J Shoulder Elbow Surg (2019) 28, 461–469

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Complications of biceps tenodesis based on location, fixation, and indication: a review of 1526 shoulders

Christopher L. McCrum, MD[a], R. Kiran Alluri, MD[b], Michael Batech, DrPH[c], Raffy Mirzayan, MD[d,*]

[a]*Department of Orthopaedic Surgery, UT Southwestern Medical Center, Dallas, TX, USA*
[b]*Department of Orthopaedic Surgery, Keck School of Medicine, University of Southern California, Los Angeles, CA, USA*
[c]*Department of Biostatistics, Programming & Research Database Services, Kaiser Permanente, Pasadena, CA, USA*
[d]*Department of Orthopaedic Surgery, Kaiser Permanente Southern California, Baldwin Park, CA, USA*

Background: Long head of the biceps tendon (LHBT) tenodesis is predominantly performed for 2 reasons: anterior shoulder pain (ASP) or structural reasons (partial tear, dislocation).
Methods: Between 2006 and 2014, all cases of primary LHBT tenodesis performed at an integrated health care system were retrospectively reviewed. Complications were analyzed by tenodesis location (below or out of the groove [OOG] vs leaving tendon in the groove [ITG]), fixation method (soft tissue vs implant), and indication (preoperative ASP vs structural).
Results: Among 1526 shoulders, persistent ASP did not differ by fixation method (11.0% for implant vs 12.8% for soft tissue, $P = .550$) or location (10.8% for OOG vs 12.9% for ITG, $P = .472$). Soft-tissue tenodesis cases had more frequent new-onset ASP (11.9% vs 2.6%, $P < .001$) and subjective weakness (8.50% vs 3.92%, $P < .001$) but less frequent revisions (0% vs 1.19%, $P = .03$) than implant tenodesis cases. No difference was found between ITG and OOG for persistent ASP (12.9% vs 10.8%, $P = .550$), new-onset ASP (6.5% vs 2.8%, $P = .339$), cramping (1.70% vs 2.31%, $P = .737$), deformity (4.72% vs 4.62%, $P = .532$), or subjective weakness (6.23% vs 4.32%, $P = .334$), but ITG cases had more revisions (1.51% vs 0.60%, $P = .001$). Among implant tenodesis cases, 1 shoulder (0.085%) sustained a fracture.
Conclusion: The overall complication rate of LHBT tenodesis was low. Of the shoulders, 10.8% to 12.9% continued to have ASP, regardless of whether the LHBT was left ITG. Soft-tissue tenodesis cases had higher rates of new-onset ASP and subjective weakness. No significant difference for tenodesis ITG or OOG was found in biceps-related complications.
Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Keywords: Shoulder; long head of biceps tendon; tenodesis; subpectoral; suprapectoral; complications; anterior shoulder pain

Institutional review board approval was received from Kaiser Permanente Southern California.

*Reprint requests: Raffy Mirzayan, MD, Department of Orthopaedic Surgery, Kaiser Permanente, 1011 Baldwin Park Blvd, Baldwin Park, CA 91706, USA.

E-mail address: raffy.mirzayan@kp.org (R. Mirzayan).

The long head of the biceps tendon (LHBT) can be a significant pain generator and a significant source of pain and dysfunction of the shoulder.[26,31,50,55] The spectrum of structural pathology includes partial and complete tears, in addition

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2018.09.005

to subluxation and superior labrum anterior-posterior (SLAP) lesions,[8,45,58] and the cause of pain is multifactorial, including a narrow bicipital groove; inflammation and hypertrophy of the tendon, as seen with the "hourglass phenomenon"; and tenosynovitis.[26,37,43,46]

Both tenotomy and a variety of tenodesis techniques have been described in the literature to treat LHBT pathologies, and they all have various advantages and drawbacks. With respect to tenodesis, many techniques have been described, including tenodesis incorporated into the lateral row of a rotator cuff repair,[27,30] percutaneous suprapectoral soft-tissue tenodesis,[54] open suprapectoral soft-tissue tenodesis,[21] arthroscopic suprapectoral tenodesis with an interference screw,[6,36,49] open tenodesis with suprapectoral anchors,[32] subpectoral tenodesis with an interference screw,[35] bicortical subpectoral tenodesis with a cortical button and interference screw, unicortical subpectoral tenodesis,[57] and keyhole tenodesis.[19,34] Although the use of tenotomy to successfully treat LHBT pathology is supported,[20,25] more frequent rates of biceps-related complications, such as cosmetic deformity and cramping,[16,20,24,44] may support the use of tenodesis in patients in whom these events would optimally be avoided, although there is no clear consensus on the preferred location of the tenodesis or fixation method with regard to outcomes. The incidence of biceps tenodesis continues to increase annually, and arthroscopic tenodesis is emerging as a more commonly used technique.[1,59,60]

The purpose of our study was to review a large series of LHBT tenodeses and characterize the incidence of complications, including deformity, cramping, subjective weakness, fracture, nerve injury, and medical complications, based on tenodesis location, technique, and fixation method. Our hypothesis was that there would be no difference in outcomes or complications based on tenodesis technique, implant, or tenodesis location.

Materials and methods

LHBT tenodeses performed between January 1, 2006, and December 31, 2014, by 84 surgeons from 14 hospitals in a multispecialty integrated health care system were retrospectively reviewed. The institutional review board incorporated 14 medical centers, and given the retrospective nature of this study, individual surgeon approval was not required. Our system does not use Current Procedural Terminology codes, so all LHBT tenodesis procedures were identified by using inter-facility codes: "arm biceps, tenodesis long head" and "arm biceps, tenodesis." The inclusion criteria were patients who underwent an arthroscopic shoulder procedure in which the LHBT was surgically released and a tenodesis was performed. The exclusion criteria included biceps tenotomy, spontaneous ruptures of the LHBT, revision tenodesis, arthroplasty, neoplastic or fracture surgery, age younger than 18 years, and incomplete data present in the hospital chart.

