J Shoulder Elbow Surg (2025) ■, 1–12

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Implant-free loop tenodesis significantly improves functional outcome in the treatment of long head of biceps brachii tendon lesions: 2-year results of a prospective case series

Maximilian Kerschbaum, MD[a], Lisa Klute, MD[a], Lina Forchhammer, MD[a], Moritz Riedl, MD[a], Stefan Greiner, MD[b], Volker Alt, MD, PhD[a], Leopold Henssler, MD[a,*]

[a]*Department of Trauma Surgery, University Hospital Regensburg, Regensburg, Germany*
[b]*Sporthopaedicum, Straubing, Germany*

Background: The purpose of this study was to investigate the mid-term functional and structural results of the implant-free arthroscopic technique of loop tenodesis procedure for the treatment of tendon pathologies of the long head of biceps brachii (LHB).
Methods: For a prospective case series, patients presenting with LHB tendinopathy, instability, partial tear or superior labrum from anterior to posterior lesions, and undergoing shoulder arthroscopy were recruited between November 2018 and November 2019. All patients received loop tenodesis of the LHB tendon alongside concomitant rotator cuff repair or labral procedures. Follow-up (FU) visits were scheduled at 6 weeks, 6 months, 12 months, and 24 months postoperatively. Biceps-related functional outcome was assessed by using the LHB score as a primary outcome parameter. Secondary outcome measures included global shoulder functional scores (Constant-Murley score [CMS] and Subjective Shoulder Value [SSV]), ultrasound assessment for tenodesis integrity, and evaluations of supination torque and elbow flexion strength.
Results: Eighty-one patients (aged 51.5 ± 9.5 years) underwent loop tenodesis to address LHB pathologies, of which 64 patients (79%) were available for the last FU after 24 months. The LHB score increased from a preoperative mean of 77 ± 13 to 82 ± 16 at the 6-month assessment and to 89 ± 15 at 24 months postoperatively ($P < .001$). Additionally, significant improvements were observed in CMS (preoperative 57 ± 18; 24 months postoperative 87 ± 13; $P < .001$) and SSV (preoperative 47 ± 19; 24 months postoperative 88 ± 15; $P < .001$). Minimal clinically important differences of the CMS and SSV were reached by 87% and 94% of patients at 24 months, respectively. A higher 12-month LHB score significantly increased the likelihood of achievement of the minimal clinically important difference of the CMS (odds ratio: 1.402; 95% confidence interval [1.073, 1.834]; $P = .013$). Ultrasound examination revealed structural failure was identified in only 2 patients (3.2%) over the entire FU. No patients required revision surgery due to biceps-related issues or tenodesis failure.

The Ethics Committee of the University of Regensburg approved this study (study #: 18-1032-101).

*Reprint requests: Leopold Henssler, MD, Department of Trauma Surgery, University Hospital Regensburg, Franz-Josef-Strauss-Allee 11, Regensburg, Germany 93053.
E-mail address: leopold.henssler@ukr.de (L. Henssler).

https://doi.org/10.1016/j.jse.2025.03.039

Conclusion: Loop tenodesis for the treatment of LHB tendon lesions significantly improved functional outcome scores within the first 2 years, providing stable suprapectoral fixation without the need for an implant. Comparative studies are needed to validate the technique.
Level of evidence: Level IV; Case Series; Treatment Study

Keywords: Arthroscopy; shoulder; rotator cuff; labrum; biceps; tendon; tenodesis; tenotomy

Arthroscopic surgeries of the shoulder rank as the fourth most frequently performed procedure by orthopedic surgeons in the United States.[11] Since pathologies of the long head of biceps brachii (LHB) tendon often serve as a primary cause of anterior shoulder pain,[32] pathologies of the LHB tendon can be identified in more than 75% of shoulder arthroscopies performed for rotator cuff tears.[3] Implant-based tenodesis techniques are currently considered the accepted gold standard for managing LHB tendon injuries, particularly in physically active patients. Although rare, complications have been reported following implant-based tenodesis techniques, including an elevated rate of wound infection compared to tenotomy,[26] persistent shoulder pain at the attachment site due to implant irritation,[13] and humeral fracture.[28] To avoid these complications, different soft tissue tenodesis techniques were proposed in the past, but showed higher rates of new-onset anterior shoulder pain and subjective weakness.[26]

