J Shoulder Elbow Surg (2017) 26, 165–169

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Biomechanical evaluation of two arthroscopic techniques for biceps tenodesis: triple loop suture versus simple suture

Roy Gigi, MD[a], Oleg Dolkart, PhD[a,*], Zachary T. Sharfman, MS[a], Yariv Goldstein, MD[a], Tamar Brosh, PhD[b], Ehud Rath, MD[a], Eran Maman, MD[a], Ofir Chechik, MD[a]

[a]*Shoulder Unit, Orthopaedic Surgery Division, Tel Aviv Sourasky Medical Center and the Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel*
[b]*Biomechanics Laboratory, School of Dental Medicine, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel*

Background: Several techniques and procedures have been described to treat long head of the biceps pathology; however, tenodesis and tenotomy are the 2 most common procedures performed. This study evaluated the initial fixation strength of the biceps tenodesis triple loop suture (TLS) technique and compared it with that of the simple suture technique (SST).
Methods: Twenty fresh frozen cadaveric human shoulders (humeral head and neck with attached biceps tendons) were harvested. The biceps tendon was tenotomized proximally before reattachment to the bicipital groove of the matching humerus using suture anchors. Tenodesis was performed using the SST or the TLS technique. Specimens were tested biomechanically for load to failure, stress, and stiffness. The mechanism of failure was evaluated and compared between the 2 suture techniques.
Results: Maximal load to failure was significantly greater using the TLS technique (122.2 ± 26.73 N) than the SST (46.12 ± 14.37 N, $P < .001$). There was no difference in the mean stiffness (SST: 7.33 ± 4.41 N/mm, TLS: 7.46 N/mm ± 2.67, $P = .94$). The failure mechanism in all SST samples occurred by suture cutout through the longitudinal fibers of the tendon. In all TLS samples, the failure occurred by suture slippage.
Conclusion: This study demonstrated superior load to failure of the TLS compared with the SST technique for biceps tenodesis. Furthermore, this study provides the first description of the TLS technique as a possible application in biceps tenodesis. Clinical application of the TLS must be carefully considered, because although it achieved a superior biomechanical profile, experience with this stitch is limited.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Biceps tenodesis; triple loop suture; simple suture; load to failure; long head of biceps; biomechanics

Long head of the biceps (LHB) tendon lesions are a common source of shoulder pain and often require surgical intervention. Several techniques and procedures have been described to treat LHB pathology; however, tenodesis and tenotomy are the 2 most common procedures performed.[1,3,9,12,13,16] Tenodesis may be preferred when the cosmetic outcome of the surgery is of concern to the patient and may also decrease the postoperative rate of cramping.

Many fixation techniques have been described for biceps tenodesis. Different surgical techniques have various biomechanical implications for the load to failure of the fixated

Institutional Review Board approval was not required for this cadaveric study.

*Reprint requests: Oleg Dolkart, PhD, Shoulder Unit, Orthopedic Surgery Division, Tel Aviv Medical Center and the Sackler Faculty of Medicine, Tel Aviv University, 6 Weizman St, Tel Aviv 64239, Israel.

E-mail address: dolkarto@gmail.com (O. Dolkart).

1058-2746/$ - see front matter © 2017 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2016.05.019

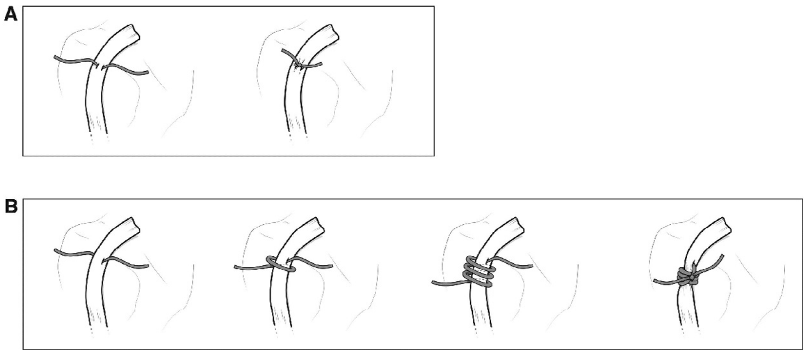

Figure 1 Schematic depiction of the **(A)** simple suture technique and the **(B)** triple loop suture technique **(B)**.

tendon. Fixation of the tendon to the bone, performed open or arthroscopically using subpectoral bone tunnel, interference screw, or suture anchors, have all demonstrated favorable load to failure characteristics.[9] Double-anchor suture techniques and percutaneous intra-articular transtendon techniques have also demonstrated favorable load to failure characteristics.[7] Among arthroscopic techniques, suture anchors provide relatively easy intra-articular fixation; however, the failure rate may be high.[4] Suture techniques, such as the simple suture technique (SST) or mattress sutures, pass the suture fiber through the tendon and rely on the tendon's remaining integrity in load to failure. Thus, the pullout mechanism in these techniques often occurs due to suture fiber pullout from the tendon.[5] Other techniques, such as the lasso loop or Krackow, involve looping the suture fiber around the tendon. In these cases, increased load on the tendon suture junction causes strangulation and a failure mechanism of suture slippage. Elucidating the independent characteristics of these suture techniques remains important for accommodating a patient's postoperative physical demands.