Data were collected via an integrated electronic medical record chart review of patient demographic data, including patient age, handedness, side of procedure, date of procedure, and date of most recent follow-up. Follow-up duration in months was calculated. We also collected the concomitant procedures performed at the time of tenodesis, which included rotator cuff repair, labral repair, superior labrum anterior-posterior (SLAP) repair (if performed in addition to tenodesis), subacromial decompression, glenohumeral débridement, subscapularis repair, and distal clavicle resection.

Data were also collected regarding procedure type and location via review of the operative reports of all included patients. The tenodesis technique, location, and implant choice were at the discretion of the treating surgeon. Fixation methods were soft tissue, interference screw, unicortical button, bicortical button, suture anchor, keyhole technique, or a combination of these procedures. We also noted the location of the tenodesis with respect to the bicipital groove. We categorized all tenodesis techniques leaving the LHBT in the groove (ITG), including tenodesis at the articular margin and in the suprapectoral region, as "suprapectoral" tenodesis. "Subpectoral" tenodesis was defined as procedures in which the LHBT was taken out of the groove (OOG); in all of these cases, tenodesis was performed below the groove or in the subpectoral region. Regarding soft-tissue tenodesis, tenodesis was recorded as suprapectoral if sutured to the anterior shoulder soft tissue (percutaneous intra-articular transtendon technique [PITT]), as described by Sekiya et al,[54] or as subpectoral if the tendon had undergone tenodesis to the undersurface of the inferior border of the pectoralis major tendon, as this places the tendon below the limits of the bicipital groove. We also recorded whether the patient underwent a fully arthroscopic procedure or a procedure that required an open or "mini-open" incision for the tenodesis technique.

Postoperative and preoperative data were collected from orthopedic notes for preoperative and postoperative anterior shoulder pain (ASP), biceps (Popeye) deformity, cramping, and subjective weakness at terminal follow-up. Patients with ASP were defined as those with bicipital groove pain to palpation or with Yergason testing. In addition, all postoperative notes were reviewed for additional complications including nerve injury, fracture, superficial and deep infection, revision biceps procedure, hospitalization, pulmonary embolism, and deep vein thrombosis.

An LHBT tenodesis was performed for 2 main reasons. The first was a presentation of preoperative ASP, in which a diagnosis was made and surgical release was planned preoperatively for the treatment of the ASP. The second was structural problems (partial tears, subluxation, or dislocation) without ASP preoperatively. We defined "persistent" ASP as residual pain that did not resolve with biceps tenodesis, indicating that the procedure failed to alleviate ASP at final follow-up. "New-onset" ASP was defined as pain that developed in the anterior shoulder after surgery in patients who did not have ASP before surgery.

Statistics

Normality of continuous variables was tested using the Shapiro-Wilk normality test. Testing of associations between groups was made using the χ^2 or Fisher exact test for categorical variables and the *t* test or nonparametric Wilcoxon ranked sum test, as appropriate. Unless otherwise stated, continuous data are reported as mean and standard deviation with median, interquartile range, and range, and categorical data are reported as frequency and column percentage for each reported group. All analyses were performed using SAS/STAT software (version 12.1; SAS Institute, Cary, NC, USA), and all tests were 2-sided at the 5% type I error rate.

Results

Demographic characteristics

A total of 1795 patients were identified through the search of our institution's database. We excluded 197 patients because they underwent only a tenotomy and no tenodesis, as well as 72 patients who had incomplete data with regard to specific implant selection or location or had no follow-up, leaving 1526 for analysis. Demographic characteristics can be seen in Table I. The average patient age was 53.7 years (range, 18-91 years). The number of procedures based on technique and location is summarized in Table II.

Anterior shoulder pain

Of the patients undergoing tenodesis in which the tendon was taken OOG, 70.6% had preoperative ASP; in contrast, of the patients in whom the tendon was left ITG, 52.8% had preoperative ASP ($P < .001$). No difference in the percentage of patients with ASP was found between those who had soft-tissue tenodesis (64.3%) and those with implant tenodesis (64.5%) ($P = .960$). Table III summarizes anterior pain relative to location and technique.

We found no significant difference in persistent ASP whether the LHBT was left ITG or taken OOG (12.9% vs 10.8%, $P = .550$). No significant difference in new-onset ASP was found whether the LHBT was left ITG or taken OOG (2.80% vs 6.48%, $P = .399$). Soft-tissue tenodesis resulted in a significantly higher rate of new-onset ASP compared with implant tenodesis (11.9% vs 2.6%, $P < .001$). No difference in persistent ASP was noted between implant and soft-tissue tenodesis (11% vs 12.8%, $P = .472$). Patients who underwent LHBT tenodesis for the purpose of structural issues had significantly less pain postoperatively than those who underwent tenodesis for pain (4.8% vs 11.4%, $P < .001$). Patients who had preoperative pain in the biceps had a higher revision rate than those without ASP preoperatively (1.22% vs 0.37%, $P = .026$). Neither anchor size ($P = .079$) nor tunnel size ($P = .403$) was associated with postoperative ASP.

Table I Demographic characteristics

Characteristic	Data (%)
Sex, n	
Male	1080 (70.8)
Female	445 (29.2)
Dominance, n	
Right	1248 (92.5)
Left	89 (6.6)
Ambidextrous or unknown	189 (12.4)
Concomitant procedure, n	
Rotator cuff repair	952 (62.4)
Mumford procedure	332 (21.1)
Labral procedure	236 (13.7)
Subscapularis repair, n	38 (2.2)
Mean follow-up, mo	10.8

Percentages reflect percentages of total population included in study.

Table II Number of biceps tenodesis techniques and locations

Technique and location	n
LHBT remains in groove	530
Soft-tissue tenodesis	144
Anchor	239
Tenodesis screw only	143
Unicortical button	2
Bicortical button only	2
LHBT below groove	996
Soft-tissue tenodesis	209
Anchor	96
Unicortical button	143
Bicortical button only	11
Bicortical button plus screw	92
Tenodesis screw only	439
Keyhole	6

LHBT, long head of biceps tendon.