Driven by the idea of omitting an implant while providing stable fixation comparable to implant-dependent tenodesis, the implant-less ''loop tenodesis'' technique was introduced and published by Kerschbaum et al[19] in 2019. It makes use of the autotenodesis mechanism of the LHB tendon after tenotomy and improves the principle by folding and, thus, doubling the proximal tendon stump. By doing this, slippage through the bicipital groove and distal migration of the tendon stump is prevented. After this technique demonstrated improved resistance to failure compared to standard tenotomy in biomechanical tests using human cadaveric shoulder joints,[18] the loop tenodesis method was evaluated in a pilot study involving a prospective cohort of patients.[29] Results showed significant short-term relief from biceps-related symptoms 6 months after surgical intervention.[29]

However, it remains uncertain whether the favorable short-term outcomes of the technique will persist over time and whether the implant-less tenodesis can endure the mechanical stresses encountered in patients' daily activities. Thus, the present study seeks to present both the structural and functional mid-term results of the loop tenodesis procedure. We hypothesized that the technique results in significant improvement of LHB-associated outcome parameters.

Methods

Patient collection and study design

This prospective case series was conducted by 2 centers with high expertise in arthroscopic shoulder surgery from November 2018 to November 2019. Patients undergoing shoulder arthroscopy for acute or degenerative lesions of the rotator cuff or labroligamentous system and additionally reporting biceps-related anterior shoulder pain were assessed for eligibility. The inclusion criteria encompassed all generally accepted indications for LHB tenodesis[5] in adult patients, including partial rupture, pulley lesions with or without tendon instability, superior labrum from anterior to posterior tears, and chronic tenosynovitis regardless of concomitant pathologies or procedures and were based on preoperative magnetic resonance imaging scans and clinical examination findings. Patients with clinically or radiologically significant osteoarthritis, shoulder stiffness, distal biceps tendon lesions, or prior surgeries on the ipsilateral or contralateral shoulder were excluded for unrestricted follow-up (FU) assessment. Every included patient underwent preoperative assessment to collect baseline data and subsequent shoulder arthroscopy. Patients with intraoperative confirmation of 1 of the above indications received loop tenodesis procedure and were evaluated at 6 weeks, 6 months, 12 months, and 24 months following surgical treatment. Informed written consent was obtained from all participants prior to their inclusion in the study. The study protocol and procedures were approved by the local Ethics Committee of the University of Regensburg (number: 18-1032-101) prior to study initiation.

Surgical technique

The arthroscopic procedure was performed according to the previously published technique of loop tenodesis[19] (Fig. 1). Following standard preoperative procedures, a posterior viewing portal and an antero-inferior working portal were established for diagnostic arthroscopy. Upon confirmation of the indication for LHB tenodesis, an additional anterolateral portal, approximately 2 cm in length, was created directly at the entry point of the LHB tendon into the bicipital groove. Débridement of the bone at the entrance of the bicipital groove was performed to promote a mildly bleeding surface to enhance tendon ingrowth. Subsequently, a surgical clamp was inserted through the anterolateral portal, securing the LHB tendon near its origin at the superior labrum. Tenotomy was then performed near to the clamp using an electrothermal device, after which the tendon was pulled extracorporeally by the surgical clamp. Approximately 0.5-1.5 cm of the tendon stump was resected, and a loop was formed by

