A biomechanical study on the effect of long head of biceps tenotomy on supraspinatus load and humeral head position during shoulder abduction

Govender Shavana, MSc[a], Jessica Y. Cronjé, MSc[a], Chris Mcduling, PrEng[b], Reinder B. Verbeek, N3 Eng[c] , Tshifhiwa Nkwenika, MSc Statistics[d] , Erik Hohmann, PhD[e,f, *], Keough Natalie, PhD [a,g]

[a]Department of Anatomy, University of Pretoria, Pretoria, South Africa
[b]Materials Science and Manufacturing, Council for Scientific and Industrial Research, Pretoria, South Africa
[c]CEO Elite Surgical Supplies, Pretoria, South Africa
[d]Biostatistics Unit, South Africa Medical Research Council, Pretoria, South Africa
[e]Medical School, University of Pretoria, Pretoria, South Africa
[f]Department of Orthopaedics Surgery and Sports Medicine, Burjeel Hospital for Advanced Surgery, Dubai, UAE
[g]Department of Anatomy and Cellular Biology, College of Medicine & Health Sciences, Khalifa University, Abu Dhabi, UAE

*Correspondence author: Erik Hohmann, PhD, School of Medicine, Faculty of Health Sciences, University of Pretoria, Cnr Bophelo and Dr Savage Road, Gezina, Pretoria 0001, South Africa.
Email: dr.erik@burjeelspecialty.com

Introduction: The purpose of this study was to determine the effect of biceps tendon tenotomy on the load of the supraspinatus tendon/muscle complex during abduction of the arm from 0° to 15°.

Methods: Eleven fresh frozen human cadaver shoulders (6 males, 5 females, age ranged 44-88 years, mean upper extremity weight 2.96 ± 0.56 kg) were included. The specimens were sequentially mounted onto a custom-made fixture attached to a pulley system and load cell. The pulley system was used to pull the supraspinatus tendon/muscle complex along its fiber directions to abduct the arm to 15°. Abduction angles were recorded with a digital inclinometer. Two conditions were tested: (1) long head biceps tendon (LHBT) intact and in normal anatomical position; (2) LHBT cut within the bicipital groove. Qualitative visual inspection of humeral head displacement during abduction was also included. Descriptive statistics were calculated. The Shapiro-Wilk test was used to establish normal data distribution, and the paired *t*-test was used to compare the 2 conditions.

Results: For the intact condition (LHBT intact), the mean load was 45.71 ± 21.04 N. For the biceps tenotomy test, the load measured 41.37 ± 23.43 N. These differences were not significant ($P = .1480$). In the tenotomy condition, the humeral head initially displaced inferior, and with initiation of abduction, the humeral head translated superior to its normal position.

Conclusion: The results suggest that the LHBT has no critical role with initial abduction of the arm. Furthermore, the LHBT does not appear to increase loads required for the supraspinatus muscle/tendon complex to perform the same action of abduction.

Level of evidence: Basic Science Study; Biomechanics

Keywords: Long head biceps tendon; biceps pulley; tenotomy; tenodesis; glenohumeral joint; supraspinatus tendon load; shoulder abduction

The role of the long head of biceps tendon (LHBT) with regard to the function of the shoulder is still controversial. Several studies reported that the LHBT acts as a glenohumeral joint stabilizer by depressing the humeral head during abduction.[9, 10, 11,15,21] In addition, it assists the deltoid and supraspinatus muscle with abduction and acts as an anterior stabilizer when the arm is abducted and externally rotated.[9, 10, 11,15,21] Some of these studies also suggest that the LHBT should be preserved to maintain shoulder function and kinematics.[10,11,15,21] However, other studies have disputed that the LHBT plays a role in glenohumeral stability or kinematics.[23,24] In addition, clinical studies did not demonstrate deficits in shoulder function after biceps tenotomy, supporting basic science studies that the biceps may not be important for shoulder stability or kinematics.[17] In general, symptomatic LHBT lesions are treated by either biceps tenotomy or tenodesis.[25]

