of post-detachment osteoarthritis insignificant.

There are several limitations in the study which should be clarified. Despite the widely accepted anatomic similarities of this well-established MRCT rat model, the different loading patterns seen in quadrupeds is not capable of exactly replicating the human shoulder. However, the rat shoulder produces large amounts of glenohumeral forward flexion during normal locomotion, which renders the rotator cuff tendons and LHBT at risk for subacromial impingement. This allows for replication of repetitive overhead activity in humans while previous studies using the rat shoulder model have shown numerous similarities to results from clinical studies.²⁸ Additionally, this study involved an acute surgical detachment of the supraspinatus and infraspinatus tendon without inducing a tendinopathic condition with overuse, which does not perfectly mimic the more commonly seen degenerative cuff tears. However, previous studies indicated that inducing overuse prior to surgery is likely to be unnecessary when examining tendons 4 weeks after a repair in the classic rat supraspinatus model.³⁴ Furthermore, the animals were allowed 4 weeks of cage activity in the presence of rotator cuff tears prior to the second tenotomy/sham surgery, which has been shown to create LHBT tendinopathy and is well correlated with clinical findings of biceps tendon pathology.^{22, 26} Also, the addition of a later time point would be interesting to check the long-term influence of the detachment of the LHBT on the shoulder joint. The teres minor tendon and humeral head cartilage were not assessed in our study, which could assist in providing a more thorough insight on the impact of biceps tenotomy on the shoulder joint. However, since the teres minor does not play a major role in stabilization of the shoulder and is not commonly injured in the presence of MRCT, its mechanical and histological properties were not investigated in this study. Further, the necessity of fixing the humeral head in PMMA for mechanical testing of the subscapularis precluded probing the mechanical response of the humeral head.^{19, 25} Despite these limitations, our study design still allows for a well-controlled comparison to investigate the role of the LHBT in the development of joint damage in a clinically relevant chronic MRCT model.

Overall, this *in vivo* rat model demonstrates that detachment of LHBT in the presence of chronic massive rotator cuff tears partially preserves overall shoulder function and potentially restores subscapularis tendon health, without detrimental effects on joint cartilage, consistent with previous animal studies and supported by most clinical outcomes.^{3, 17, 30, 32} This clinically relevant laboratory study provides basic scientific evidence to support the use of detachment of LHBT in patients with tears of both the supraspinatus and infraspinatus. Randomized control trials are still needed to examine the clinical utility of this procedure and the long-term consequence of long head of the bicep tenotomy on the glenohumeral joint.

REFERENCES

1. Alexander S, Southgate DF, Bull AM, Wallace AL. The role of negative intraarticular pressure and the long head of biceps tendon on passive stability of the glenohumeral joint. *J Shoulder Elbow Surg.* 2013;22(1):94–101. [PubMed: 22516568]
2. Beach ZM, Tucker JJ, Thomas SJ, et al. Biceps tenotomy in the presence of a supraspinatus tear alters the adjacent intact tendons and glenoid cartilage. *J Biomech.* 2017;63:151–157. [PubMed: 28893394]