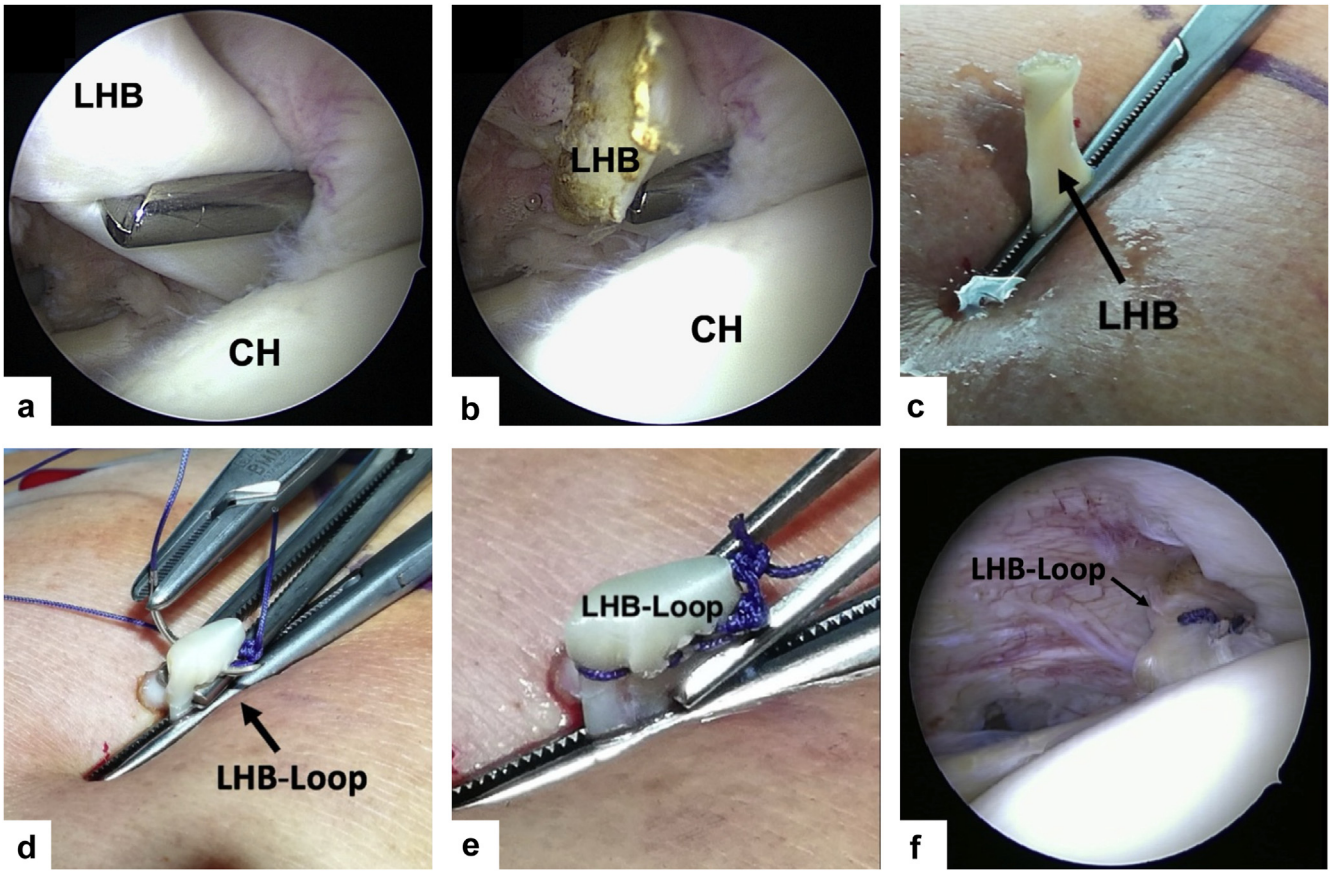

Figure 1 Surgical technique of loop tenodesis procedure as originally described in Kerschbaum et al.[19] After grabbing the LHB tendon with a (**a**) clamp and (**b**) tenotomy, (**c**) the tendon is pulled extracorporally by the clamp and (**d**) after resection of the first 0.5-1.5 cm of the tendon, the LHB is doubled and (**e**) the created loop is secured by mattress stitch technique. (**f**) Finally, the tendon loop gets pushed onto the entrance of the bicipital groove where it blocks itself from slippage into the groove (Modified and reprinted from Arthrosc Tech, vol 8; Kerschbaum et al. The arthroscopic loop tenodesis procedure: an implant-free technique to treat long biceps tendon pathologies; pp e503-6, 2019; with permission from Elsevier.). *LHB*, long head of biceps brachii; *CH*, caput humeri.

doubling the proximal tendon stump. This loop was secured using a resorbable suture (Vicryl No. 1; Ethicon, Somerville, NJ, USA), reintroduced into the joint, and positioned at the entrance of the bicipital groove, where it is blocked from slippage through the groove by the transverse humeral ligament. Following the loop tenodesis procedure, arthroscopic treatment for any concurrent pathologies was undertaken as necessary.