The supraspinatus muscle originates from the supraspinous fossa of the scapula, passes under the acromion, and inserts on the greater tubercle of the humerus.[14] It is responsible for the initiation of arm abduction and controls arm abduction for the first 15°.[12,14] Past 15°, it only assists the deltoid with the abduction of the arm up to 90°.[12,14] In addition, the supraspinatus contributes to shoulder joint stability by providing resistance to gravitational forces acting on the joint and maintaining contact between the head of the humerus and the glenoid fossa.[12,14,22]

Whether the LHBT contributes to initiating abduction is not clear.[2] However, Chalmers et al[2] showed that the LHBT has EMG activity similar to that of the deltoid muscle as the arm is abducted. Eshuis et al[5] also suggested that the LHBT contributes to internal rotation of the humerus in the neutral arm position at 0° of abduction, but restricts the rotation at angles above 45° of abduction.

The purpose of this study was to determine the effect of biceps tendon tenotomy on the load of the supraspinatus tendon/muscle complex during abduction of the arm from 0° to 15°. It was hypothesized that a biceps tenotomy has no effect on supraspinatus load during initial abduction.

Methods

Eleven (5 left and 6 right) fresh frozen human specimens of the upper extremity with an age range of 44-88 years and a mean weight of 2.96 ± 0.56 kg were used in this study and sourced from the National Tissue Bank. Samples were included if they did not show any visible signs of the shoulder surgery or pathology of the long head biceps, the rotator cuff, or deltoid muscle. Samples were excluded if there were any visible signs of previous surgery, macroscopic full thickness, or partial thickness tear of the supraspinatus tendon. This study was approved by the ethics committee of the University of Pretoria and complied with all requirements set out in the National Health Act 63 of 2003.

Specimen preparation

The samples were received and kept frozen (−5°C) in a walk-in freezer. Approximately 24 hours before testing, the prepared shoulders were placed into a refrigerator to thaw and resume their "natural" state. Experiments were performed at room temperatures of approximately 22°C-23°C. The specimens were sprayed with a saline solution during testing to keep them moist.

The overlying skin and fascia of the upper arm and shoulder region were carefully dissected to expose the muscles. All extraneous muscles with the exception of the deltoid, supra- and infraspinatus, and subscapularis were then removed to expose the scapula. The deltoid tendon was dissected off its insertion at the deltoid tuberosity and reflected to expose the LHBT within the bicipital groove. The supraspinatus muscle was carefully dissected from its origin along the supraspinous fossa, but great care was taken to keep the muscle and tendon intact from its origin to the insertion point on the greater tubercle of the humerus (Fig. 1).