The triple loop stitch (TLS) technique was developed to optimize biomechanical strength of the fixation of the biceps tendon. The TLS technique, further described in this report, consists of a single passage of the suture limb through the LHB tendon. The suture limb is then looped around the tendon 3 times and is tied using 4 half hitches under tension, followed by a single reverse half hitch and a final half hitch for security.

This study compared the biomechanical properties of the TLS suture technique to that of SST technique. The primary outcome was maximal load to failure, and the secondary outcome was the descriptive pullout mechanism. The study hypothesis was that the TLS suture technique would endure greater force before failure and would have a different mechanism of failure than the SST.

Materials and methods

This study used 22 fresh frozen cadaveric human bicep tendons and humerus bones. Two specimens were discarded due to gross signs of soft tissue damage, biceps tears and fraying, leaving 20 samples for testing. The deceased donors were a mean age of 75 years, and 50% were male. The specimens were thawed in saline at room temperature for 24 hours before dissection. The shoulder joint was dissected free of soft tissue, taking care to preserve the proximal humerus and proximal LHB tendon as a free graft. During this process, the biceps tendon origin was cut from its attachment to the superior labrum. Specimens were grossly inspected for signs of soft tissue damage, biceps tears or fraying, biceps rupture, or evidence of prior surgery.

Suture technique

A single loaded 5-mm suture anchor was impacted in the bicipital groove 1 cm distal to the articular surface. Biceps tenodesis was then performed using the SST or TLS technique. Each specimen was allocated randomly to a group, and biomechanical testing immediately followed to prevent the tendon from drying.

The SST was performed using a single strand of United States Pharmacopeia size #2 ultra-high-molecular-weight polyethylene braided suture (Tornier Insite, Lyon, France). The suture was threaded through the LHB tendon at one-third and two-thirds of its width, leaving adequate margins at both lateral borders and at a distance of 1.5 cm from the superior end of the stump. Four half hitches were placed while holding tension, followed by a single reverse half hitch to lock the suture and a final half hitch to ensure security (Fig. 1).

The TLS technique was performed using the same suture strand as the SST (a single strand of United States Pharmacopeia size #2, ultra-high-molecular-weight). One limb of the suture was transferred through the tendon, and then the other limb was passed around the tendon 3 times. The suture was tied with 4 half hitches while holding tension on the post, followed by a single reverse half hitch to lock the knot and a final half hitch for security (Fig. 1).

All procedures were performed by a single fellowship trained shoulder surgeon in an open fashion using arthroscopic instruments: straight penetrating grasper (T.A.G. Medical Products Corporation Ltd., Kibbutz Gaaton, Israel) for suture passing and a knot pusher for knot tying.

Biomechanical testing

Biomechanical testing was conducted with a material testing machine (Model 4502; Instron, Norwood, MA, USA). The humeral shaft was fixated with two 2-mm Kirschner wires into a custom-made frame (Fig. 2). The humerus and biceps tendon were aligned such that the tensile forces throughout the protocol were applied parallel to the longitudinal axis of the humerus, thus approximating the in vivo force