Postoperative follow-up treatment

All enrolled patients underwent a standardized FU treatment regimen consistent with current postoperative care standards following arthroscopic LHB tenodesis procedures.[2,4] Daily supervised passive and active-assisted movements were initiated in both the shoulder and elbow starting from the second postoperative day. Patients with rotator cuff repair had an abduction brace for 6 weeks day and night but shoulders were passively mobilized by physical therapists and during patients' self-exercises for 6 weeks up to horizontal without active movements or loading against resistance. For patients undergoing rotator cuff repair, loading of the arm with more than 2 kg was restricted for 12 postoperative weeks. Patients undergoing shoulder stabilization by arthroscopic labral repair had an orthosis for 3 weeks day and night and another 3 weeks at night. Active motion of the shoulder was initiated under physiotherapeutic guidance from day 2 after surgery but elevation over 90° abduction or forward flexion was restricted for 6 weeks. Loading and weight-bearing and external rotation in abduction were prohibited for 12 weeks in these patients. For patients who received only LHB tenodesis and subacromial or acromioclavicular decompression without any of the above procedures, only a 2-week restriction of a maximum abduction of 90° was imposed.

Irrespective of concomitant procedures, active flexion and supination exercises against resistance for the elbow were similarly restricted for 6 weeks, accompanied by limitations on weight-bearing (up to a maximum of 1 kg) in all patients. Furthermore, patients were recommended to wear a commercially available upper arm compression bandage for 6 weeks following surgery to prevent distalization of the biceps muscle.

Outcome assessment

Functional outcomes were evaluated by 2 independent experienced observers, who were not directly involved in the

arthroscopic treatment process. The LHB score (LHBS), a score highly specific to display LHB-associated postoperative outcome and introduced by Scheibel et al in 2011,[30] was chosen as a primary outcome parameter to allow independent assessment of biceps-related symptoms irrespective of concomitant procedures. The LHB score encompasses various components: patient-reported symptoms such as "Pain," "Tenderness," and "Speed-Test," each rated on a Numeric Rating Scale ranging from 1 to 10; assessment of upper arm "cramping" graded on a 3-point scale with maximum 20 points; evaluation of Popeye deformity by both the examiner and the patient with maximum 15 points each; and assessment of "flexion strength," categorized based on a comparison with the corresponding measurement from the healthy contralateral arm with maximum 20 points in case of unrestricted strength.[15,30]

To ensure a comprehensive assessment of patient outcomes, the Constant-Murley score (CMS) and the Subjective Shoulder Value (SSV), which provide a measure of global shoulder function, were combined with the aforementioned disease-specific score. Both flexion strength, as part of the LHB score, and abduction strength, a component of the CMS calculation, were assessed using an isometric dynamometer (IsoBex Dynamometer; MDS AG, Burgdorf, Switzerland), with 3 repetitions performed and mean values recorded. Additionally, supination torque was measured separately alongside the score assessments, conducted with the elbow flexed at 90° and the forearm in a neutral rotation, using a hydraulic dynamometer (Baseline Hydraulic Wrist Dynamometer with Shovel handle; Fabrication Enterprises Inc., White Plains, NY, USA).

Additionally, at each FU visit, patients underwent standardized ultrasound assessment (Aloka Prosound 6 ultrasound system; Hitachi, Tokyo, Japan, equipped with a linear array transducer, 6-15 MHz). The evaluation was conducted in B-mode, assessing both transverse and longitudinal planes. Specifically, the examination aimed to ascertain the presence and positioning of the LHB tendon within the bicipital groove. Structural failure of the loop tenodesis technique was defined by the absence of the LHB tendon in the deepest region of the groove, identified as the "empty sulcus sign."