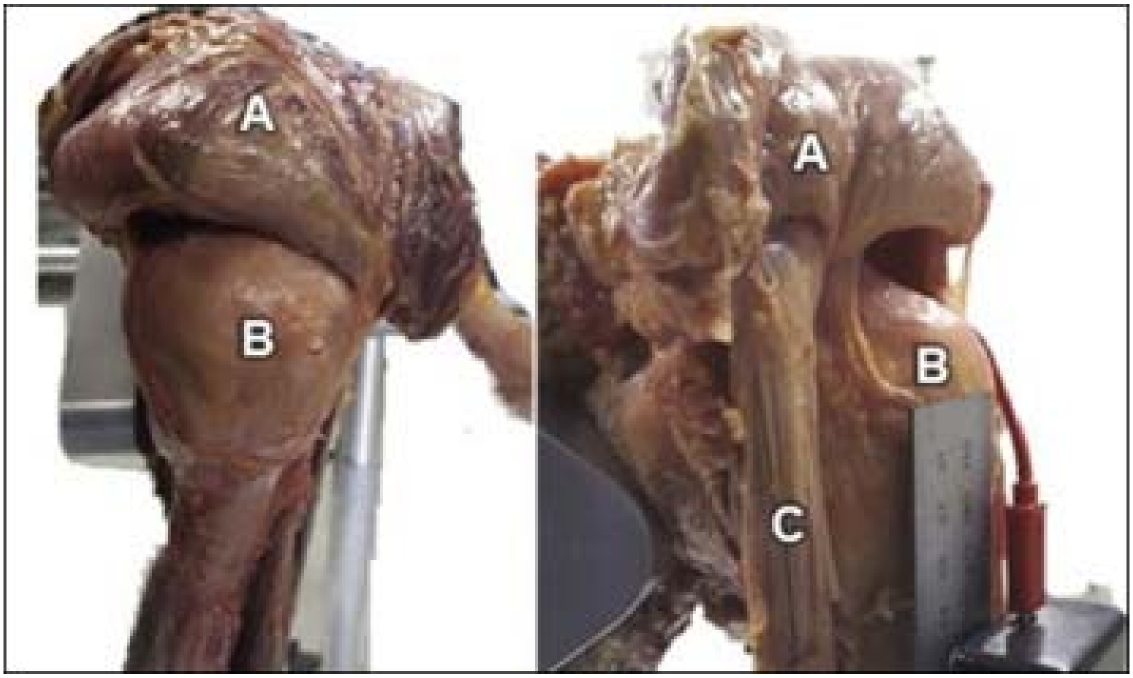

Figure 1. Image showing the humeral head displacement observed before and after the LHBT was cut. Left: Lateral view of a right humeral head in condition 1. Right: Anterior view of a left humeral head in condition 2. Inferior humeral head displacement: A—deltoid; B—humeral head; C—short head of the biceps brachii.

Test setup

Custom-made fixtures for the scapula blades were designed and manufactured by Fluorovizion (Pty) Ltd (Sandton, South Africa). The fixture consisted of 2 spiked clamps that were attached to a base and stem that stood approximately a meter high. The stem was further connected to a pulley system that consisted of a load cell (2000N, HBM [HBM, 2019]) and a smaller clamp with tooth-like projections (Fig. 2). The scapula of the prepared specimens was placed between the 2 spiked clamps. It was ensured that the glenoid was placed vertical to the floor using an inclinometer. The clamps were then gradually tightened to secure the scapula. The specimens were positioned so that the medial border of the scapula was adjacent to the smaller clamp and pulley system, allowing the arm to be positioned away from the stem of the base. With only the scapula fixed to the jig it allowed the arm to abduct and adduct freely. Once the scapula was secured, the elbow joint was fixed to isolate the function of the LHBT at the shoulder.[13] An inclinometer was placed on the distal aspect of the arm to record the angle of inclination. The initial angle displayed by the inclinometer was defined as the neutral position. The small clamp with tooth-like projections was attached 2 cm medial to the dissected free end of the supraspinatus muscle. The clamp was then connected to the load cell and pulley system that was adjusted to correctly align with the fibers of the supraspinatus. Finally, both the inclinometer and the load cell were connected to the software and data acquisition program (Labview (v2017); National Instruments (NI)).