Biceps-related complications

Implant tenodesis was more likely than soft-tissue tenodesis to result in revision surgery (1.19% vs 0%, $P = .03$). Patients with soft-tissue tenodesis were significantly more likely to experience subjective weakness postoperatively than those with implant tenodesis (8.50% vs 3.92%, $P < .001$). We found no difference in cramping ($P = .531$) and deformity ($P = .677$) between soft-tissue and implant tenodesis. Table IV summarizes biceps-related complications relative to technique and location of tenodesis.

When considering biceps-related complications by tenodesis location, we found no difference in cramping ($P = .737$), deformity ($P = .532$), or subjective weakness ($P = .334$) between techniques leaving the tendon ITG and those taking the tendon OOG. A higher revision rate was noted in ITG procedures (1.51%) compared with OOG procedures (0.60%) ($P = .001$).

Nerve injuries

A total of 18 nerve injuries were encountered, all of which resolved completely within 3 months (Table V). These transient neurapraxias occurred significantly more frequently with tenodesis below the groove (1.70%) compared with ITG (0.19%) ($P = .016$).

Fractures

Only 1 shoulder sustained a proximal humeral fracture after subpectoral LHBT tenodesis. When removing the

Table III Incidence of postoperative shoulder pain by technique and location after tenodesis of long head of biceps tendon

Tenodesis procedure	n	Preoperative pain		Persistent pain		New-onset pain	
		n (%)	*P* value	n (%)	*P* value	n (%)	*P* value
OOG	996	703 (70.6)	<.001*	76 (10.8)	.550	19 (6.5)	.399
ITG	530	280 (52.8)		36 (12.9)		7 (2.8)	
Soft tissue	353	227 (64.3)	.960	29 (12.8)	.472	15 (11.9)	<.001*
Implant	1173	756 (64.5)		83 (11)		11 (2.6)	
Total	1526	983 (64.4)		112 (11.4)		26 (4.8)	

OOG, tenodesis performed with tendon out of groove (below groove); *ITG*, tenodesis performed with portion of tendon remaining in groove.
* *P* values reached statistical significance at $P < .05$ level.

Table IV Biceps-related complications by technique after tenodesis of long head of biceps tendon

Tenodesis technique	n	Cramping (%)	Deformity (Popeye) (%)	Subjective weakness (%)	Revision (%)
Soft tissue	353	6 (1.70)	15 (4.25)	30 (8.50)	0 (0)
Implant	1173	26 (2.22)	56 (4.77)	46 (3.92)	14 (1.19)
Soft tissue vs implant		$P = .531$	$P = .677$	$P < .001$*	$P = .03$*
OOG	996	23 (2.31)	46 (4.62)	43 (4.32)	6 (0.60)
ITG	530	9 (1.70)	25 (4.72)	33 (6.23)	8 (1.51)
OOG vs ITG		$P = .737$	$P = .532$	$P = .334$	$P = .001$*
All tenodeses	1526	32 (2.10)	70 (4.59)	76 (4.98)	14 (0.92)

OOG, out of groove; *ITG*, in groove.
* Statistical significance reached at $P < .05$.

Table V Nerve complications by technique and location after tenodesis of long head of biceps tendon

Technique and location	Musculocutaneous (%)	Axillary (%)	Median (%)	Ulnar (%)	Radial (%)	Overall (%)
Subpectoral tenodesis screw	5 (1.13)	1 (0.23)	2 (0.45)	2 (0.45)	1 (0.23)	11 (2.5)
Subpectoral bicortical button plus tenodesis screw	1 (1.10)	2 (2.15)	0 (0)	0 (0)	1 (1.10)	4 (4.3)
Subpectoral unicortical button	2 (1.38)	0 (0)	0 (0)	0 (0)	0 (0)	2 (1.38)
Anchor in rotator cuff repair	1 (0.67)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.67)

Percentages are expressed as the frequency of the injury relative to the number of each specific technique and location. One should note that only the 4 techniques listed had any nerve-related complications.

soft-tissue tenodesis cases, we found that 1173 underwent a tenodesis in which cortical violation was made, making the incidence of postoperative fracture less than 0.085%. Among the patients who underwent subpectoral tenodesis with an implant (n = 787), the incidence was 0.123%.

The postoperative fracture occurred after a unicortical LHBT button tenodesis in the subpectoral region; the drill hole measured 3.2 mm (Fig. 1). Radiographs showed that the fracture occurred proximal to the tenodesis site and was most likely not related to the tenodesis.

Infections

Open and mini-open techniques showed a significantly higher rate of superficial infection compared with arthroscopic techniques (2.32% vs 0.60%, $P = .029$).

Other complications

Medical complications after LHBT tenodesis were rare. We noted 2 pulmonary emboli (0.13%) and 2 cases of deep vein thrombosis (0.13%). In 1 patient (0.066%), hospitalization was required postoperatively because of the pulmonary embolism.