3. Boileau P, Baque F, Valerio L, Ahrens P, Chuinard C, Trojani C. Isolated arthroscopic biceps tenotomy or tenodesis improves symptoms in patients with massive irreparable rotator cuff tears. *J Bone Joint Surg Am.* 2007;89(4):747–757. [PubMed: 17403796]
4. Burkhart SS. Arthroscopic Treatment of Massive Rotator Cuff Tears - Clinical-Results and Biomechanical Rationale. *Clinical Orthopaedics and Related Research.* 1991(267):45–56.
5. Campion WM. Multiple Imputation for Nonresponse in Surveys - Rubin,Db. *Journal of Marketing Research.* 1989;26(4):485–486.
6. Desai SS, Mata HK. Long Head of Biceps Tendon Pathology and Results of Tenotomy in Full-Thickness Reparable Rotator Cuff Tear. *Arthroscopy.* 2017.
7. Ditsios K, Agathangelidis F, Boutsiadis A, Karataglis D, Papadopoulos P. Long head of the biceps pathology combined with rotator cuff tears. *Adv Orthop.* 2012;2012:405472. [PubMed: 23209915]
8. Favata M, Beredjiklian PK, Zgonis MH, et al. Regenerative properties of fetal sheep tendon are not adversely affected by transplantation into an adult environment. *J Orthop Res.* 2006;24(11):2124–2132. [PubMed: 16944473]
9. Gerber C, Fuchs B, Hodler J. The results of repair of massive tears of the rotator cuff. *J Bone Joint Surg Am.* 2000;82(4):505–515. [PubMed: 10761941]
10. Hayes WC, Keer LM, Herrmann G, Mockros LF. A mathematical analysis for indentation tests of articular cartilage. *J Biomech.* 1972;5(5):541–551. [PubMed: 4667277]
11. Hsu JE, Reuther KE, Sarver JJ, et al. Restoration of Anterior-Posterior Rotator Cuff Force Balance Improves Shoulder Function in a Rat Model of Chronic Massive Tears. *Journal of Orthopaedic Research.* 2011;29(7):1028–1033. [PubMed: 21308755]
12. Itoi E, Kuechle DK, Newman SR, Morrey BF, An KN. Stabilising function of the biceps in stable and unstable shoulders. *J Bone Joint Surg Br.* 1993;75(4):546–550. [PubMed: 8331107]
13. Itoi E, Newman SR, Kuechle DK, Morrey BF, An KN. Dynamic anterior stabilisers of the shoulder with the arm in abduction. *J Bone Joint Surg Br.* 1994;76(5):834–836. [PubMed: 8083280]
14. Khazzam M, George MS, Churchill RS, Kuhn JE. Disorders of the long head of biceps tendon. *J Shoulder Elbow Surg.* 2012;21(1):136–145. [PubMed: 22005126]
15. Kido T, Itoi E, Konno N, Sano A, Urayama M, Sato K. Electromyographic activities of the biceps during arm elevation in shoulders with rotator cuff tears. *Acta Orthop Scand.* 1998;69(6):575–579. [PubMed: 9930100]
16. Kido T, Itoi E, Konno N, Sano A, Urayama M, Sato K. The depressor function of biceps on the head of the humerus in shoulders with tears of the rotator cuff. *J Bone Joint Surg Br.* 2000;82(3):416–419. [PubMed: 10813181]
17. Kim SJ, Lee IS, Kim SH, Woo CM, Chun YM. Arthroscopic repair of concomitant type II SLAP lesions in large to massive rotator cuff tears: comparison with biceps tenotomy. *Am J Sports Med.* 2012;40(12):2786–2793. [PubMed: 23108636]
18. Levy AS, Kelly BT, Lintner SA, Osbahr DC, Speer KP. Function of the long head of the biceps at the shoulder: electromyographic analysis. *J Shoulder Elbow Surg.* 2001;10(3):250–255. [PubMed: 11408907]
19. Melis B, DeFranco MJ, Ladermann A, Barthelemy R, Walch G. The teres minor muscle in rotator cuff tendon tears. *Skeletal Radiol.* 2011;40(10):1335–1344. [PubMed: 21604212]
20. Neer CS, 2nd, Craig EV, Fukuda H. Cuff-tear arthropathy. *J Bone Joint Surg Am.* 1983;65(9):1232–1244. [PubMed: 6654936]
21. Pagnani MJ, Deng XH, Warren RF, Torzilli PA, O'Brien SJ. Role of the long head of the biceps brachii in glenohumeral stability: a biomechanical study in cadavera. *J Shoulder Elbow Surg.* 1996;5(4):255–262. [PubMed: 8872922]
22. Peltz CD, Hsu JE, Zgonis MH, Trasolini NA, Glaser DL, Soslowsky LJ. Biceps tendon properties worsen initially but improve over time following rotator cuff tears in a rat model. *J Orthop Res.* 2011;29(6):874–879. [PubMed: 21246618]
23. Peltz CD, Hsu JE, Zgonis MH, Trasolini NA, Glaser DL, Soslowsky LJ. Intra-articular changes precede extra-articular changes in the biceps tendon after rotator cuff tears in a rat model. *J Shoulder Elbow Surg.* 2012;21(7):873–881. [PubMed: 21816629]
24. Refior HJ, Sowa D. Long tendon of the biceps brachii: sites of predilection for degenerative lesions. *J Shoulder Elbow Surg.* 1995;4(6):436–440. [PubMed: 8665288]