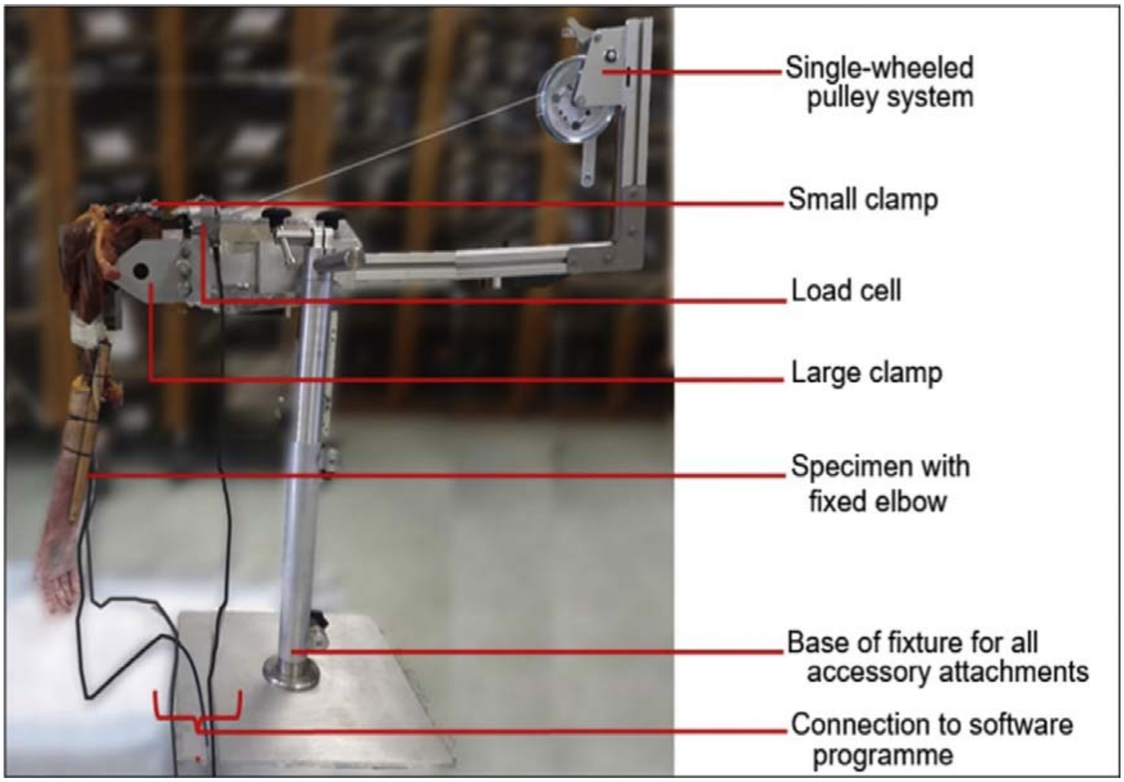

Figure 2. Image showing the equipment setup for each test with the load cell attached to the small clamp. Attached to the large clamp is a right specimen fixed at the elbow.

Test protocol

A static loading force was applied manually to a single wheeled pulley system by rotating the handle of the pulley to wind up the cable and pull the supraspinatus muscle in a horizontal plane (direction of fibers), best replicating its anatomical function, until the arm was abducted to 15° (Fig. 3). The load force applied was recorded in Newtons (N) during inclination. This procedure was repeated 3 times on each specimen for each condition, and the 3 measures were then averaged. After testing of the intact specimens, the LHBT was then cut within the bicipital groove and the test protocol was repeated. It is accepted that biceps tenotomy is normally performed at its insertion. However, as the capsule is an important shoulder stabilizer,[8] tenotomy at the bicipital groove ensured that the integrity of the capsule was maintained. As a secondary outcome measure the humeral head position was visually inspected during manual force loading. The acromion process was used as a reference and the kinematics was reported in a qualitative fashion. The results from the data acquisition program were recorded and exported into an excel spreadsheet for every test.