Statistical analysis

Statistical analyses were conducted using IBM SPSS Statistics (version 29; IBM Inc., Armonk, NY, USA), with significance set at $P < .05$. Pairwise deletion was used to handle missing data. Continuous data were analyzed and presented as the mean and standard deviation and the range. Categorical data were presented as the total count and percentage. Normality of the data was assessed using Shapiro-Wilk testing. The Friedman test, along with the Bonferroni post hoc test for multiple comparisons, was used to compare changes in each outcome parameter over time. Additionally, the Wilcoxon test was used to compare outcome parameters of the affected side with those of the healthy side at 24 months. To assess the clinical relevance of the detected changes, the CMS and the SSV were compared with the previously published minimal clinically important difference (MCID) in patients with rotator cuff disease: According to previous studies, a change of 13 in the SSV and 6.7 in the CMS were considered the MCIDs.[20,35] Since there are no published thresholds for MCID of the LHB score, a multivariate binomial logistic regression was performed to determine the effect of sex, age, body mass index, preoperative CMS, and the 12-month LHB score on the likelihood of reaching the MCID of the CMS after 12 months. The Chi-squared test was used to compare the proportion of patients achieving the MCID between the group with isolated LHB tenodesis vs. the group with concomitant procedures and the subgroups with vs. without rotator cuff repair.

Results

Patient collective

Initially, 110 consecutive patients presenting with anterior shoulder pain and 1 of the indications for biceps tenodesis on preoperative magnetic resonance imaging scans were screened for eligibility. Three patients were excluded due to meeting exclusion criteria, and an additional 26 patients were excluded due to a lack of indication for LHB tenodesis during diagnostic arthroscopy (Fig. 2). Consequently, a total of 81 patients (63 males and 18 females) with an average age of 51.5 ± 9.5 years (range: 24-71 years) underwent loop tenodesis of the LHB tendon as part of the study cohort. The most common intraoperative indication for tenodesis (as shown in Table I) was a biceps pulley lesion with or without LHB instability/subluxation. Only 4 patients (4.9%) demonstrated isolated pathology of the LHB tendon without concurrent shoulder pathologies during diagnostic arthroscopy, while the majority presented with concurrent pathologies that were identified and addressed intraoperatively (Table I). Subsequently, only 4 patients underwent isolated LHB tenodesis, while a total of 69 patients had arthroscopic rotator cuff repair and subacromial decompression, 5 had arthroscopic Bankart repair, and 3 had LHB tenodesis with subacromial decompression as a concomitant procedure. After 24 months, 6 patients (7.4%) were lost to FU and additional 11 patients (13.6%) refused to fill the outcome assessment forms.

Primary functional outcome parameter: LHB score

The LHB score was evaluable in all cases both preoperatively and at the 6-week FU. At 6 months, 1 year, and 2 years postoperatively, the score could be calculated in 61 patients, 46 patients, and 61 of 81 patients, respectively. The preoperative baseline score averaged 77.1 ± 12.7 points (range: 42-100 points) and did not exhibit significant change at 6 weeks postoperatively ($P > .05$, Fig. 3). However, the total LHB score demonstrated a progressive increase (Table II), commencing after 6 months and ultimately reaching a score of 88.6 ± 15.2 points (range: 26-100 points) after 2 years (Fig. 3). While the initial increase at the 6-month FU did not achieve statistical significance compared to the preoperative state ($P = .118$), the first significant enhancements in comparison to baseline were evident after 1 postoperative year ($P < .001$). This substantial improvement in biceps-related outcomes persisted