Concomitant procedures

Of the patients, 81 underwent a tenodesis alone whereas 1445 underwent at least 1 concomitant procedure. After LHBT tenodesis, patients who underwent a rotator cuff repair were more likely to have postoperative cramping (odds ratio, 2.57; 95% confidence interval, 1.22-5.39; $P = .01$), and patients who underwent the Mumford procedure (distal clavicle resection) were significantly more likely to have subjective weakness

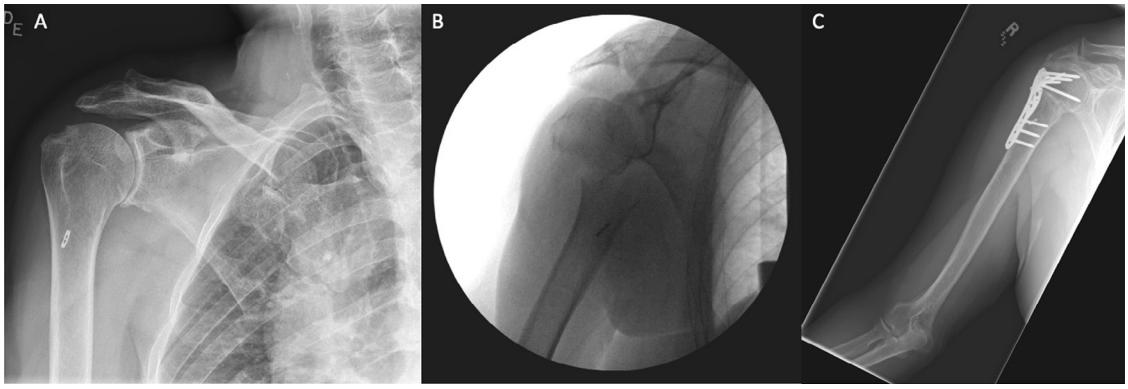

Figure 1 **(A)** Anteroposterior view of a right shoulder after subpectoral unicortical long head of the biceps tendon tenodesis with a suture button through a 3.2-mm drill hole. **(B)** Proximal humeral fracture. **(C)** Open reduction and internal fixation.

Table VI Influence of concomitant procedures on postoperative complications

	Persistent ASP	New-onset ASP	Deformity	Cramping	Subjective weakness
Rotator cuff repair					
P value	*P* = .62	*P* = .73	*P* = .59	*P* = .01*	*P* = .70
OR	1.30	1.11	1.15	2.57	0.91
95% CI	0.46-3.66	0.63-1.96	0.70-1.90	1.22-5.39	0.55-1.49
Subacromial decompression					
P value	*P* = .94	*P* = .52	*P* = .54	*P* = .21	*P* = .97
OR	1.04	1.22	1.18	1.62	0.99
95% CI	0.34-3.17	0.67-2.20	0.70-2.00	0.77-3.43	0.58-1.70
Mumford procedure					
P value	*P* = .75	*P* = .56	*P* = .50	*P* = .71	*P* = .03*
OR	1.21	1.22	1.22	0.84	1.81
95% CI	0.37-4.02	0.63-2.38)	0.68-2.20	0.33-2.15	1.06-3.10
Labral procedure					
P value	*P* = .26	*P* = .55	*P* = .96	*P* = .42	*P* = .14
OR	1.98	0.76	1.02	0.63	0.49
95% CI	0.60-6.54	0.31-1.85	0.50-2.07	0.21-1.89	0.19-1.25

ASP, anterior shoulder pain; *OR*, odds ratio; *CI*, confidence interval.
* Significant at *P* = .05 level.

postoperatively. The concomitant procedures performed in addition to the biceps tenodesis did not significantly influence the frequency of new-onset or persistent pain, nor did the concomitant procedures otherwise significantly influence postoperative complications, as shown in Table VI.

Discussion

This study investigated the effectiveness of LHBT tenodesis in relieving ASP, biceps-related complications, and other surgical complications using various fixation methods, locations, and surgical approaches in a large series. We hypothesized that there would be no difference in outcomes or complications based on tenodesis technique, implant, or tenodesis location, and we did indeed find no difference in persistent ASP, cramping, deformity, or subjective weakness in patients who underwent OOG versus ITG tenodesis. Most important, we found that when a tenodesis was performed to alleviate ASP, an average of 11.4% of patients continued to have persistent ASP regardless of technique or location of tenodesis. This finding suggests that there are other causes of pain ITG than the biceps tendon itself. We found several differences among techniques, including a higher rate of transient nerve injuries for subpectoral tenodesis techniques. Soft-tissue tenodesis had significantly higher rates of new-onset ASP and subjective weakness than implant tenodesis, as well a statistically lower revision rate. Open or mini-open procedures had a higher superficial infection rate than arthroscopic procedures, but no difference in deep infections occurred.

We found that patients who underwent LHBT tenodesis for the purpose of structural issues had significantly less pain postoperatively than those who underwent tenodesis

for pain (4.8% vs 11.4%, $P < .001$). In addition, patients who had preoperative ASP had a higher revision rate than those without ASP preoperatively (1.22% vs 0.37%, $P = .026$). When one compares our findings with the literature, it is important to consider that there are 2 main reasons for performing an LHBT tenodesis. The first is for structural damage to the tendon such as partial tears and dislocation or subluxation from the groove. This scenario is usually encountered intraoperatively, and patients do not necessarily have pain ITG. The second is for the treatment of ASP, which has been linked to the biceps tendon ITG. Currently, most studies combine the results of these 2 groups or compare their findings with other publications of different pathology. This heterogeneity may contribute to the wide range of postoperative pain rates found in the literature, which are reported anywhere from 0.57% to 40%.[38,42,44,63] However, the pathophysiology of these 2 indications is different because patients with ASP have been shown to have a chronic inflammatory process present ITG[41] whereas those with structural issues may not have an inflammatory process present ITG. Therefore, it is important to differentiate patients undergoing tenodesis into those with preoperative ASP and those who do not have pain and undergo tenodesis for structural reasons. Considering this, our findings are similar to what Brady et al[7] reported in a review of 1083 LHBT tenodeses at the articular margin performed for structural reasons: Only 0.4% required revision because of development of biceps-related complications postoperatively, which is consistent with our finding of 0.37%. This helps explain the differences regarding higher revision rates in the literature, up to 2% to 6%,[6,10,33] which partially reflect this difference in the indication for tenodesis.

We also found that regardless of tenodesis technique or location, 11.4% of patients continued to have ASP. This finding implies that there is a component of ASP that may not be directly related to the biceps tendon. This could be from residual tenosynovitis, if complete débridement is not achieved at the time of surgery; "hidden" extra-articular lesions of the LHBT missed using intra-articular tenodesis techniques[40]; or missed diagnoses, such as subscapularis tears or subcoracoid impingement, as Brady et al[7] have indicated.