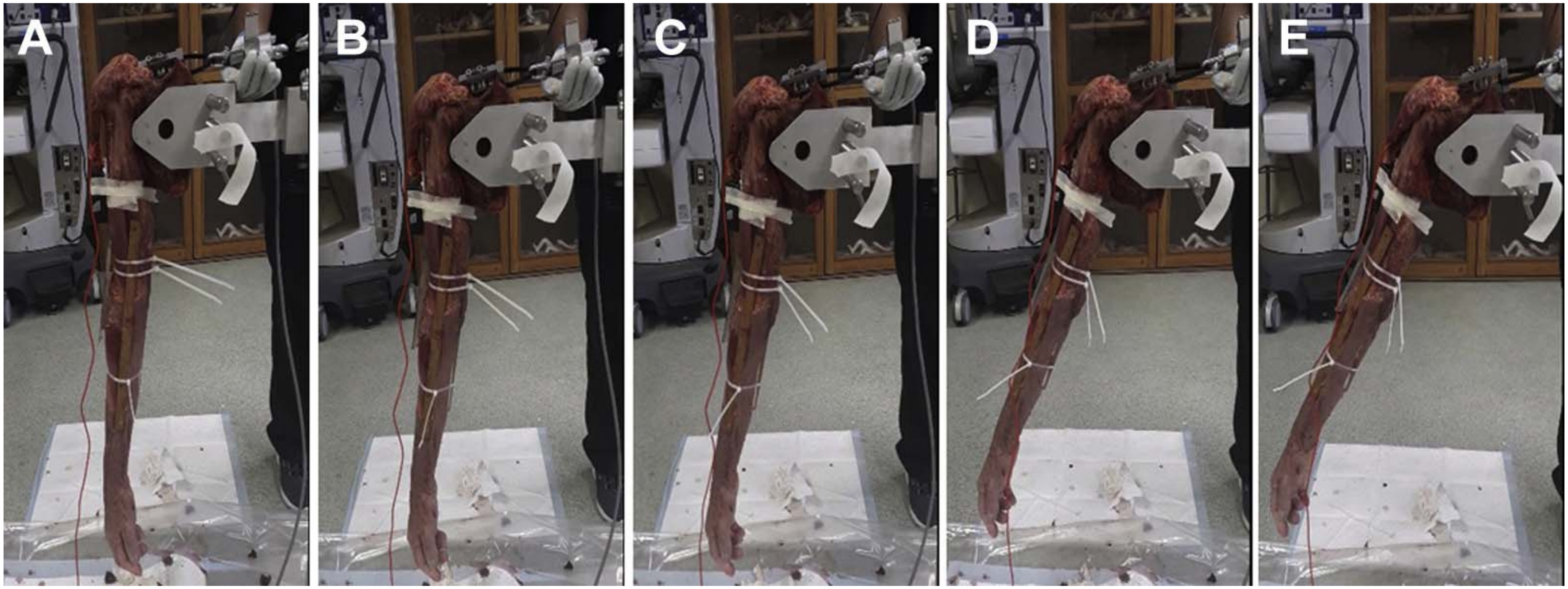

Figure 3. Image showing video frames depicting the lateral rotation of the humeral head and arm during abduction of Arm 009. (**A**) Arm in neutral position. (**B**) Initiating abduction of the arm. (**C**) Abducted arm starts to laterally rotate. (**D**) Abduction and lateral rotation continues. (**E**) The arm at approximately 20° with visible lateral rotation.

Statistical analysis

Descriptive statistics were used for all measures. Mean load (N), final angle measures (degrees), and the standard deviation were calculated. Normal data distribution was assessed with the Shapiro-Wilk test, and homogeneity of variance verified with Levene's test. Between-condition comparisons were conducted using a 2-sample paired *t*-test. A level of significance of $P < .05$ was selected for all analyses. Pearson's moment correlations were used to investigate possible relationships between force required for abduction, angle of abduction, and weight of the arm. An a priori sample size calculation was performed using the following parameters: alpha 0.05, power 0.8, effect size 0.5, mean shoulder abduction force of the supraspinatus muscle at 15° of shoulder abduction 30 N (derived from the paper by Wuelker et al[22]), standard deviation 25% of the applied mean abduction force, and a confidence level of 95% of a minimum acceptable probability of preventing type I error. The calculations determined that a minimum of 10 samples were required to achieve a power of 80%. All analyses were conducted using STATA SE (Version 12.0; StataCorp, College Station, TX, USA) for Windows.

Results

The results for all specimens for both LHBT intact and tenotomy conditions are summarized in Table I. The neutral position for the LHBT intact group was 4.89° ± 1.84°, and the neutral position for the tenotomy group was 4.90° ± 1.82°. The mean load for the LHBT intact group was 45.71 ± 21.04 N and 41.37 ± 23.43 N for the tenotomy group. The load varied among the specimens and was lowest for specimen 7 (7.02 N) and highest for specimen 3 (94.51 N). The mean abduction angle was very similar in both groups (LHBT intact: 15.42°, tenotomy: 15.4°). The 95% confidence interval for both groups was between 14.4° and 16.5°. Pearson's correlation coefficients revealed that there were no significant relationships between angle of abduction and arm weight ($r = 0.156$; $P = .49$) and force needed for abduction and arm weight ($r = 0.071$; $P = .75$).

Table I. Descriptive statistics for condition 1 (LHBT intact) and condition 2 (LHBT cut)

Arm	Condition 1		Condition 2	
	Angle	**Load**	**Angle**	**Load**
001	14.85	58.60	14.85	58.67
002	13.94	62.70	13.95	53.44
003	15.35	84.90	15.35	94.51
004	17.85	61.27	17.85	54.00
005	16.75	30.84	16.63	21.78
006	16.00	38.14	16.04	27.18
007	11.44	7.02	11.50	7.38
008	15.18	25.43	15.13	36.60
009	18.10	44.94	18.10	40.60
010	15.08	45.32	15.04	24.98
011	15.09	43.62	15.03	36.14
Mean	15.42	45.71	15.40	41.37
SD	1.84	21.04	1.82	23.43
SE	0.55	6.34	0.55	7.06
95% CI	14.44-16.52	33.85-57.75	14.40-16.49	27.29-53.80

LHBT, long head of biceps tendon; *SD*, standard deviation; *SE*, standard error; *CI*, confidence interval.

