Improvement in long head of biceps function and lower rate of biceps deformities after subpectoral tenodesis with cortical button and interference screw vs. arthroscopic tenotomy: a 4-year follow-up

Filipe Ferreira Carvalho, MD, MSc[a,b,*], Philip-Christian Nolte, MD, MA[c], Joao Pinheiro, MD[a], Thorsten Guehring, MD[d], Michael Egenolf, MD[a], Thomas Chatterjee, MD[a]

[a]Evangelisches Krankenhaus, Clinic for Trauma and Orthopaedic Surgery, Bad Dürkheim, Germany
[b]Medical Faculty Heidelberg of Heidelberg University, Heidelberg, Germany
[c]BG Trauma Center Ludwigshafen at the University of Heidelberg, Clinic for Trauma and Orthopaedic Surgery, Ludwigshafen, Germany
[d]Diakonie Klinikum, Paulinenhilfe, Clinic for Trauma Orthopaedic Surgery, Stuttgart, Germany

ARTICLE INFO

Background: This study aimed to evaluate clinical, cosmetic, and strength midterm outcomes in arthroscopic biceps tenotomy and subpectoral biceps tenodesis using bicortical endobutton and interference screw.

Methods: In this retrospective study, inclusion criteria were long head of the biceps (LHB) pathologies treated either with tenotomy or an additional tenodesis. Postoperative assessment included Long Head of Biceps Score (LHBS), age-adjusted Constant-Murley Score, and Subjective Shoulder Value. Elbow flexion and forearm supination strength were measured. The presence of Popeye sign, cramps, and tenderness over the bicipital grove was evaluated. Statistical analysis of continuous variables without normal distribution was performed using Mann-Whitney U test. Grouped analysis was performed using 2-way analysis of variance. Binominal data were analyzed using chi-square test.

Results: A total of 73 patients with a mean age of 63.1 ± 9.6 years and a mean follow-up of 4.2 ± 0.5 years were included. Tenotomy was performed in 34 and tenodesis in 39 patients. Tenodesis group displayed a significantly higher LHB score ($P = .0006$), but no significant differences were detected for the age-adjusted Constant-Murley Score and Subjective Shoulder Value. Tenodesis group showed a significantly lower rate of Popeye deformities ($P = .0007$) and tenderness over the bicipital groove ($P = .004$). Patients from the tenotomy group with biceps deformity showed a significantly higher mean contralateral supination strength ($P = .002$) but no significant difference in contralateral elbow flexion compared with patients without biceps deformity. There was one (1.4%) complication in the tenotomy group (postoperative shoulder stiffness).

Conclusion: Both techniques resulted in comparable outcome scores on preselected patients, with tenodesis leading to better LHB function. Tenodesis did not improve elbow flexion and forearm supination strength beyond the tenotomy; however, it reduced the frequency of biceps deformities and tenderness over the bicipital groove. Patients with a strong contralateral forearm supination strength could be at risk of developing a biceps deformity after tenotomy.

Long head of biceps tendon (LHB tendon) lesions typically generate pain in the anterior shoulder and can cause severe disability.[39,55] Recently, these lesions were classified into 6 categories: traumatic injuries, instability, tendinopathies, biomechanical dysfunction, capsular involvement, and superior labral anterior-posterior lesions.[59] They can occur either isolated or in combination with other pathologies; for instance, the presence of instability can contribute to further intraarticular damage, such as supraspinatus and subscapularis tears.[5,59]

The initial approach to LHB tendon disorders is usually nonsurgical and typically includes activity modification, nonsteroidal anti-inflammatory drugs, and ice therapy with gradual strengthening exercises, eventually supported with physical therapy.[8,39]

When symptoms do not resolve and activities of daily living are impaired, a surgical approach may be considered. However, the optimal surgical procedure to address LHB tendon pathology is still controversial.[16,43]

Both tenotomy and tenodesis gained acceptance worldwide as reliable approaches to manage isolated LHB tendon lesions, as well as combined lesions of the rotator cuff and labrum complex.[11]

The first simple arthroscopic tenotomy was performed several decades ago, and Gill et al[16] were the first to report outcomes after treating primary LHB tendon pathology. Their study group reported high rates of pain relief, return to sports, and return to work. This simple and reliable technique rapidly gained popularity by not requiring prolonged postoperative rehabilitation and having a minimal surgical morbidity rate.[16,29,39,42,51,58] Regarding elbow flexion and forearm supination strength, the results are controversial. Although some studies showed a preserved elbow flexion and forearm supination strength after tenotomy, others demonstrated a loss of elbow flexion strength.[2,10,26,32,33,50] In addition, this technique can lead to cosmetic deformity, cramps, and residual pain on the bicipital groove, eventually causing significant impairment in young patients, heavy laborers, and athletes.[3,10,14,26,30,37,42,51,57,58]

Aiming to overcome the disadvantages of tenotomy, the LHB tendon tenodesis has been developed. Through surgical fixation of LHB tendon, patients have demonstrated retained muscle strength, cosmesis, and reduced biceps-related symptoms, making this technique appropriate for young patients, heavy laborers, and athletes.[19]

Although the first tenodesis was described many decades ago, this technique gained popularity only recently, with exponential new techniques in the last decade.[4,20,24,25,36,38] Surgical fixation of the LHB tendon can be performed either open or arthroscopically, and the LHB tendon can be reinserted either intraarticular or extraarticular.[1] Extraarticular placement is usually done below the bicipital groove, and it is classified according to its relationship to the pectoralis major tendon (PMT): suprapectoral, which lies over the superior border of the PMT; or subpectoral, which lies below the inferior border of the PMT.[45] Additional locations have been reported in the literature, such as the conjoint tendon or soft tissue sites, but lost relevance over the years.[12,56] Concerning the fixation methods, suture anchors, bone bridges, interference screws (IS), endobuttons (EB), and combinations of these techniques can be used.[34,35,44,49]