25. Reuther KE, Sarver JJ, Schultz SM, et al. Glenoid cartilage mechanical properties decrease after rotator cuff tears in a rat model. *J Orthop Res*. 2012;30(9):1435–1439. [PubMed: 22407524]
26. Reuther KE, Thomas SJ, Tucker JJ, et al. Disruption of the anterior-posterior rotator cuff force balance alters joint function and leads to joint damage in a rat model. *J Orthop Res*. 2014;32(5):638–644. [PubMed: 24464961]
27. Sarver JJ, Dishowitz MI, Kim SY, Soslowsky LJ. Transient decreases in forelimb gait and ground reaction forces following rotator cuff injury and repair in a rat model. *J Biomech*. 2010;43(4):778–782. [PubMed: 19931082]
28. Soslowsky LJ, Carpenter JE, DeBano CM, Banerji I, Moalli MR. Development and use of an animal model for investigations on rotator cuff disease. *J Shoulder Elbow Surg*. 1996;5(5):383–392. [PubMed: 8933461]
29. Su WR, Budoff JE, Luo ZP. The effect of posterosuperior rotator cuff tears and biceps loading on glenohumeral translation. *Arthroscopy*. 2010;26(5):578–586. [PubMed: 20434653]
30. Szabo I, Boileau P, Walch G. The proximal biceps as a pain generator and results of tenotomy. *Sports Med Arthrosc*. 2008;16(3):180–186. [PubMed: 18703979]
31. Thomas SJ, Miller KS, Soslowsky LJ. The upper band of the subscapularis tendon in the rat has altered mechanical and histologic properties. *J Shoulder Elbow Surg*. 2012;21(12):1687–1693. [PubMed: 22484390]
32. Thomas SJ, Reuther KE, Tucker JJ, et al. Biceps detachment decreases joint damage in a rotator cuff tear rat model. *Clin Orthop Relat Res*. 2014;472(8):2404–2412. [PubMed: 24326594]
33. Thomopoulos S, Williams GR, Soslowsky LJ. Tendon to bone healing: differences in biomechanical, structural, and compositional properties due to a range of activity levels. *J Biomech Eng*. 2003;125(1):106–113. [PubMed: 12661203]
34. Tucker JJ, Riggan CN, Connizzo BK, et al. Effect of overuse-induced tendinopathy on tendon healing in a rat supraspinatus repair model. *J Orthop Res*. 2016;34(1):161–166. [PubMed: 26218457]
35. Walch G, Edwards TB, Boulahia A, Nove-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. *J Shoulder Elbow Surg*. 2005;14(3):238–246. [PubMed: 15889020]
36. Yamaguchi K, Riew KD, Galatz LM, Syme JA, Neviaser RJ. Biceps activity during shoulder motion: an electromyographic analysis. *Clin Orthop Relat Res*. 1997(336):122–129.
37. Zhang Q, Zhou J, Ge H, Cheng B. Tenotomy or tenodesis for long head biceps lesions in shoulders with reparable rotator cuff tears: a prospective randomised trial. *Knee Surg Sports Traumatol Arthrosc*. 2015;23(2):464–469. [PubMed: 23828089]

What is known about the subject:

Lesions of the long head of the biceps tendon (LHBT) are often associated with massive rotator cuff tears (MRCT) and may be responsible for shoulder pain and dysfunction. As a palliative treatment, biceps tenotomy is frequently recommended for pain relief and potential functional improvement. Despite numerous studies reporting favorable clinical outcomes of biceps tenotomy in the presence of MRCT, the effect of this surgery, on surrounding joint structures, including the intact rotator cuff tendons and glenoid cartilage, still need to be elucidated. Therefore, the objective of this study was to define the impact of surgical detachment of the biceps tendon as a potential treatment in a chronic MRCT rat model. We hypothesized that biceps tenotomy would result in improved mechanical and histological properties of the intact subscapularis tendon and improved *in vivo* shoulder function, while not compromising the glenoid cartilage properties.

What this study adds to existing knowledge:

We found that biceps tenotomy in the presence of chronic massive rotator cuff tears partially preserves overall shoulder function and potentially restores subscapularis tendon health, without detrimental effects on glenoid cartilage. This clinically relevant laboratory study provides substantial basic science evidence to support the use of detachment of LHBT in patients with tears of both the supraspinatus and infraspinatus. This study also adds to the growing literature regarding the protective effects of biceps tenotomy on the shoulder joint in patients suffering from chronic MRCT.