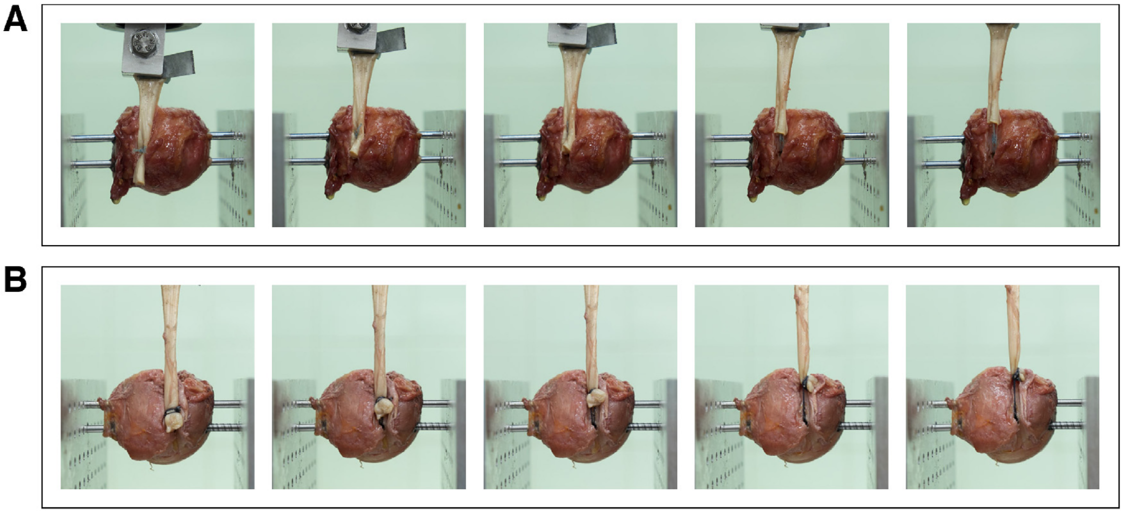

Figure 2 Real-time photographic sequence of biomechanical tension testing of the **(A)** simple suture and **(B)** triple loop suture biceps tenodesis. The sequence can be viewed from left to right. In the left-most images, the tendon can be seen under preload tension progressing to the pullout in the right-most images.

vector of the biceps muscle and tendon as described by Golish et al.[3] Each specimen underwent the same biomechanical testing protocol. An initial preload of 5 N was applied to pretension the tendon.[3] A load to failure protocol was then performed at a displacement rate of 1 mm/s.[3] Load to failure was recorded for each specimen, and stiffness was then calculated within the linear region of the load-displacement curve. Tendon stress was calculated based on load to failure and the cross-sectional tendon area.

Statistical analysis

Power analysis was performed with regard to the primary outcome measure of maximal load to failure on biomechanical testing. Power of 80% is achieved using 10 specimens per group with $\alpha = .05$. A 25% increase in load to failure was set as clinically significant for the current study.[5] Sample power was performed with SPSS SamplePower software (IBM Corp, Armonk, NY, USA). Data are presented as mean ± standard deviation. Student t tests were used to assess significance between the groups. SPSS 21 software (IBM Corp) was used for data analysis. Differences were considered statistically significant at $P < .05$.

Results

Twenty-two cadaveric specimens were dissected. The average tendon cross-sectional area was 18.79 mm^2 (range, 13-29 mm^2) in the TLS group and 19.35 mm^2 (range, 13-29 mm^2) in the SST group (Table I). The cross-sectional area did not differ significantly between the groups ($P = .84$). Load to failure was significantly higher in the TLS group than in the SST group (TLS: 122.2 ± 26.73 N, SST: 46.12 ± 14.37 N, $P < .001$; Table I). There was no difference in the mean stiffness between groups (TLS: 7.46 ± 2.67 N/mm, SST: 7.33 ± 4.41N/mm, $P = .94$; Table I). The mean stress was 5.17 ± 1.94 in the TLS group and 2.48 ± 0.99 in the SST group (Table I). This differed significantly between the groups ($P < .001$).

Table I Biomechanical testing data

Variable*	SST	TLS	*P* value
Cross sectional area, mm	19.35 ± 5.15	18.79 ± 4.95	.84
Load to failure, N	46.12 ± 14.37	122.2 ± 26.73	<.001
Stiffness, N/mm	7.33 ± 4.41	7.46 ± 2.67	.94
Stress, N/m^2	2.48 ± 0.99	5.17 ± 1.94	<.001
Mechanism of failure	Sliding	Slippage	

SST, simple suture technique; *TLS*, triple loop suture.
* Data are reported as means ± standard deviation.

The point of failure in all specimens occurred at the suture–tendon interface. No anchor pullout occurred. In the SST group, the sutures split the LHB tendon in line with the longitudinal tendon fibers until exiting the tendon (Fig. 3). The failure in all TLS samples occurred by suture slippage at the suture tendon junction (Fig. 3).

Discussion

The principal result of this study showed superior load to failure in the TLS group compared with the SST group. In addition, the mechanism of failure consistently differed between the 2 techniques, confirming the study hypothesis. In the SST, the suture fibers cutout through the tendons, whereas the TLS failed due to suture slippage at the suture–tendon junction.