The extraarticular tenodesis offers advantages over the intraarticular, namely, the direct visualization of the inflamed synovium and the sheath release on the LHB tendon can result in lower revision rates, as reported by Sanders et al.[46] Biomechanical studies have shown that tenodesis of the proximal LHB tendon with IS displays a higher ultimate failure load over suture anchor and bone bridges.[34,45]

Previous studies have shown that the highest pullout strength for distal biceps reinsertion was provided by EB[18,35] and that EB combined with IS for the distal biceps repair optimized the initial fixation strength and reduced gap formation.[20,48] Based on these studies, Mithoefer developed the tenodesis of the proximal LHB tendon using a combination of bicortical EB with IS augmentation in a miniopen subpectoral fashion. This combination leads to the restoration of the optimal length-tension relationship of the LHB tendon while providing a high pullout strength.[38,49]

To our knowledge, only a single study described the clinical outcomes after open subpectoral biceps tenodesis (tenodesis) using bicortical EB fixation with IS augmentation and no studies compared clinical outcomes of tenotomy and tenodesis using bicortical EB fixation with IS augmentation.[41]

Therefore, the purpose of this study is to evaluate clinical, cosmetic, and strength midterm outcomes in arthroscopic biceps tenotomy and subpectoral biceps tenodesis using bicortical EB and IS.

We hypothesized that tenodesis patients would perform better on LHB function, forearm supination, and elbow flexion strength and that there would be no difference between the 2 groups on shoulder function and overall satisfaction. In addition, it was postulated a lower prevalence of Popeye sign, cramps, and tenderness over the bicipital groove would occur in tenodesis patients.

Methods

After approval from the local ethics committee, a systematic search for cases including biceps tenodesis or biceps tenotomy was performed at our institution. All electronic records from patients who underwent an tenotomy or a tenodesis using a combination of a bicortical EB with IS augmentation from September 2014 to December 2016 were reviewed.

Patient eligibility

Inclusion criteria were (1) arthroscopically verified proximal LHB tendon pathology and (2) age ≥18 years. Exclusion criteria were (1) previous history of shoulder surgery, (2) history of shoulder revision surgery, (3) history of surgically managed shoulder stiffness, (4) cartilage damage (Outerbridge classification >2), (5) irreparable rotator cuff tear, (6) neuromuscular disorders, (7) concomitant open tendon repair besides tenodesis, (8) ipsilateral or contralateral distal LHB tendon pathology and elbow pathology, and (9) contralateral proximal LHB tendon pathology.

A total of 101 patients met the inclusion criteria, as illustrated in Figure 1. After contacting the patients, 28 refused to participate in the study. Finally, 73 patients were included and signed the written informed consent before undertaking any study procedures and were therefore enrolled in the study.

Operative technique

Patients with a suspected LHB tendon pathology based on clinical examination including at least one positive biceps-specific test (Palm-Up, Yergason, Speed Test),[6] who did not respond to nonsurgical therapy, underwent preoperative counseling regarding the benefits and disadvantages of both techniques. Heavy laborers and physically active patients with high shoulder demand were counseled toward tenodesis; older patients, physically inactive or with low shoulder demand, were counseled toward tenotomy. Patients were empowered to participate in the decision-making process; thus, randomization to either one of the techniques was not possible.

Patients were placed in a modified beach-chair position, and preoperative single-shot antibiotics were administered. After draping and sterilization, diagnostic arthroscopy with standard arthroscopy portals was performed. After intraoperative confirmation of LHB tendon pathology, tenotomy was performed. After completing the diagnostic round, further surgical procedures were performed if additional intraarticular pathologies were present.

On preselected patients, tenodesis was performed according to the technique described by Mithoefer[38]: The arm was slightly abducted and externally rotated, a vertical 3 cm incision was made at the inferior border of the PMT. After blunt dissection, the bone bed was prepared for LHB tendon reinsertion. After identifying the bicipital groove and LHB tendon, the latter was retracted out of the joint and marked and cut 2 cm proximal to the muscle-tendon
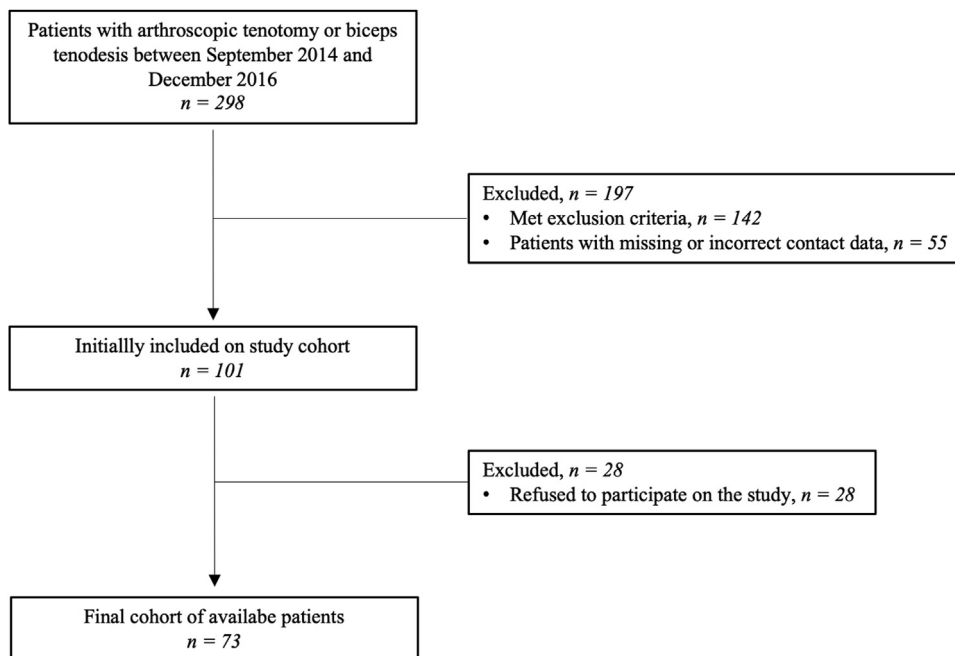
Figure 1 Flowchart diagram of study design.