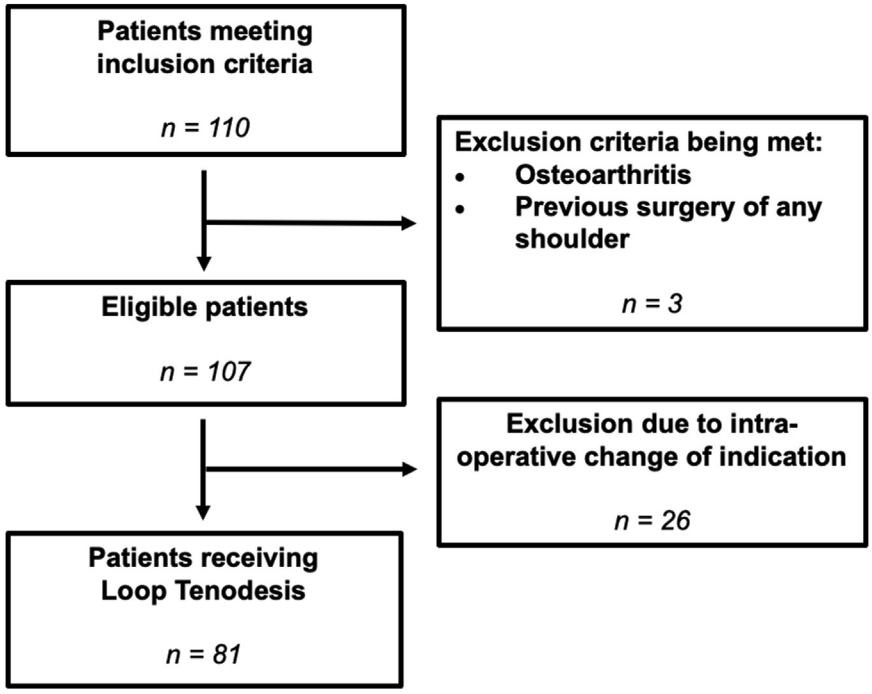

Figure 2 CONSORT (Consolidated Standards of Reporting Trials) flow diagram of patients recruited for study participation.

Table I Intraoperative findings regarding LHB tendon disorders and concomitant pathologies

	Number of patients (%)
LHB tendon disorders	
Partial rupture	39 (48.1)
Pulley lesion with instability/subluxation	37 (45.7)
Pulley lesion without subluxation	26 (32.1)
Isolated tenosynovitis	8 (9.9)
SLAP lesions	7 (8.6)
Concomitant pathologies	
Subacromial impingement syndrome	63 (77.8)
Partial-thickness rotator cuff lesion	49 (60.5)
Full-thickness rotator cuff lesion	22 (27.2)
Anteroinferior labrum lesion	5 (6.2)
Acromioclavicular osteoarthritis	3 (3.7)

LHB, long head of biceps brachii; *SLAP*, superior labrum from anterior to posterior.

through the final 24-month FU ($P < .001$ each). Nonetheless, the total LHB score remained impaired relative to the unaffected contralateral shoulder even after 2 years ($P = .003$; Table II).

Analysis of the LHBS subcategories (Fig. 3) revealed continuous improvement in all values related to biceps-related complaints following surgical intervention. While ''tenderness'' over the bicipital groove demonstrated significant improvement immediately postsurgery ($P = .020$; Fig. 3), ''pain'' at rest and the results of the ''Speed Test'' exhibited delayed significant improvement after 6 months compared to the preoperative baseline score ($P = .033$ and $P = .001$, respectively). ''Pain'' once again significantly subsided between the 6-month and 12-month FU ($P = .049$). Elbow ''flexion strength'' demonstrated a significant increase between the 6-week FU and the subsequent examination after 6 months ($P = .017$) following a temporary decline in strength in the immediate postoperative phase. Compared to the initial preoperative state, flexion strength improved significantly after 12 months postoperatively ($P = .049$) and remained improved at the final FU ($P = .015$). No statistically significant changes were noted in terms of ''cramps'' or ''cosmesis'' from either the examiner's or the patient's perspective ($P > .05$ each).

However, after 2 years, examiners observed severe Popeye deformity in 2 patients, while an additional 4 patients displayed moderate and 13 patients showed mild deformities. However, from the patients' self-assessment after 24 months, only 1 rated his cosmetic deformity of the upper arm as severe, 4 as moderate, and 3 recognized a mild deformity.