Angle in degrees and Load in Newtons (N).

Humeral head displacements were observed in the tenotomy group. The humeral head initially displaced inferiorly, and when abduction was initiated superior translation of the humeral head was observed (Fig. 1). With time-framed images recorded of each protocol, the tenotomy group also showed increased external rotation movements (Fig. 3).

Discussion

This study demonstrated no significant differences between the mean load of abduction on the supraspinatus muscle when the LHBT was present or when the LHBT was tenotomized. These results suggest that biceps tenotomy, but also tenodesis, does not alter the function of the supraspinatus tendon/muscle complex during initial abduction of the arm. Under these testing parameters, the tenotomy did not increase the load of supraspinatus to perform the same action of abduction. Although no significant differences were demonstrated between the abduction force for each arm under the 2 testing conditions, a decrease in supraspinatus load was noted in 73% of the sample when the biceps tendon was tenotomized. This suggests that the LHBT has more of a stabilizing effect during early abduction, and a tenotomy subsequently decreases the amount of load required by the supraspinatus to initiate the same function.

Both Yamaguchi et al[13, 23] and Levy et al[13, 23] did not find any biceps EMG activity during abduction movements. This is in contrast to Chalmer et al[2] and Sakurai et al,[19] who recorded EMG activity of the biceps during flexion and abduction, which was very similar to deltoid muscle EMG activity. These 4 studies are contradictory, and one could argue that the stabilizing force is most likely related to passive resistance. In all likelihood, an intact LHBT provides some resistance on the glenohumeral joint during the initiation of abduction, stabilizes the joint, and ensures controlled and steady movement.[13] However, additional forces from the capsuloligamentous structures also contribute and can potentially compensate for the stabilizing loss from the LHBT. In theory, these altered biomechanics of the shoulder may pose a greater risk of pathology to the capsuloligamentous structures than the dynamic stabilizers.

It has been suggested that the LHBT plays a pivotal role in reducing strain on the inferior glenohumeral ligaments during abduction; therefore, biceps tenotomy or tenodesis may result in higher strains on the inferior glenohumeral ligament (IGHL) during abduction movements.[18] These theoretical assumptions, however, have not been confirmed by clinical studies.[16] In fact, there is a possible relationship between the LHBT pathology and the rotator interval soft-tissue structures.[1] Arai et al[1] showed that the superior glenohumeral ligament provides buttress support and keeps the biceps tendon in place.

Alternatively, the LHBT may have no significant effect on stabilization of the supraspinatus but when absent may destabilize and disrupt the normal biomechanics. Chen et al[3] and earlier Thomas et al[20] showed that biceps tenotomy partially restored in vivo shoulder function, and gait and ground reaction forces parameters returning close to baseline in a rat model with a massive tear of the rotator cuff. With evolution, the coracoid migrated anteriorly, and with bipeds starting to exist, the biceps tendon divided into a long and short head.[6] The LHBT was positioned between the 2 tubercles as it has been in quadrupeds, but now it had no more stabilizing effect but instead restricted overall motion.[6] As such, it could be considered a vestigial structure causing significant clinical symptoms.[6] These considerations are supported by good and excellent outcomes after either biceps tenodesis or tenotomy.[4] In vivo studies also demonstrated that biceps tenodesis had minimal effects on glenohumeral position, at least negligible compared with normal physiological translations or interpatient variability.[7]

After biceps tenodesis, inferior humeral displacement of the neutral arm was observed. It could be argued that the inferior migration, followed by superior translation after abduction, is a strong argument that the LHBT has a role as a humeral head depressor and stabilizer. However, these findings are defined by the study setup as the deltoid muscle was detached from its insertion for both testing conditions, thereby neglecting the suspensory action of the deltoid on the humerus. This reflection of the deltoid left only the capsuloligamentous structures and the clamped supraspinatus tendon/muscle complex as the only static structures to reduce physiological inferior displacement. The major inferior movement was noted only when the biceps was severed. More importantly, the results of this study showed that biceps tenotomy resulted in an external rotation movement that increased with increasing abduction. Eshuis and De Gast[5] showed that biceps tendon load caused an increase in internal rotation. Obviously, the stabilizing function of the LHBT for rotation is lost once the LHBT is tenotomized.