junction. The tendon was then examined, and the inflamed synovium was released and removed. A high-strength suture (FiberWire No. 2; Arthrex, Naples, FL, USA) was used to suture the tendon in a whipstitch fashion. An EB (BicepsButton; Arthrex, Naples, FL, USA) was placed at the end of the suture, and the diameter of the tendon was measured. A 3.2 mm guide pin was placed into the anterior humerus 2 cm below the pectoralis tendon and drilled straight through the anterior and posterior cortex. A cannulated reamer with the previously measured tendon's diameter was drilled through the anterior humeral cortex into the medullary canal without drilling into the posterior cortex. The EB was then passed through the posterior cortex with a short redon drain and a guide pin as previously described by Nolte et al[40] and then flipped. Subsequently, the tendon was dynamically reduced into the humeral tunnel by tensioning the sutures. After achieving the tendon's optimal length-tension relationship, an IS with a diameter 1 mm smaller as the tendon was then placed into the tunnel.

Postoperative care

For patients with rotator cuff repair and LHB tendon lesions, the arm was placed into an abduction sling (ADVAGOshoulder; OPED, Valley, Germany) for 4-6 weeks, and during this period, only passive ROM of the shoulder was allowed.

If a tenotomy without rotator cuff repair was performed, the arm was placed into a sling (SUPROshoulder; OPED) for 2 days, and patients were advised to wear it at night for 2 weeks. Gradually, full active range of motion (ROM) of the shoulder was allowed after the second day.

For the tenodesis without cuff repair, the arm was also placed into a sling (SUPROshoulder) for 2 weeks. Full active-assisted ROM of the shoulder and elbow were allowed. Patients were advised to wear it at night for a total of 4 weeks. After the third week, active ROM of the shoulder and elbow was allowed without exceeding 1 kg of elbow flexion until the sixth week. Progressive resistance training was allowed after the seventh week, and a return to sport or heavy labor was possible after 3 months.

Surgical data

Patients who agreed to participate in this study were invited for a follow-up in-person clinical examination performed by an examiner who did not perform the surgeries. Age, gender, body mass index, follow-up time, surgical time, additional surgical procedures, complications, and intraoperative findings were also collected. Patients were asked to complete the age-adjusted Constant-Murley Score (CMSa),[9,52] Long Head of Biceps Score (LHBS),[27,47] and Subjective Shoulder Value (SSV)[15] after they arrived at the clinic. To obtain strength values for CMSa and LHBS, a tension spring balance (Macro-Linie 35 kg; Pesola, Schindellegi, Switzerland) was used. Because of the significant difference in age and gender between groups (Table I), the CMS was first collected and then corrected for age and gender.[52]

Elbow flexion strength on both sides was measured using a tension spring balance (Macro-Linie 35 kg) with the patient standing and the fully supinated elbow bent at 90°. After a rest time of 5 minutes, forearm supination strength was measured using a hydraulic wrist dynamometer with door handle attachment (Baseline Hydraulic Wrist Dynamometer; Fabrication Enterprises Inc., White Plains, NY, USA). This device was attached to a custom-made wall created for this purpose. The patient stood in front of the device with the elbow bent at 90° and the forearm in a neutral position. The patient maintained the grip on the door handle while supinating the forearm.

Statistical analysis

Data are presented as mean, range, and standard deviation if continuous and as numbers and percentages if categorical. Normal distribution was assessed using Shapiro-Wilk test. Statistical analysis of continuous variables without normal distribution was performed using Mann-Whitney U test. Grouped analysis was performed using 2-way analysis of variance. Binominal data were analyzed using chi-square. The significance level was set at $P < .05$. The data analysis was performed using PRISM 8 (GraphPad Software, San Diego, CA, USA).

Table I
Patient demographic and additional surgical procedures

Characteristic	Tenotomy (n = 34)	Tenodesis (n = 39)	P value
Mean age (SD), yr	67.3 (9.6)	59.5 (8.0)	**.001**
Sex, n (%)			**.008**
Male	14 (41.2)	28 (71.8)	
Female	20 (58.8)	11 (28.2)	
Mean BMI (SD), kg/m^2	28.4 (4.6)	28.2 (4.6)	.826
Mean follow-up (SD), yr	4.1 (0.4)	4.3 (0.5)	**.045**
Mean surgical time (SD), min	79.3 (33.3)	92.3 (29.6)	.083
Mean contralateral strength (SD), kg			
Flexion	16.6 (7.5)	23.8 (8.6)	**.0004**
Supination	100.7 (40.5)	146.7 (44.9)	**<.0001**
Additional surgical procedures[*], n (%)			
Rotator cuff repair	21 (61.8)	14 (35.9)	**.027**
Subacromial bursectomy	34 (100.0)	39 (100.0)	>.999
Débridement of calcific deposit	1 (2.9)	7 (17.9)	**.041**
Acromioclavicular joint resection	4 (11.8)	2 (5.1)	.303
Acromioplasty	10 (29.4)	11 (28.2)	.910

BMI, body mass index; *SD*, standard deviation.
The significance value was set at $P < .05$.
  [*]All performed arthroscopically.

Results

Patient demographic, additional surgical procedures, and intraoperative findings

A total of 73 patients were included in the final follow-up. Both groups were significantly different regarding age, gender, contralateral flexion, and supination strength and whether they underwent a rotator cuff repair. Demographic information and additional surgical procedures for each group are listed in Table I. The intraoperative findings are listed in Table II. There was no significant difference regarding the type of LHB tendon lesion between groups.

Functional outcomes

Functional outcomes for each group are listed in Table III. The CMSa was higher for the tenodesis group without statistical significance ($P = .056$). The LHBS was significantly higher for the tenodesis group ($P = .0006$). Patients in the tenodesis group displayed higher, but not statistically significant, satisfaction rates compared with the tenotomy group ($P = .051$). Maximum elbow flexion and forearm supination were significantly higher for the tenodesis group ($P = .0006$ and $P < .0001$, respectively). However, there was no statistical difference between both arms among groups ($P = .359$ and .309, respectively).