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

Figure 1:

Study design. Pre-injury baseline (Pre) kinematic and kinetic data were collected one day before the detachment of supraspinatus and infraspinatus tendons. Then all the animals underwent the detachment procedure followed by 4 weeks of cage activity to create a chronic MRCT. The animals were randomly allocated into 2 groups receiving either biceps tenotomy or sham surgery as the second intervention (I), following which all animals maintained normal cage activity for an additional 4 weeks before sacrifice. Kinematic and kinetic data were collected 1 day before the second intervention (Pre-I, biceps tenotomy or sham) and at 3, 7, 10, 14, 21 and 28 days post-intervention (BT/SS). (*: Quantitative Ambulation; X: Sacrifice)

Figure 2A:

Quantitative ambulation. Kinetic data: Decreased medial/lateral forces were observed 7d after the intervention in the BT group when compared to pre-intervention values. Decreased propulsion forces were observed in the BT group 10d after the intervention and remained significantly lower when compared to the SS group. Decreased braking forces were observed in both groups during the early post-intervention period but recovered during the later post-intervention period. More evident decrease in vertical forces was observed in the BT groups in early post-intervention period but the rate of loading was higher in the BT group compared to the SS group in later post-intervention period.

Figure 2B:

Quantitative ambulation. Kinematic data: Rats in the SS group showed significantly higher lateral stride width than the BT group at 4 weeks after the intervention. Significantly decreased right limb stride length in the BT group was observed 7d after the intervention but resolved at the 4-week time point. A significant increase in contralateral limb stride length was observed in the SS group 4 weeks post-intervention (Pre: Pre-injury baseline value; Pre-I: 1d pre-intervention; Solid bar: $p < 0.05$, SS = Sham surgery; BT = Biceps tenotomy.)

Figure 3:

Tendon mechanical properties. Lower band of the subscapularis tendon in the BT group showed (A) decreased stress relaxation and (B) increased stiffness, but (C) insertion site modulus was decreased while no difference was found in mid-substance modulus (D). Data are shown as mean with SD. SS = Sham surgery; BT = Biceps tenotomy

Figure 4:

Cartilage mechanical properties. There were no differences observed between groups for cartilage equilibrium elastic modulus (A) or cartilage thickness (B). Data are shown as mean with SD. SS = Sham surgery; BT = Biceps tenotomy; C = center; AS = anterior-superior; AI = anterior-inferior; PS = posterior-superior; PI = posterior-inferior.

Figure 5:

Representative images for the posterior-inferior region of the glenoid cartilage are displayed (Stain, safranin O, fast green and iron hematoxylin; Original magnification, $\times 200$; Scale bar, $5\mu\text{m}$). Posterior-inferior region the glenoid cartilage in (B) the BT group showed an increase of cell density compared to (A) the SS group. SS = Sham surgery; BT = Biceps tenotomy.

Table 1:

Tendon histology. * Values are expressed as median, with range in parentheses; SS = Sham surgery; BT = Biceps tenotomy.

Tendon	Group	Region	Cellularity (Grade)*	p value	Cell shape (Grade)*	p value
Upper Subscapularis	SS	Insertion	1.5 (1–2)	0.99	2.0 (2–3)	0.99
	BT		2.5 (1–3)		2.5 (2–3)	
	SS	Mid-substance	2.0 (1–2)	0.49	1.5 (1–2)	0.43
	BT		1.0 (1–2)		2.0 (2)	
Lower Subscapularis	SS	Insertion	1.0 (1–2)	0.09	2.5 (1–3)	0.99
	BT		2.5 (2–3)		2.5 (2–3)	
	SS	Mid-substance	2.0 (1–3)	0.99	1.5 (1–3)	0.74
	BT		1.5 (1–3)		2.5 (1–3)	

Table 2:

Cartilage histology. *Values are expressed as mean $\pm$ SD; †values are expressed as median, with range in parentheses; SS = Sham surgery; BT = Biceps tenotomy.

Region	Group	Cell density (cells/area)*	p value	Modified Mankin score†	p value
Anterior-inferior	SS	0.44 $\pm$ 0.07	0.66	2.25(2.0–3.0)	0.71
	BT	0.41 $\pm$ 0.06		2.75(2.0–4.0)	
Anterior-superior	SS	0.55 $\pm$ 0.12	0.66	2.25(2.0–3.0)	0.99
	BT	0.52 $\pm$ 0.08		2.5(2.0–3.0)	
Central	SS	0.44 $\pm$ 0.08	0.66	2.5(2.0–4.0)	0.99
	BT	0.49 $\pm$ 0.10		2.5(2.0–4.0)	
Posterior-inferior	SS	0.32 $\pm$ 0.03	0.03	3(2.0–4.0)	0.37
	BT	0.48 $\pm$ 0.06		2.25(2.0–3.0)	
Posterior-superior	SS	0.50 $\pm$ 0.22	0.66	2.75(2.0–4.0)	0.99
	BT	0.54 $\pm$ 0.07		2.5(2.0–3.0)	