Physicians often use biceps tenodesis procedures to achieve restoration of anatomy, preservation of strength, and good cosmetic outcomes (ie, avoiding Popeye's deformity), and to reduce fatigue or discomfort.[2,6,8] However, biceps tenodesis can be complicated by failures of suture pullout and failure

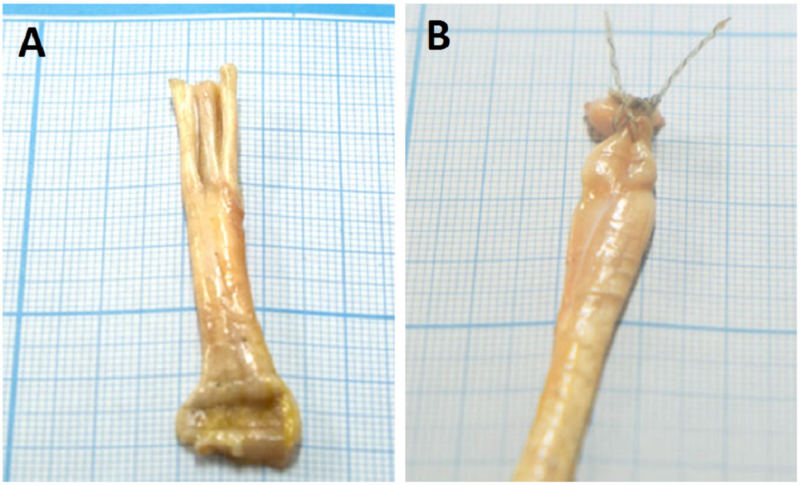

Figure 3 Photographs after tendon failure of the **(A)** simple suture and **(B)** triple loop suture techniques.

at the bone–tendon interface. Patzer et al[11] and Nordin and Frankel[10] estimated that a 112 N load to failure force in LHB tenodesis was adequate to maintain activities of daily living. On the basis of this definition, the TLS technique was shown in this study to provide adequate strength to maintain activities of daily living, whereas the SST was not. However, TLS was still weaker than alternative techniques such as the intraosseous subpectoral cortical button tenodesis (272.0 ± 114.3 N)[14] and the interference screw (280 ± 95 N).[15]

The rationale for the TLS technique was to create a tendon–suture junction without multiple passages of the suture fiber through the tendon, which may weaken the tendon. TLS was also designed to increase contact area between the suture fiber and the tendon, thus increasing the friction force in the suture–tendon junction. In addition, the multiple suture loops are designed to cinch the tendon when loaded, creating an "hourglass" phenomenon to prevent suture slippage.

In 2005, Mazzocca et al[9] tested load to failure of 4 fixation techniques for proximal biceps tenodesis in human cadavers: subpectoral Bio-Tenodesis screws (Arthrex, Naples, FL, USA), subpectoral bone tunnels, arthroscopic interference screws, and arthroscopic suture anchors. They found no significant differences in the load to failure among the 4 techniques.

In a more recent report, Kaback et al[5] compared 3 common suture techniques for proximal biceps tenodesis. They found that the load to failure was 158.3 N for the Krackow suture technique, 46.6 N for the lasso loupe technique, and 109.8 N for the SST technique. The SST and lasso loupe techniques failed by suture pullout through the longitudinal tendon fibers.[5] The Krackow suture failed due to suture breakage between the anchor and tendon–suture junction, whereas the TLS used in this study failed by suture slippage. However, the Krackow suture technique cannot be performed arthroscopically, whereas the TLS can.

The load to failure of the SST reported by Kaback et al[5] was greater than that reported in this study. There are many possible factors that could influence this observation, such as cadaveric age (59 vs. 73 years), different suture strands, and different biomechanical testing apparatus. However, the failure mechanism was similar in both studies. Regardless of the reported load to failure force differences in SST techniques, both shared a common "weak link." More relevant than the numeric value of load to failure reported in this study and the study by Kaback et al[5] are the relative increases in load to failure between the study groups. Maximum load to failure increased by 165% between the SST and TLS groups in the present study and by 45% between the SST and Krackow group in the study by Kaback et al.[5]

This study has some limitations. Results obtained from a cadaveric study must be carefully considered because ex vivo experiments may not accurately represent in vivo forces. Bone density was not assessed in this study; however, no anchor pullout failures were recorded. This demonstrated that the load-bearing capacity of the anchor–bone junction was not reached, regardless of bone quality in the tested specimens. Tendon-healing capacity of the TLS technique was not tested. It would be of value to compare the TLS technique against other commonly used techniques such as the lasso loop, Krackow, bone tunnel, interference screw fixation, or multiple suture anchors. This study did not test cyclical loading. The samples were thawed in saline; however, the biomechanical analysis was not performed under saline.