Rotator cuff repair

Patients who underwent rotator cuff repair in the tenotomy group (n = 21) had similar outcomes regarding CMSa (77.55 ± 20.48 vs. 69.45 ± 21.17; $P = .215$), LHBS (85.90 ± 13.41 vs. 79.77 ± 15.90; $P = .165$), and SSV (84.29 ± 15.27 vs. 81.92 ± 19.64; $P = .798$) compared with participants within the same group who did not undergo rotator cuff repair (n = 13). Similar results were observed for patients in the tenodesis group regarding CMSa (86.00 ± 17.75 vs. 82.35 ± 17.12; $P = .266$), LHBS (96.71 ± 7.14 vs. 92.32 ± 9.08; $P = .077$), and SSV (92.14 ± 9.75 vs. 90.08 ± 10.85; $P = .541$).

Cosmetic outcome measures and other local findings

Cosmetic outcome measures and other local findings for each group are listed in Table IV.

Patients in the tenodesis group had significantly fewer Popeye signs ($P = .0007$) and tenderness over the bicipital groove ($P = .004$). Although there was no significant difference regarding cramps between both groups ($P = .565$), some patients without history of contralateral shoulder pathology reported cramps in both arms. After adjusting for this factor and comparing only the presence of unilateral cramps on the treated shoulder, there was a significantly lower presence of cramps among participants in the tenodesis group (0/33 vs. 5/33; $P = .02$).

Functional outcome among participants with Popeye deformity

Patients from the tenotomy group who developed a Popeye sign (n = 14) showed a significantly higher contralateral forearm supination strength than the patients from this group without deformity ($131.0 \text{ kg} \pm 47.8$ vs. $83.1 \text{ kg} \pm 26.8$; $P = .002$) and a slightly higher contralateral elbow flexion, without reaching statistical significance ($18.9 \text{ kg} \pm 8.9$ vs. $15.1 \text{ kg} \pm 6.2$; $P = .227$), as shown in Figure 2. There was no statistical difference regarding CMSa (76.94 ± 24.19 vs. 72.71 ± 18.56; $P = .207$), LHBS (78.43 ± 14.80 vs. 87.15 ± 13.49; $P = .084$), and SSV (83.93 ± 14.17 vs. 83.00 ± 18.81; $P = .965$).

On the contrary, patients from tenodesis group with and without the deformity did not show any difference regarding contralateral forearm supination ($137.3 \text{ kg} \pm 25.4$ vs. $147.4 \text{ kg} \pm 46.31$; $P = .702$) and no significant difference in contralateral elbow flexion strength ($20.83 \text{ kg} \pm 6.53$ vs. $24.08 \text{ kg} \pm 8.84$; $P = .590$). The LHBS was significantly lower for patients within this group with Popeye deformity (82.33 ± 6.81 vs. 94.86 ± 8.10; $P = .014$). There was no statistical difference regarding CMSa (74.20 ± 22.81 vs. 84.45 ± 16.83; $P = .510$) and SSV (85.00 ± 13.23 vs. 91.31 ± 10.19; $P = .466$).

Complications

The analyzed cohort of 73 patients revealed one complication: 1 postoperative shoulder stiffness (1.4%), which was managed nonsurgically. There were no infections, no neurovascular injuries, and no postoperative fractures of the humerus.

Discussion

This study demonstrates that using specific selection criteria, patients can be directed into 2 different modes of treatment of biceps pathology, which results in a comparable outcome regarding shoulder function and satisfaction. Patients in the tenodesis group

Table II
Intraoperative findings

Finding	Tenotomy (n = 34)	Tenodesis (n = 39)	*P* value
Proximal biceps tendon			
Tenosynovitis, n (%)	6 (17.6)	5 (12.8)	.565
SLAP lesion, n (%)	22 (64.7)	31 (79.5)	.158
Type I	2 (9.1)	2 (6.5)	.888
Type II	20 (90.9)	26 (83.9)	.489
Type III	0 (0)	2 (6.5)	.181
Type IV	0 (0)	1 (3.2)	.347
Pulley lesion, n (%)	9 (26.5)	15 (38.5)	.277
Partial and complete tear, n (%)	2 (5.9)	1 (2.6)	.476
Rotator cuff	23 (67.6)	22 (56.4)	.325
Supraspinatus and infraspinatus tear	22 (64.7)	21 (53.8)	.347
Partial-thickness tear, n (%)	4 (11.8)	9 (23.1)	.208
<3 mm, (<25%)	1 (25.0)	5 (55.6)	.125
3-6 mm, (25-50%)	0 (0)	1 (11.1)	.347
>6 mm, (>50%)	3 (75.0)	2 (22.2)	.533
Full-thickness tear, n (%)	18 (52.9)	12 (30.8)	.055
Small (0-1 cm)	2 (11.1)	1 (8.3)	.476
Medium (1-3 cm)	1 (5.6)	6 (50.0)	.072
Large (3-5 cm)	14 (77.8)	4 (33.3)	**.002**
Massive (>5 cm)	1 (5.6)	1 (8.3)	.922
Subscapularis tear, n (%)	3 (8.8)	3 (7.7)	.861
Partial-thickness tear	2 (66.7)	2 (66.7)	.888
Full-thickness tear of the upper 25%	1 (33.3)	1 (33.3)	.922
Calcifying tendinitis, n (%)	1 (2.9)	7 (17.9)	**.041**
AC joint arthritis	4 (11.8)	3 (7.7)	.584

AC, acromioclavicular; *SLAP*, superior labrum anterior posterior.
The significance value was set at *P* < .05.