Limitations

This study has limitations. As always, the small sample size with cadaveric laboratory studies could potentially result in both type I and type II errors. The mean age of the specimen ranged from 44 to 88 years, and tissue quality could have resulted in selection and measurement bias. Biceps tenotomy was performed at the bicipital groove rather than at the superior glenoid to maintain shoulder capsule integrity. It is unlikely that this has influenced test results, but it is theoretically possible that the intra-articular tendon stump may have influenced outcome measures. The degree of chondral and degenerative changes of the articulating surfaces have not been specifically checked, and there is the theoretical possibility that more severe degrees of chondral damage could have influenced loads measured. However, the results were consistent for all specimens reducing the likelihood of these errors. Dissection of the shoulder soft-tissue structures and failure to immobilize the elbow could have resulted in error. Manual pull to achieve the desired abduction angles could have resulted in different load-displacement curves. As these relationships were not the primary goal, it is unlikely that these potential differences in abduction speed would have caused different final mean loads at the desired angle. Finally, a considerable variance for load was observed, and one could argue that the weight of the arm was a possible confounder influencing force vectors. However, Pearson’s moment correlations did demonstrate weak and nonsignificant relationships indicating that the arm weight is unlikely to have influenced the results.

Conclusion

The results suggest that the LHBT has no critical role with initial abduction of the arm. Furthermore, the LHBT does not appear to increase loads required for the supraspinatus muscle/tendon complex to perform the same action of abduction. The LHBT does however play a role in maintaining stability and orientation of the joint during abduction.

Disclaimers:

Funding: This research was funded by the National Research Foundation (NRF; grant no. 105920). Any results obtained, opinions or conclusions expressed are those of the authors and, therefore, the NRF does not accept any liability with regard thereto.

Conflicts of interest: The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Acknowledgments

The authors would like to express their gratitude to the body donors and their families for donating to the National Tissue Bank, Department of Anatomy, School of Medicine of the University of Pretoria; without their contributions this study would not have been possible.