We found that the frequency of Popeye deformity did not change depending on fixation method (4.25% with soft-tissue tenodesis and 4.77% with implant tenodesis) or tenodesis location (4.72% with the tendon left ITG and 4.62% with the tendon below the groove). Although the literature is heterogeneous in technique, these findings fall within the range of 0.57% to 8% reported in most studies.[22,33,42]

We found the rate of cramping to be much lower than in these reports, however, as we noted a rate of only 2.1% for all tenodesis patients, with no significant differences by technique, location, or implant. However, the rates of cramping have been noted to be as high as 40%.[44] One possible explanation for the higher frequency of cramping with tenodesis noted by our study is the increased frequency of cramping when rotator cuff repair is performed concomitantly with biceps tenodesis. Although our study is not designed to understand why this interesting finding occurs, a possible explanation for the increased frequency of cramping is the increased surgical duration of rotator cuff repair compared with procedures such as subacromial decompression with or without the Mumford procedure. This duration, in addition to the rotator cuff repair itself, can distort the anatomy both locally and owing to swelling of the arm in general. Given that cramping may result from abnormal restoration of the length-tension relation during fixation of the tenodesis,[11,13,28] distortion of the anatomy may make achieving the ideal length-tension relationship more challenging.

When comparing tenodesis techniques, our study found that soft-tissue tenodesis cases had a higher rate of subjective weakness than implant tenodesis cases. This finding is consistent with what has been reported by some authors.[23,52] One possible explanation is that implant tenodesis may provide a more secure fixation, which may result in less change in the length-tension relationship over the course of healing, as under-tensioning of the biceps may result in early fatigue.[11,28] This belies the importance of sturdy fixation of the tenodesis, with anatomic restoration of the length-tension relationship of this muscle, which may be more difficult with tendon-to-tendon repair compared with tenodesis to bone.

Our study noted a reoperation rate of less than 1% for tenodesis of the LHBT, which is lower than what has been reported in the literature.[4] We found that implant tenodesis cases had a significantly higher rate of revision than soft-tissue tenodesis cases (1.19% vs 0%). However, we acknowledge that this finding may be due to selection bias, as it is possible that surgeons performed soft-tissue tenodesis in patients whom they may have believed were lower-demand patients or may not have required strong fixation. In addition, cases of tenodesis with the tendon remaining ITG had a higher revision rate than cases of tenodesis below the groove (1.51% vs 0.60%), which is supported by the biomechanical literature. Werner et al[61] showed increased implant pullout for arthroscopic suprapectoral tenodesis compared with open subpectoral tenodesis. In another study, they found that arthroscopic suprapectoral biceps tenodesis using an interference screw may over-tension the LHBT and result in a decreased ultimate load to failure compared with an open subpectoral technique.[62] Furthermore, the lack of difference between implants in the OOG group noted in our study is also supported by biomechanical work by Buchholz et al,[9] who found no difference in load-to-failure biomechanical testing between subpectoral interference screws and unicortical buttons; other authors have noted no difference in biomechanical failure.[32]

Nerve injury is a potentially devastating complication after tenodesis, specifically with regard to tenodesis distal to the bicipital groove.[48] We found that injury to the nerve is a rare complication, and we encountered no cases that resulted in permanent neurologic dysfunction. However,

neurapraxia does occur significantly more frequently with subpectoral tenodesis techniques (1.70% vs 0.19%). We found that the highest rate of injury occurred for bicortical drilling techniques, at 4.3%, although we did note neurapraxias in cases without bicortical drilling for several subpectoral techniques. The increased frequency of nerve injury with subpectoral techniques is supported by the anatomic relationship of the surrounding neurologic structures and the location of the subpectoral tenodesis, leaving them susceptible to injury from aberrantly placed retractors or the drills and implants themselves. In the subpectoral area, the axillary nerve can be as close as 3 to 36.7 mm from the tenodesis site, the radial nerve can be as close as 26.2 to 48.0 mm from the location of the subpectoral tenodesis, and the musculocutaneous nerve can be between 20.1 and 37.4 mm from the site of the subpectoral tenodesis.[2,15,29,51,56] Despite the near proximity of the axillary nerve shown in cadaveric studies,[2] the incidence of axillary nerve injury was extremely low and temporary, which may result from the swelling of the surrounding soft tissues after arthroscopy. Given the complete recovery of the nerve injuries, it is less likely that these nerves were directly injured by drill bits or implants. These findings suggest that care should be used when placing retractors, specifically medially on the coracobrachialis and short head of the biceps tendon, about the proximal humerus.[5,14]

Given that subpectoral tenodesis fixation in the metaphyseal-diaphyseal bone may act as a stress riser, there may be increased risk of proximal humeral fracture, with several cases reported in the literature.[12,18,47,53] Our study suggests that this complication is extremely rare and is the first to set the incidence of this complication at less than 0.085% in shoulders undergoing implant tenodesis in which a cortical violation is made. This fracture occurred after LHBT tenodesis with a unicortical suture button with a 3.2-mm drill hole; however, we believe that it was not related to the tenodesis site as the fracture occurred much more proximally at the surgical neck, so we believe this to be a coincidental fracture. No other fractures occurred in our study, despite an average tunnel size of 4.9 mm, with tunnel sizes ranging up to 9 mm. Nevertheless, some authors have noted decreased humeral strength to fractures with eccentrically placed tenodesis tunnels, as well as with increasing tunnel size,[17] whereas others have suggested that larger interference screws do not increase the biomechanical risk of fracture.[3] Given that it is uncommon for LHBT length to require a tunnel larger than 5.5 mm,[39] it may be safer to use smaller tunnels to minimize the risk of fracture.