Table III
Functional outcome measures

Outcome	Tenotomy (n = 34)	Tenodesis (n = 39)	*P* value
Constant-Murley Score (age adjusted)	74.45 (20.81)	83.66 (17.20)	.056
Long Head of Biceps Score	83.56 (14.50)	93.90 (8.60)	**.0006**
Subjective Shoulder Score	83.38 (16.82)	90.82 (10.38)	.051
Mean strength, kg			
Flexion	15.69 (8.06)	23.26 (9.24)	**.0006**
Ratio (treated/nontreated)	0.96 (0.30)	0.97 (0.16)	.359
Supination	102.80 (45.71)	150.70 (49.28)	**<.0001**
Ratio (treated/nontreated)	0.99 (0.26)	1.03 (0.17)	.309

The significance value was set at *P* < .05.

Table IV
Cosmetic outcome measures and other local findings

Outcome	Tenotomy (n = 34)	Tenodesis (n = 39)	*P* value
Popeye sign, n (%)	14 (41.2)	3 (7.7)	**.0007**
Mild	10 (71.4)	2 (66.7)	
Moderate	2 (14.3)	1 (33.3)	
Severe	2 (14.3)	0 (0)	
Tenderness over the bicipital grove, n (%)	17 (50.0)	7 (17.9)	**.004**
Cramps, n (%)	6 (17.6)	5 (12.8)	.565
At rest	5 (83.3)	4 (80.0)	
On exertion	1 (16.7)	1 (20.0)	

The significance value was set at *P* < .05.

display an improved LHB function by means of a significantly higher LHBS, which does not result in higher satisfaction rates.

In addition, tenodesis resulted in a lower rate of Popeye sign, tenderness over the bicipital groove, and unilateral cramps. However, this technique does not increase the force generation of biceps beyond that of tenotomy.

The decision criteria described by Hsu et al[21] were used to advise our patients, except the age, which was not considered as a crucial decision factor. Indeed, we consider that the biological age should play a more substantial role rather than using a predefined age value.

One of the major findings of this work was that tenodesis does not influence postoperative shoulder function and the overall satisfaction over tenotomy, as assessed by CMSa and SSV. This is in accordance with the previous results published by Kerschbaum et al,[28] who conducted a study with a similar design on pre-selected patients according to the criteria described by Hsu et al.[21] However, in contrast to this study, our tenodesis group showed a significantly higher LHBS compared with the tenotomy group, mainly due to the low presence of Popeye sign and the low rate of tenderness over the bicipital groove. A possible reason for the discrepancy between studies can be explained by the biomechanically proven higher primary stability of intraosseous biceps tenodesis compared with epiosseus tenodesis, potentially resulting in higher rates of failure in comparison to intraosseous techniques.[25,44,49]
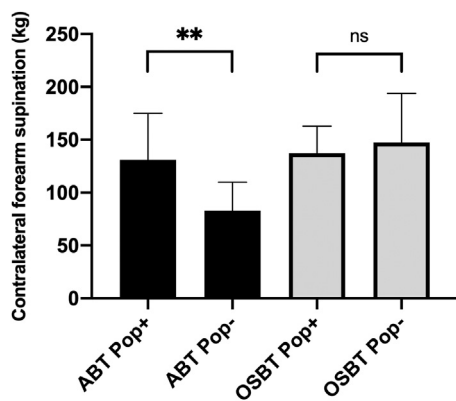
Figure 2 Mean contralateral forearm supination among patients with and without Popeye sign. *ABT Pop+*, arthroscopic biceps tenotomy group with Popeye sign; *ABT Pop−*, arthroscopic biceps tenotomy group without Popeye sign; *OSBT Pop+*, open subpectoral biceps tenodesis with Popeye sign; *OSBT Pop−*, open subpectoral biceps tenodesis without Popeye sign; **P = .002.

Regarding strength, the tenodesis group displayed a significantly higher elbow flexion and forearm supination on the treated arm when compared with the tenotomy group. This does not reflect a higher force generation due to improved restoration of the optimal length-tension relationship of the LHB tendon as proposed by Mithoefer, but rather the effect of preselecting patients according to Hsu criteria.[21,38] In fact, also the nontreated arm displayed a significantly higher elbow flexion and forearm supination strength. As the strength ratio treated/nontreated arm did not show any significant difference between the groups, we conclude that both techniques do not impair the force generation of the biceps. Similar findings were previously shown by Shank et al[50] and Friedman et al,[13] who did not find strength differences for both flexion and supination on tenodesis and tenotomy.

Moreover, the first prospective randomized trial on tenotomy and arthroscopic suprapectoral tenodesis with a small cohort of 42 patients did not find a difference in elbow flexion and forearm supination at 12 months.[22] Conversely, a retrospective study from Kerschbaum et al[28] showed a significantly higher force generation for both supination and flexion for arthroscopic suprapectoral tenodesis, compared with the unimpaired contralateral side, over patients after tenotomy. This difference could be attributed to the heterogeneity of the groups and the different techniques, materials, and anchor systems used.

Another important finding of our study is related to the cosmetic outcome. Only 7.7% of the tenodesis group participants developed a Popeye sign, compared with 41.2% in the tenotomy group. Similar observations have been described in previous studies.[7,31,51,58] Studies in which earlier techniques were used reported higher rates of Popeye sign after tenodesis, which could be linked to the lower primary stability of the anchor systems used at the time.[21,34] Furthermore, we were able to show that the presence of unilateral cramps on the treated arm is also lower in patients who underwent tenodesis (0% vs. 11.8%). This could be supported by the biomechanically proven high primary stability of the used hardware and the ability to tension the tendon, which restores the tendon's resting length, thus reducing the potential for muscle cramping.[38,49] Therefore, restoring the optimal length-tension relationship of the LHB seems to contribute to a lower rate of unilateral cramps.