References

1. Arai R, Mochizuki T, Yamaguchi K, Sugaya H, Kobayashi M, Nakamura T, et al. Functional anatomy of the superior glenohumeral and coracohumeral ligaments and the subscapularis tendon in view of stabilization of the long head of the biceps tendon. J Shoulder Elbow Surg 2010;19:58-64. https://doi.org/10.1016/j.jse.2009.04.001
2. Chalmers PN, Cip J, Trombley R, Cole BJ, Wimmer MA, Romeo AA, et al. Glenohumeral function of the long head of the biceps muscle: an electromyographic analysis. 2325967114523902. Orthop J Sports Med 2014;2. https://doi.org/10.1177/2325967114523902
3. Chen M, Shetye SS, Huegel J, Riggin CN, Gittings DJ, Nuss CA, et al. Biceps detachments preserves joint function in a chronic massive rotator cuff tear rat model. Am J Sports Med 2018;46:3486-94. https://doi.org/10.1177/0363546518805091
4. Daou JP, Nagaya DY, Matsunaga FT, Tamaoki MJS. Does biceps tenotomy or tenodesis have better results after surgery? A systematic review and meta-analysis. Clin Orth Relat Res 2021;479:1561-73. https://doi.org/10.1097/CORR.0000000000001672
5. Eshuis R, De Gast A. Role of the long head of the biceps brachii muscle in axial humeral rotation control. Clin Anat 2012;25:737-45. https://doi.org/10.1002/ca.22001
6. Garcia JC, Nunes CV, Raffaelli MDP, Sasaki AD, Salem SH, Rowinski S, et al. Long head of bicepsda vestigial structure. Acta Shoulder Elbow Surg 2017;2:22-7.
7. Giphart JE, Elser F, Dewing CB, Torry MR, Millett PJ. The long head of the biceps tendon has minimal effect on in vivo glenohumeral kinematics: a biplane fluoroscopy study. Am J Sports Med 2012;40:202-12. https://doi.org/10.1177/0363546511423629
8. Gohlke F, Essigkrug B, Schmitz F. The pattern of the collagen fiber bundles of the capsule of the glenohumeral joint. J Shoulder Elbow Surg 1994;3:111-28.
9. Itoi EI, Kuechle DK, Newman SR, Morrey BF, An KN. Stabilising function of the biceps in stable and unstable shoulders. J Bone Joint Surg Br 1993;75:546-50.
10. 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;82:416-9.
11. Kumar VP, Satku K, Balasubramaniam P. The role of the long head of biceps brachii in the stabilization of the head of the humerus. Clin Orthop Relat Res 1989;244:172-5.
12. Lam JH, Bordoni B. Anatomy, shoulder and upper limb, arm abductor muscles. Stat Pearls. Treasure Island, FL: StatPearls Publishing; 2021.
13. 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;10:250-5.
14. McCausland C, Sawyer E, Eovaldi BJ, Varacello M. Anatomy, shoulder and upper limb, shoulder muscles. Stat Pearls. Treasure Island, FL: StatPearls Publishing; 2021.
15. McMahon PJ, Burkart A, Musahl V, Debski RE. Glenohumeral translations are increased after a type II superior labrum anterior-posterior lesions: a cadaveric study of severity of passive stabilizer injury. J Shoulder Elbow Surg 2004;13:39-44. https://doi.org/10.1016/j.jse.2003.09.004

16. Murthi AM, Vosburgh CL, Neviaser TJ. The incidence of pathologic changes of the long head of the biceps tendon. J Shoulder Elbow Surg 2000;9:382-5.
17. Nho SJ, Strauss EJ, Lenart BA, Provencher MT, Mazzocca AD, Verma NN, et al. Long head of the biceps tendinopathy: diagnosis and management. J Am Acad Orthop Surg 2010;18:645-56. https://doi.org/10.5435/00124635-201011000-00002
18. Rodosky MW, Harner CD, Fu FH. The role of the longhead of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. Am J Sports Med 1994;22:121-30.
19. Sakurai G, Ozaki J, Tomita Y, Nishimoto K, Tamai S. Electromyographic analysis of shoulder joint function of the biceps brachii muscle during isometric contraction. Clin Orthop Relat Res 1998;354:123-31.
20. Thomas SJ, Reuther KE, Tucker JJ, Sarver JJ, Yannascoli SM, Caro AC, et al. Biceps detachment decreases joint damage in a rotator cuff treat rat model. Clin Orthop Relat Res 2014;472:2404-12. https://doi.org/10.1007/s11999-013-3422-8
21. Warner JJ, McMahon PJ. The role of the long head of the biceps brachii in superior stability of the glenohumeral joint. J Bone Joint Surg Am 1995;77:366-72.
22. Wuelker N, Plitz W, Roetman B, Wirth CJ. Function of the supraspinatus muscle. Abduction of the humerus studies in cadavers. Acta Orthop Scand 1994;65:442-6.
23. Yamaguchi K, Riew DK, Galatz LM, Syme JA, Neviaser RJ. Biceps activity during shoulder motion: an electromyographic analysis. Clin Orth Relat Res 1997;336:122-9.
24. Youm T, Tibone JE, ElAttrache NS, McGarry MH, Lee TQ. Simulated type II superior anterior posterior lesions do not alter the path of glenohumeral articulation: a cadaveric biomechanical study. Am J Sport Med 2008;36:767-74. https://doi.org/10.1177/0363546507312169
25. Zhou P, Liu P, Deng X, Li Z. Biceps tenotomy versus tenodesis for lesions of the long head of the biceps tendon: a systematic review and meta-analysis of randomized controlled trials. Medicine (Baltimore) 2021;100:e23993. https://doi.org/10.1097/MD.0000000000023993