We found that although there was no difference in the rate of deep infections, arthroscopic procedures resulted in a significantly lower rate of superficial postoperative infections (2.32% vs 0.60%). Infections have been shown to occur very infrequently after LHBT tenodesis. A recent meta-analysis reported 3 superficial infections among 271 patients in the open tenodesis group and no superficial infections among 205 patients in the arthroscopic LHBT tenodesis group. As in our study, all superficial infections resolved with antibiotics.

Limitations

Our study is not without limitations. One weakness of this study is its retrospective nature. As such, patients may undergo follow-up at different intervals and durations during the course of their treatment. In addition, our average follow-up period was 10.8 months (range, 3-260 months). This is a somewhat shorter duration of follow-up in relation to some studies published in the literature and was limited by the duration of follow-up that each particular surgeon deemed necessary. In particular, patients who were doing well 3 to 6 months postoperatively were routinely discharged from continued clinical follow-up; however, given that we evaluated outcomes in an integrated health system, patients who had complications, emergency department visits, or clinical follow-up with another physician most often returned to be evaluated by a physician within the system, thus capturing these events, which could be missed by similar retrospective work performed elsewhere. As such, the design of this study in our particular health system allows for capturing complications that occur later postoperatively than the average follow-up may suggest.

Additional limitations of this study include that procedure selection may be subject to selection bias, as the treating physicians may vary their chosen tenodesis decisions based on pathology that may not be captured in our analysis. Furthermore, decisions to perform revision surgery may be influenced by the same factors. Pain scores may also have some limitation in our study, as we chose tenderness in the bicipital groove to palpation and with Yergason testing as a definition of ASP, whereas other testing such as the Speed and O'Brien tests was not performed, as these tests cause subacromial impingement and lead to confounding the etiology of the pain with concomitant rotator cuff or acromioclavicular pathology. In addition, we were unable to include validated outcome scores, such as quantitative pain scores, or patient-reported outcome measures, such as American Shoulder and Elbow Surgeons and Constant shoulder function scores, as these were not routinely collected by all surgeons included in our study. With regard to biceps strength, deformity, and cramping, we rely only on patients self-reporting these symptoms to the treating physician, so we may not capture the full degree of complications that may occur postoperatively.

Conclusion

The overall complication rate of biceps tenodesis was very low. Of the shoulders, 10.8% to 12.9% continued to have ASP in the groove (ITG) regardless of whether the LHBT was left ITG. This finding suggests that there could be other

sources of pain ITG than the LHBT. Soft-tissue tenodesis cases had higher rates of new-onset ASP and subjective weakness. No significant difference was found in ASP, cramping, weakness, or deformity for tenodesis ITG versus OOG. Subpectoral tenodesis had an increased risk of transient nerve injury.

Disclaimer

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.