Tenodesis also reduced the presence of tenderness over the bicipital groove by 2.79-fold. Taylor et al[54] found that 45% of patients with an intraarticular lesion of LHB tendon also had a concomitant hidden tunnel lesion. Therefore, tenotomy and proximal tenodesis techniques may leave hidden tunnel lesions unaddressed. Anatomically, the bicipital groove is a closed compartment with 3 different zones: a proximal and an intermediate one, which have similar histological features, including the presence of synovium; a distal one, in which the transition from the intermedial region creates a functional bottleneck.[53] A retrospective study from 2012 on a cohort of 117 patients reported a lower incidence of tenderness over the bicipital groove among patients who underwent open subpectoral tenodesis (0%) than patients who underwent arthroscopic proximal biceps tenodesis (5.4%) after 12 months. Indeed, this is the main advantage of the extraarticular tenodesis over the intraarticular, as the direct visualization of the inflamed synovium and the sheath release on the LHB tendon can lead to lower revision rates, as found by Sanders et al.[46]

Patients within the tenotomy group who developed Popeye deformity had a statistically significantly higher contralateral forearm supination strength (131 kg vs. 83.1 kg) than the patients from this group without this deformity. Whereas this difference could not be found in the tenodesis group, the patients from this group displayed higher mean forearm supination strength for those with and without the deformity (137.3 kg vs. 147.4 kg). As only 3 of these patients (7.7%) developed a Popeye deformity, it seems that this technique using both IS and EB can resist high pullout forces *in vivo*. Further prospective studies are needed to assess the forearm supination strength as a risk factor for the development of biceps deformities after tenotomy.

As the vinculum of the LHB tendon may limit further migration of the tendon below the bicipital groove as found by Gothelf et al,[17] strong biceps contractions could generate forces that overwhelm the resistance provided by the vinculum within the bicipital sulcus. This could prevent the known autotenodesis effect provided through the vinculum, leading to more frequent Popeye deformities. Indeed, 64.3% (9/14) of the tenotomy patients who developed a Popeye deformity had a contralateral forearm supination strength of over 131 kg. To our knowledge, there are no studies that relate the strength of participants to the development of Popeye sign.

It is important to note that rotator cuff repair within both groups did not influence the outcome scores after 4 years of follow-up. Two major aspects might justify this result: first, modern arthroscopically techniques are known to achieve very satisfactory outcome results with very low complication rates in patients with rotator cuff repair[23]; second, patients with revision surgery were excluded, which may contribute to this finding.

Limitations

This study was conducted retrospectively on a small cohort of preselected patients. There was intergroup heterogeneity among groups, as the tenotomy patients were older and with a higher ratio of female/male. In comparison, tenodesis patients were younger and displayed a higher male/female ratio. Furthermore, there was intraoperative a higher rate of rotator cuff tears in the tenotomy group and calcifying tendinitis among the tenodesis group. Both elbow flexion and forearm supination strength were measured using analog devices, which could be less accurate than digital devices. The SARS-CoV-2 (COVID-19) pandemic also played an important role in the follow-up rate, as some patients declined participation in the study because of the fear of contracting an infection.

Conclusion

Both techniques resulted in a comparable outcome on preselected patients regarding shoulder function and satisfaction, with

tenodesis leading to better LHB function. Tenodesis did not improve elbow flexion and forearm supination strength beyond the tenotomy; however, it reduced the frequency of biceps deformities and tenderness over the bicipital groove. Patients with a strong contralateral forearm supination strength could be at risk of developing a biceps deformity after tenotomy.

Acknowledgments

Disclaimers:

References

1. Abraham VT, Tan BH, Kumar VP. Systematic Review of Biceps Tenodesis: Arthroscopic Versus Open. Arthroscopy 2016;32(2):365-71. https://doi.org/10.1016/j.arthro.2015.07.028.
2. Almeida A, Valin MR, de Almeida NC, Roveda G, Agostini AP. Comparative Analysis on Muscle Strength among Patients Who Underwent Arthroscopic Tenotomy of the Long Head of the Biceps in Relation to Esthetic Deformity. Rev Bras Ortop 2012;47(5):593-7. https://doi.org/10.1016/S2255-4971(15)30009-4.
3. Boileau P, Baque F, Valerio L, Ahrens P, Chuinard C, Trojani C. Isolated arthroscopic biceps tenotomy or tenodesis improves symptoms in patients with massive irreparable rotator cuff tears. J Bone Joint Surg Am 2007;89(4):747-57. https://doi.org/10.2106/JBJS.E.01097.
4. Boileau P, Krishnan SG, Coste JS, Walch G. Arthroscopic biceps tenodesis: a new technique using bioabsorbable interference screw fixation. Arthroscopy 2002;18(9):1002-12. https://doi.org/10.1053/jars.2002.36488.
5. Braun S, Horan MP, Elser F, Millett PJ. Lesions of the biceps pulley. Am J Sports Med 2011;39(4):790-5. https://doi.org/10.1177/0363546510393942.
6. Cardoso A, Amaro P, Barbosa L, Coelho AM, Alonso R, Pires L. Diagnostic accuracy of clinical tests directed to the long head of biceps tendon in a surgical population: a combination of old and new tests. J Shoulder Elbow Surg 2019;28(12):2272-8. https://doi.org/10.1016/j.jse.2019.07.007.
7. Castricini R, Familiari F, De Gori M, Riccelli DA, De Benedetto M, Orlando N, et al. Tenodesis is not superior to tenotomy in the treatment of the long head of biceps tendon lesions. Knee Surg Sports Traumatol Arthrosc 2018;26(1):169-75. https://doi.org/10.1007/s00167-017-4609-4.
8. Chen RE, Voloshin I. Long Head of Biceps Injury: Treatment Options and Decision Making. Sports Med Arthrosc Rev 2018;26(3):139-44. https://doi.org/10.1097/JSA.0000000000000206.
9. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;214:160-4.
10. Duff SJ, Campbell PT. Patient acceptance of long head of biceps brachii tenotomy. J Shoulder Elbow Surg 2012;21(1):61-5. https://doi.org/10.1016/j.jse.2011.01.014.
11. Elser F, Braun S, Dewing CB, Giphart JE, Millett PJ. Anatomy, function, injuries, and treatment of the long head of the biceps brachii tendon. Arthroscopy 2011;27(4):581-92. https://doi.org/10.1016/j.arthro.2010.10.014.
12. Franceschi F, Longo UG, Ruzzini L, Rizzello G, Maffulli N, Denaro V. Soft tissue tenodesis of the long head of the biceps tendon associated to the Roman Bridge repair. BMC Musculoskelet Disord 2008;9:78. https://doi.org/10.1186/1471-2474-9-78.
13. Friedman JL, FitzPatrick JL, Rylander LS, Bennett C, Vidal AF, McCarty EC. Biceps Tenotomy Versus Tenodesis in Active Patients Younger Than 55 Years: Is There a Difference in Strength and Outcomes? Orthop J Sports Med 2015;3(2):2325967115570848. https://doi.org/10.1177/2325967115570848.
14. 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(4):828-33. https://doi.org/10.1177/0363546508322179.
15. Gilbart MK, Gerber C. Comparison of the subjective shoulder value and the Constant score. J Shoulder Elbow Surg 2007;16(6):717-21. https://doi.org/10.1016/j.jse.2007.02.123.
16. 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(3):247-9.
17. Gothelf TK, Bell D, Goldberg JA, Harper W, Pelletier M, Yu Y, et al. Anatomic and biomechanical study of the biceps vinculum, a structure within the biceps sheath. Arthroscopy 2009;25(5):515-21. https://doi.org/10.1016/j.arthro.2008.10.026.
18. Greenberg JA, Fernandez JJ, Wang T, Turner C. EndoButton-assisted repair of distal biceps tendon ruptures. J Shoulder Elbow Surg 2003;12(5):484-90. https://doi.org/10.1016/s1058-2746(03)00173-3.
19. Hassan S, Patel V. Biceps tenodesis versus biceps tenotomy for biceps tendinitis without rotator cuff tears. J Clin Orthop Trauma 2019;10(2):248-56. https://doi.org/10.1016/j.jcot.2018.12.013.
20. Heinzelmann AD, Savoie FH 3rd, Ramsey JR, Field LD, Mazzocca AD. A combined technique for distal biceps repair using a soft tissue button and biotenodesis interference screw. Am J Sports Med 2009;37(5):989-94. https://doi.org/10.1177/0363546508330130.
21. 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(2):326-32. https://doi.org/10.1016/j.jse.2010.08.019.
22. Hufeland M, Wicke S, Verde PE, Krauspe R, Patzer T. Biceps tenodesis versus tenotomy in isolated LHB lesions: a prospective randomized clinical trial. Arch Orthop Trauma Surg 2019;139(7):961-70. https://doi.org/10.1007/s00402-019-03136-4.
23. Hurley ET, Maye AB, Mullett H. Arthroscopic Rotator Cuff Repair: A Systematic Review of Overlapping Meta-Analyses. JBJS Rev 2019;7(4):e1. https://doi.org/10.2106/JBJS.RVW.18.00027.
24. Javed S, Gheorghiu D, Walton M. Subpectoral biceps tenodesis using a novel anterior cortical button technique. Shoulder Elbow 2018;10(4):292-5. https://doi.org/10.1177/1758573218778799.
25. Katthagen JC, Grimmas P, Jensen G, Voigt C, Lill H. [Suprapectoral mini-open biceps tenodesis - functional and sonographic results]. Z Orthop Unfall 2015;153(2):153-9. https://doi.org/10.1055/s-0034-1396158.
26. 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(2):208-13. https://doi.org/10.1177/0363546504269555.
27. Kerschbaum M, Arndt L, Bartsch M, Chen J, Gerhardt C, Scheibel M. Using the LHB score for assessment of LHB pathologies and LHB surgery: a prospective study. Arch Orthop Trauma Surg 2016;136(4):469-75. https://doi.org/10.1007/s00402-015-2391-7.
28. Kerschbaum M, Maziak N, Scheuermann M, Scheibel M. [Arthroscopic tenodesis or tenotomy of the long head of the biceps tendon in preselected patients : Does it make a difference?]. Orthopade 2017;46(3):215-21. https://doi.org/10.1007/s00132-016-3358-2.
29. Klinger HM, Spahn G, Baums MH, Steckel H. Arthroscopic debridement of irreparable massive rotator cuff tears–a comparison of debridement alone and combined procedure with biceps tenotomy. Acta Chir Belg 2005;105(3):297-301. https://doi.org/10.1080/00015458.2005.11679720.
30. Koh KH, Ahn JH, Kim SM, Yoo JC. Treatment of biceps tendon lesions in the setting of rotator cuff tears: prospective cohort study of tenotomy versus tenodesis. Am J Sports Med 2010;38(8):1584-90. https://doi.org/10.1177/0363546510364053.
31. Lim TK, Moon ES, Koh KH, Yoo JC. Patient-related factors and complications after arthroscopic tenotomy of the long head of the biceps tendon. Am J Sports Med 2011;39(4):783-9. https://doi.org/10.1177/0363546510388158.
32. 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.
33. Maynou C, Mehdi N, Cassagnaud X, Audebert S, Mestdagh H. [Clinical results of arthroscopic tenotomy of the long head of the biceps brachii in full thickness tears of the rotator cuff without repair: 40 cases]. Rev Chir Orthop Reparatrice Appar Mot 2005;91(4):300-6. https://doi.org/10.1016/s0035-1040(05)84327-2.
34. Mazzocca AD, Bicos J, Santangelo S, Romeo AA, Arciero RA. The biomechanical evaluation of four fixation techniques for proximal biceps tenodesis. Arthroscopy 2005;21(11):1296-306. https://doi.org/10.1016/j.arthro.2005.08.008.
35. Mazzocca AD, Burton KJ, Romeo AA, Santangelo S, Adams DA, Arciero RA. Biomechanical evaluation of 4 techniques of distal biceps brachii tendon repair. Am J Sports Med 2007;35(2):252-8. https://doi.org/10.1177/0363546506294854.
36. 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(10):1922-9. https://doi.org/10.1177/0363546508318192.
37. Mirzayan R, McCrum C, Butler RK, Alluri RK. Risk Factors and Complications Following Arthroscopic Tenotomy of the Long Head of the Biceps Tendon. Orthop J Sports Med 2020;8(2):2325967120904361. https://doi.org/10.1177/2325967120904361.
38. Mithoefer K. Subpectoral Biceps Tenodesis Using Dynamic Endobutton Fixation in a Humeral Bone Tunnel With Interference Screw Augmentation. Techniques in Shoulder & Elbow Surgery 2011;12:51-5. https://doi.org/10.1097/BTE.0b013e3182270fab.
39. 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(11):645-56. https://doi.org/10.5435/00124635-201011000-00002.