Conclusions

This study demonstrated superior load to failure of the TLS compared with the SST technique for biceps tenodesis. Furthermore, this study provides the first description of the TLS technique as a possible application in biceps tenodesis. Clinical application of the TLS technique must be carefully considered, because although it achieved a biomechanical profile superior to that of the SST technique, experience with this stitch is limited.

Disclaimer

The authors, their immediate families, and any research foundation 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.

References

1. Boileau P, Krishnan SG, Coste JS, Walch G. Arthroscopic biceps tenodesis: a new technique using bioabsorbable interference screw fixation. Arthroscopy 2002;18:1002-12. http://dx.doi.org/10.1053/jars.2002.36488
2. Frost A, Zafar MS, Maffulli N. Tenotomy versus tenodesis in the management of pathologic lesions of the tendon of the long head of the biceps brachii. Am J Sports Med 2009;37:828-33. http://dx.doi.org/10.1177/0363546508322179
3. Golish SR, Caldwell PE 3rd, Miller MD, Singanamala N, Ranawat AS, Treme G, et al. Interference screw versus suture anchor fixation for subpectoral tenodesis of the proximal biceps tendon: a cadaveric study. Arthroscopy 2008;24:1103-8. http://dx.doi.org/10.1016/j.arthro.2008.05.005
4. Hsu AR, Ghodadra NS, Provencher MT, Lewis PB, Bach BR. Biceps tenotomy versus tenodesis: a review of clinical outcomes and biomechanical results. J Shoulder Elbow Surg 2011;20:326-32. http://dx.doi.org/10.1016/j.jse.2010.08.019
5. Kaback LA, Gowda AL, Paller D, Green A, Blaine T. Long head biceps tenodesis with a knotless cinch suture anchor: a biomechanical analysis. Arthroscopy 2015;31:831-5. http://dx.doi.org/10.1016/j.arthro.2014.11.043
6. Kelly AM, Drakos MC, Fealy S, Taylor SA, O'Brien SJ. Arthroscopic release of the long head of the biceps tendon: functional outcome and clinical results. Am J Sports Med 2005;33:208-13. http://dx.doi.org/10.1177/0363546504269555
7. Lopez-Vidriero E, Costic RS, Fu FH, Rodosky MW. Biomechanical evaluation of 2 arthroscopic biceps tenodeses: double-anchor versus percutaneous intra-articular transtendon (PITT) techniques. Am J Sports Med 2010;38:146-52. http://dx.doi.org/10.1177/0363546509343803
8. Mariani EM, Cofield RH, Askew LJ, Li GP, Chao EY. Rupture of the tendon of the long head of the biceps brachii. Surgical versus nonsurgical treatment. Clin Orthop Relat Res 1988;228:233-9.
9. Mazzocca AD, Bicos J, Santangelo S, Romeo AA, Arciero RA. The biomechanical evaluation of four fixation techniques for proximal biceps tenodesis. Arthroscopy 2005;21:1296-306. http://dx.doi.org/10.1016/j.arthro.2005.08.008
10. Nordin M, Frankel VH. Basic biomechanics of the musculoskeletal system. Philadelphia: Lippincott Williams & Wilkins; 2003.
11. Patzer T, Rundic JM, Bobrowitsch E, Olender GD, Hurschler C, Schofer MD. Biomechanical comparison of arthroscopically performable techniques for suprapectoral biceps tenodesis. Arthroscopy 2011;27:1036-47. http://dx.doi.org/10.1016/j.arthro.2011.03.082
12. Richards DP, Burkhart SS. A biomechanical analysis of two biceps tenodesis fixation techniques. Arthroscopy 2005;21:861-6. http://dx.doi.org/10.1016/j.arthro.2005.03.020
13. Romeo AA, Mazzocca AD, Tauro JC. Arthroscopic biceps tenodesis. Arthroscopy 2004;20:206-13. http://dx.doi.org/10.1016/j.arthro.2003.11.033
14. Sampatacos N, Gillette BP, Snyder SJ, Henninger HB. Biomechanics of a novel technique for suprapectoral intraosseous biceps tenodesis. J Shoulder Elbow Surg 2016;25:149-57. http://dx.doi.org/10.1016/j.jse.2015.07.017
15. Tashjian RZ, Henninger HB. Biomechanical evaluation of subpectoral biceps tenodesis: dual suture anchor versus interference screw fixation. J Shoulder Elbow Surg 2013;22:1408-12. http://dx.doi.org/10.1016/j.jse.2012.12.039
16. Walch G, Nove-Josserand L, Boileau P, Levigne C. Subluxations and dislocations of the tendon of the long head of the biceps. J Shoulder Elbow Surg 1998;7:100-8.