References

1. Abraham VT, Tan BHM, Kumar VP. Systematic review of biceps tenodesis: arthroscopic versus open. Arthroscopy 2016;32:365-71. http://dx.doi.org/10.1016/j.arthro.2015.07.028
2. Arora AS, Singh A, Koonce RC. Biomechanical evaluation of a unicortical button versus interference screw for subpectoral biceps tenodesis. Arthroscopy 2013;29:638-44. http://dx.doi.org/10.1016/j.arthro.2012.11.018
3. Beason DP, Shah JP, Duckett JW, Jost PW, Fleisig GS, Cain EL. Torsional fracture of the humerus after subpectoral biceps tenodesis with an interference screw: a biomechanical cadaveric study. Clin Biomech (Bristol, Avon) 2015;30:915-20. http://dx.doi.org/10.1016/j.clinbiomech.2015.07.009
4. Becker DA, Cofield RH. Tenodesis of the long head of the biceps brachii for chronic bicipital tendinitis. Long-term results. J Bone Joint Surg Am 1989;71:376-81.
5. Boileau P, Baqué 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;89:747-57. http://dx.doi.org/10.2106/JBJS.E.01097
6. Boileau P, Krishnan SG, Coste J-S, Walch G. Arthroscopic biceps tenodesis: a new technique using bioabsorbable interference screw fixation. Arthroscopy 2002;18:1002-12. https://doi.org/10.1053/jars.2002.36488
7. Brady PC, Narbona P, Adams CR, Huberty D, Parten P, Hartzler RU, et al. Arthroscopic proximal biceps tenodesis at the articular margin: evaluation of outcomes, complications, and revision rate. Arthroscopy 2015;31:470-6. http://dx.doi.org/10.1016/j.arthro.2014.08.024
8. Braun S, Horan MP, Elser F, Millett PJ. Lesions of the biceps pulley. Am J Sports Med 2011;39:790-5. http://dx.doi.org/10.1177/0363546510393942
9. Buchholz A, Martetschläger F, Siebenlist S, Sandmann GH, Hapfelmeier A, Lenich A, et al. Biomechanical comparison of intramedullary cortical button fixation and interference screw technique for subpectoral biceps tenodesis. Arthroscopy 2013;29:845-53. http://dx.doi.org/10.1016/j.arthro.2013.01.010
10. Checchia SL, Doneux PS, Miyazaki AN, Silva LA, Fregoneze M, Ossada A, et al. Biceps tenodesis associated with arthroscopic repair of rotator cuff tears. J Shoulder Elbow Surg 2005;14:138-44. http://dx.doi.org/10.1016/j.jse.2004.07.013
11. David TS, Schildhorn JC. Arthroscopic suprapectoral tenodesis of the long head biceps: reproducing an anatomic length-tension relationship. Arthrosc Tech 2012;1:e127-32. http://dx.doi.org/10.1016/j.eats.2012.05.004
12. Dein EJ, Huri G, Gordon JC, McFarland EG. A humerus fracture in a baseball pitcher after biceps tenodesis. Am J Sports Med 2014;42:877-9. http://dx.doi.org/10.1177/0363546513519218
13. Denard PJ, Dai X, Hanypsiak BT, Burkhart SS. Anatomy of the biceps tendon: implications for restoring physiological length-tension relation during biceps tenodesis with interference screw fixation. Arthroscopy 2012;28:1352-8. http://dx.doi.org/10.1016/j.arthro.2012.04.143
14. Dickens JF, Kilcoyne KG, Tintle SM, Giuliani J, Schaefer RA, Rue J-P. Subpectoral biceps tenodesis: an anatomic study and evaluation of at-risk structures. Am J Sports Med 2012;40:2337-41. http://dx.doi.org/10.1177/0363546512457654
15. Ding DY, Gupta A, Snir N, Wolfson T, Meislin RJ. Nerve proximity during bicortical drilling for subpectoral biceps tenodesis: a cadaveric study. Arthroscopy 2014;30:942-6. http://dx.doi.org/10.1016/j.arthro.2014.03.026
16. Duff SJ, Campbell PT. Patient acceptance of long head of biceps brachii tenotomy. J Shoulder Elbow Surg 2012;21:61-5. http://dx.doi.org/10.1016/j.jse.2011.01.014
17. Euler SA, Smith SD, Williams BT, Dornan GJ, Millett PJ, Wijdicks CA. Biomechanical analysis of subpectoral biceps tenodesis: effect of screw malpositioning on proximal humeral strength. Am J Sports Med 2015;43:69-74. http://dx.doi.org/10.1177/0363546514554563
18. Friedel R, Markgraf E, Schmidt I, Dönicke T. Die proximale Humerusschaftfraktur als Komplikation nach der Schlüssellochplastik. Ein Fallbericht [Proximal humerus shaft fracture as a complication after keyhole-plasty. A case report]. Unfallchirurgie 1995;21:198-201 [in German].
19. Froimson AI, Oh I. Keyhole tenodesis of biceps origin at the shoulder. Clin Orthop Relat Res 1975;(112):245-9.
20. Gill TJ, McIrvin E, Mair SD, Hawkins RJ. Results of biceps tenotomy for treatment of pathology of the long head of the biceps brachii. J Shoulder Elbow Surg 2001;10:247-9.
21. Hitchcock HH, Bechtol CO. Painful shoulder; observations on the role of the tendon of the long head of the biceps brachii in its causation. J Bone Joint Surg Am 1948;30:263-73.
22. 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
23. Hwang J-T, Yang CJ, Noh K-C, Yoo Y-S, Hyun YS, Lee YB, et al. Which is better for arthroscopic tenodesis of the long head of the biceps: soft tissue or bony interference fixation? Arthroscopy 2016;32:560-7. http://dx.doi.org/10.1016/j.arthro.2015.10.024
24. 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
25. Kempf JF, Gleyze P, Bonnomet F, Walch G, Mole D, Frank A, et al. A multicenter study of 210 rotator cuff tears treated by arthroscopic acromioplasty. Arthroscopy 1999;15:56-66.
26. Khazzam M, George MS, Churchill RS, Kuhn JE. Disorders of the long head of biceps tendon. J Shoulder Elbow Surg 2012;21:136-45. http://dx.doi.org/10.1016/j.jse.2011.07.016
27. Lafosse L, Van Raebroeckx A, Brzoska R. A new technique to improve tissue grip: "the lasso-loop stitch". Arthroscopy 2006;22:1246.e1-3. http://dx.doi.org/10.1016/j.arthro.2006.05.021
28. Lafrance R, Madsen W, Yaseen Z, Giordano B, Maloney M, Voloshin I. Relevant anatomic landmarks and measurements for biceps tenodesis. Am J Sports Med 2013;41:1395-9. http://dx.doi.org/10.1177/0363546513482297
29. Lancaster S, Smith G, Ogunleye O, Packham I. Proximity of the axillary nerve during bicortical drilling for biceps tenodesis. Knee Surg Sports Traumatol Arthrosc 2016;24:1925-30. http://dx.doi.org/10.1007/s00167-014-3214-z
30. Levy JC. Simultaneous rotator cuff repair and arthroscopic biceps tenodesis using lateral row anchor. Arthrosc Tech 2012;1:e1-4. http://dx.doi.org/10.1016/j.eats.2011.12.003