40. Nolte PC, Kantz M, Chatterjee T. Einführhilfe für den BicepsButton™ bei der subpektoralen Tenodese der langen Bizepssehne. Arthroskopie 2018;31(1):82-4. https://doi.org/10.1007/s00142-017-0185-3.

41. Nolte PC, Pister N, Holz F, Egenolf M, Chatterjee T. [Subpectoral tenodesis of the long head of the biceps tendon with an interference screw and a cortical button : Clinical and cosmetic results after 1 year]. Orthopade 2017;46(10):864-71. https://doi.org/10.1007/s00132-017-3458-7.

42. Osbahr DC, Diamond AB, Speer KP. The cosmetic appearance of the biceps muscle after long-head tenotomy versus tenodesis. Arthroscopy 2002;18(5):483-7. https://doi.org/10.1053/jars.2002.32233.

43. Patel KV, Bravman J, Vidal A, Chrisman A, McCarty E. Biceps Tenotomy Versus Tenodesis. Clin Sports Med 2016;35(1):93-111. https://doi.org/10.1016/j.csm.2015.08.008.

44. 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(8):1036-47. https://doi.org/10.1016/j.arthro.2011.03.082.

45. Patzer T, Santo G, Olender GD, Wellmann M, Hurschler C, Schofer MD. Suprapectoral or subpectoral position for biceps tenodesis: biomechanical comparison of four different techniques in both positions. J Shoulder Elbow Surg 2012;21(1):116-25. https://doi.org/10.1016/j.jse.2011.01.022.

46. Sanders B, Lavery KP, Pennington S, Warner JJ. Clinical success of biceps tenodesis with and without release of the transverse humeral ligament. J Shoulder Elbow Surg 2012;21(1):66-71. https://doi.org/10.1016/j.jse.2011.01.037.

47. Scheibel M, Schroder RJ, 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(5):1046-52. https://doi.org/10.1177/0363546510390777.

48. Sethi P, Obopilwe E, Rincon L, Miller S, Mazzocca A. Biomechanical evaluation of distal biceps reconstruction with cortical button and interference screw fixation. J Shoulder Elbow Surg 2010;19(1):53-7. https://doi.org/10.1016/j.jse.2009.05.007.

49. Sethi PM, Rajaram A, Beitzel K, Hackett TR, Chowaniec DM, Mazzocca AD. Biomechanical performance of subpectoral biceps tenodesis: a comparison of interference screw fixation, cortical button fixation, and interference screw

50. Shank JR, Singleton SB, Braun S, Kissenberth MJ, Ramappa A, Ellis H, et al. A comparison of forearm supination and elbow flexion strength in patients with long head of the biceps tenotomy or tenodesis. Arthroscopy 2011;27(1):9-16. https://doi.org/10.1016/j.arthro.2010.06.022.

51. Slenker NR, Lawson K, Ciccotti MG, Dodson CC, Cohen SB. Biceps tenotomy versus tenodesis: clinical outcomes. Arthroscopy 2012;28(4):576-82. https://doi.org/10.1016/j.arthro.2011.10.017.

52. Tavakkolizadeh A, Ghassemi A, Colegate-Stone T, Latif A, Sinha J. Gender-specific Constant score correction for age. Knee Surg Sports Traumatol Arthrosc 2009;17(5):529-33. https://doi.org/10.1007/s00167-009-0744-x.

53. Taylor SA, Fabricant PD, Bansal M, Khair MM, McLawhorn A, DiCarlo EF, et al. The anatomy and histology of the bicipital tunnel of the shoulder. J Shoulder Elbow Surg 2015;24(4):511-9. https://doi.org/10.1016/j.jse.2014.09.026.

54. Taylor SA, Khair MM, Gulotta LV, Pearle AD, Baret NJ, Newman AM, et al. Diagnostic glenohumeral arthroscopy fails to fully evaluate the biceps-labral complex. Arthroscopy 2015;31(2):215-24. https://doi.org/10.1016/j.arthro.2014.10.017.

55. Vangsness CT Jr, Jorgenson SS, Watson T, Johnson DL. The origin of the long head of the biceps from the scapula and glenoid labrum. An anatomical study of 100 shoulders. J Bone Joint Surg Br 1994;76(6):951-4.

56. Verma NN, Drakos M, O'Brien SJ. Arthroscopic transfer of the long head biceps to the conjoint tendon. Arthroscopy 2005;21(6):764. https://doi.org/10.1016/j.arthro.2005.03.032.

57. Virk MS, Nicholson GP. Complications of Proximal Biceps Tenotomy and Tenodesis. Clin Sports Med 2016;35(1):181-8. https://doi.org/10.1016/j.csm.2015.08.011.

58. Walch G, Edwards TB, Boulahia A, Nove-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. J Shoulder Elbow Surg 2005;14(3):238-46. https://doi.org/10.1016/j.jse.2004.07.008.

59. Wilk KE, Hooks TR. The Painful Long Head of the Biceps Brachii: Nonoperative Treatment Approaches. Clin Sports Med 2016;35(1):75-92. https://doi.org/10.1016/j.csm.2015.08.012.