31. Longo UG, Loppini M, Marineo G, Khan WS, Maffulli N, Denaro V. Tendinopathy of the tendon of the long head of the biceps. Sports Med Arthrosc Rev 2011;19:321-32. http://dx.doi.org/10.1097/JSA.0b013e3182393e23
32. 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
33. Mazzocca AD, Cote MP, Arciero CL, Romeo AA, Arciero RA. Clinical outcomes after subpectoral biceps tenodesis with an interference screw. Am J Sports Med 2008;36:1922-9. http://dx.doi.org/10.1177/0363546508318192
34. Mazzocca AD, Noerdlinger MA, Romeo AA. Mini open and sub pectoral bicepstenodesis. Oper Tech Sports Med 2003;11:24-31. http://dx.doi.org/10.1053/otsm.2003.35887
35. Mazzocca AD, Rios CG, Romeo AA, Arciero RA. Subpectoral biceps tenodesis with interference screw fixation. Arthroscopy 2005;21:896. http://dx.doi.org/10.1016/j.arthro.2005.04.002
36. Mazzocca AD, Romeo AA. Arthroscopic biceps tenodesis in the beach chair position. Oper Tech Sports Med 2003;11:6-14. http://dx.doi.org/10.1053/otsm.2003.35895
37. Mellano CR, Shin JJ, Yanke AB, Verma NN. Disorders of the long head of the biceps tendon. Instr Course Lect 2015;64:567-76.
38. Millett PJ, Sanders B, Gobezie R, Braun S, Warner JJP. Interference screw vs. suture anchor fixation for open subpectoral biceps tenodesis: does it matter? BMC Musculoskelet Disord 2008;9:121. http://dx.doi.org/10.1186/1471-2474-9-121
39. Mirzayan R, Takara T, Batech M, McCrum CL. In vivo analysis of biceps tendon characteristics in subpectoral tenodesis. Arthroscopy 2017;33:1495-502. http://dx.doi.org/10.1016/j.arthro.2017.03.024
40. Moon SC, Cho NS, Rhee YG. Analysis of "hidden lesions" of the extra-articular biceps after subpectoral biceps tenodesis: the subpectoral portion as the optimal tenodesis site. Am J Sports Med 2015;43:63-8. http://dx.doi.org/10.1177/0363546514554193
41. 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.
42. Nho SJ, Reiff SN, Verma NN, Slabaugh MA, Mazzocca AD, Romeo AA. Complications associated with subpectoral biceps tenodesis: low rates of incidence following surgery. J Shoulder Elbow Surg 2010;19:764-8. http://dx.doi.org/10.1016/j.jse.2010.01.024
43. 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.
44. Osbahr DC, Diamond AB, Speer KP. The cosmetic appearance of the biceps muscle after long-head tenotomy versus tenodesis. Arthroscopy 2002;18:483-7. http://dx.doi.org/10.1053/jars.2002.32233
45. Patzer T, Kircher J, Lichtenberg S, Sauter M, Magosch P, Habermeyer P. Is there an association between SLAP lesions and biceps pulley lesions? Arthroscopy 2011;27:611-8. http://dx.doi.org/10.1016/j.arthro.2011.01.005
46. Refior HJ, Sowa D. Long tendon of the biceps brachii: sites of predilection for degenerative lesions. J Shoulder Elbow Surg 1995;4:436-40.
47. Reiff SN, Nho SJ, Romeo AA. Proximal humerus fracture after keyhole biceps tenodesis. Am J Orthop (Belle Mead NJ) 2010;39:E61-3.
48. Rhee PC, Spinner RJ, Bishop AT, Shin AY. Iatrogenic brachial plexus injuries associated with open subpectoral biceps tenodesis: a report of 4 cases. Am J Sports Med 2013;41:2048-53. http://dx.doi.org/10.1177/0363546513495646
49. Richards DP, Burkhart SS, Lo IK. Arthroscopic biceps tenodesis with interference screw fixation: the lateral decubitus position. Oper Tech Sports Med 2003;11:15-23. http://dx.doi.org/10.1053/otsm.2003.35893
50. Rodosky MW, Harner CD, Fu FH. The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. Am J Sports Med 1994;22:121-30.
51. Saithna A, Longo A, Jordan RW, Leiter J, MacDonald P, Old J. A cadaveric assessment of the risk of nerve injury during open subpectoral biceps tenodesis using a bicortical guidewire. Knee Surg Sports Traumatol Arthrosc 2017;25:2858-63. http://dx.doi.org/10.1007/s00167-015-3972-2
52. Scheibel M, Schröder R-J, Chen J, Bartsch M. Arthroscopic soft tissue tenodesis versus bony fixation anchor tenodesis of the long head of the biceps tendon. Am J Sports Med 2011;39:1046-52. http://dx.doi.org/10.1177/0363546510390777
53. Sears BW, Spencer EE, Getz CL. Humeral fracture following subpectoral biceps tenodesis in 2 active, healthy patients. J Shoulder Elbow Surg 2011;20:e7-11. http://dx.doi.org/10.1016/j.jse.2011.02.020
54. Sekiya JK, Elkousy HA, Rodosky MW. Arthroscopic biceps tenodesis using the percutaneous intra-articular transtendon technique. Arthroscopy 2003;19:1137-41. http://dx.doi.org/10.1016/j.arthro.2003.10.022
55. Sethi N, Wright R, Yamaguchi K. Disorders of the long head of the biceps tendon. J Shoulder Elbow Surg 1999;8:644-54.
56. Sethi PM, Vadasdi K, Greene RT, Vitale MA, Duong M, Miller SR. Safety of open suprapectoral and subpectoral biceps tenodesis: an anatomic assessment of risk for neurologic injury. J Shoulder Elbow Surg 2015;24:138-42. http://dx.doi.org/10.1016/j.jse.2014.06.038
57. Snir N, Hamula M, Wolfson T, Laible C, Sherman O. Long head of the biceps tenodesis with cortical button technique. Arthrosc Tech 2013;2:e95-7. http://dx.doi.org/10.1016/j.eats.2012.12.001
58. Szabó I, Boileau P, Walch G. The proximal biceps as a pain generator and results of tenotomy. Sports Med Arthrosc Rev 2008;16:180-6. http://dx.doi.org/10.1097/JSA.0b013e3181824f1e
59. Vellios EE, Nazemi AK, Yeranosian MG, Cohen JR, Wang JC, McAllister DR, et al. Demographic trends in arthroscopic and open biceps tenodesis across the United States. J Shoulder Elbow Surg 2015;24:e279-85. http://dx.doi.org/10.1016/j.jse.2015.04.021
60. Werner BC, Brockmeier SF, Gwathmey FW. Trends in long head biceps tenodesis. Am J Sports Med 2015;43:570-8. http://dx.doi.org/10.1177/0363546514560155
61. Werner BC, Evans CL, Holzgrefe RE, Tuman JM, Hart JM, Carson EW, et al. Arthroscopic suprapectoral and open subpectoral biceps tenodesis: a comparison of minimum 2-year clinical outcomes. Am J Sports Med 2014;42:2583-90. http://dx.doi.org/10.1177/0363546514547226
62. Werner BC, Lyons ML, Evans CL, Griffin JW, Hart JM, Miller MD, et al. Arthroscopic suprapectoral and open subpectoral biceps tenodesis: a comparison of restoration of length-tension and mechanical strength between techniques. Arthroscopy 2015;31:620-7. http://dx.doi.org/10.1016/j.arthro.2014.10.012
63. Yi Y, Lee J-M, Kwon SH, Kim J-W. Arthroscopic proximal versus open subpectoral biceps tenodesis with arthroscopic repair of small- or medium-sized rotator cuff tears. Knee Surg Sports Traumatol Arthrosc 2016;24:3772-8. http://dx.doi.org/10.1007/s00167-015-3641-5