Secondary functional outcome parameters: CMS

Values of the CMS were obtainable for all patients at both the preoperative and 6-week postoperative assessments, and for 73 patients, 67 patients and 62 of 81 patients after 6 months, 12 months, and 24 months, respectively. At the initial 6-week FU, the CMS did not exhibit a significant

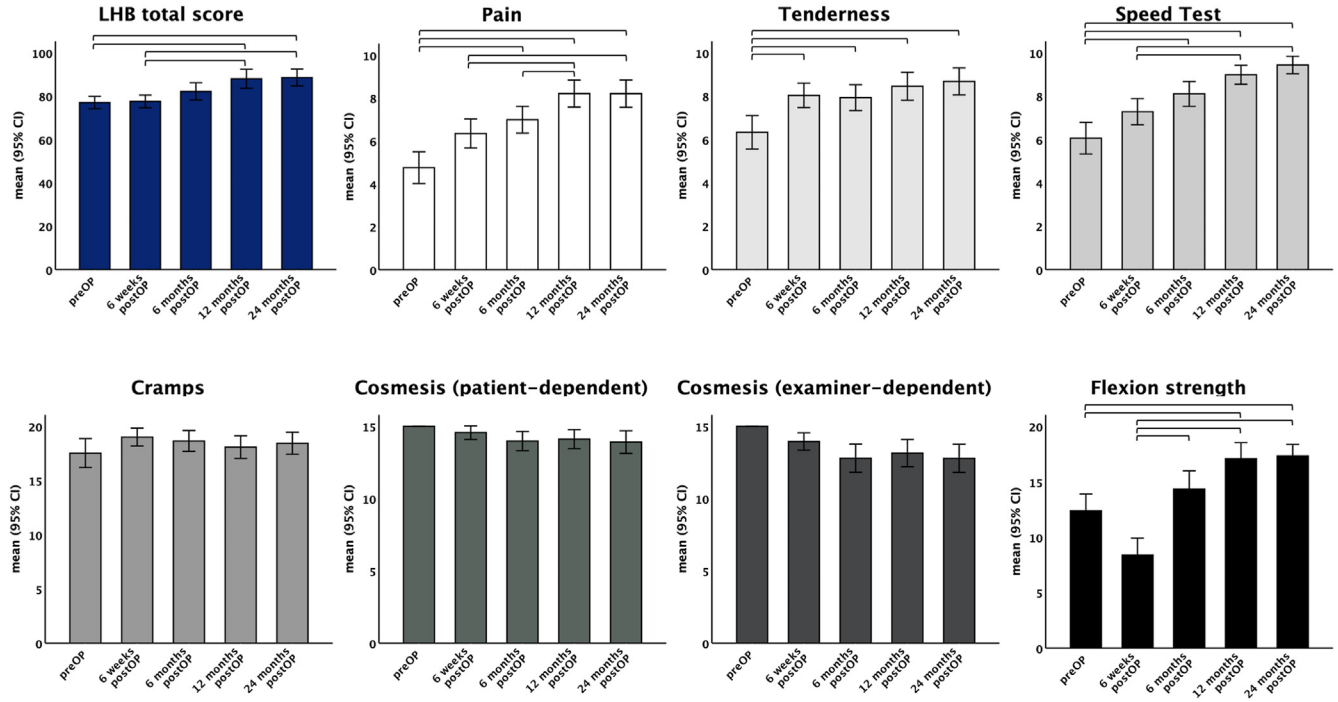

Figure 3 LHB score (*blue*) and its subcategories (*white*, *grey tones*, and *black*) changing from baseline values over the follow-up period of 2 years after surgical treatment. Error bars represent 95% confidence intervals. Significant differences ($P < .05$) are marked by brackets. *LHB*, long head of biceps brachii; *CI*, confidence interval.

change ($P > .05$) from the preoperative state (Table II). Subsequently, the CMS continuously improved from the sixth postoperative week, with a significant increase to the 6-month FU ($P < .001$), and another significant increase to the subsequent visit after 12 months ($P = .009$; Fig. 4). The final score after 2 years reached 86.5 ± 13.0 points, which still represented significant impairment ($P = .01$) compared to the score of the unaffected contralateral side (Table II).

The proportion of patients achieving the MCID was 73% at 6 months, 79% at 12 months, and 87% at 24 months. Of the 5 variables entered into the binomial logistic regression model, 2 contributed significantly to predicting the MCID of the CMS after 12 months (Table III): The preoperative CMS ($P = .018$) and the 12-month LHB score ($P = .013$), while the other variables showed no significant effect (Table III). While higher preoperative CMS had a negative effect, reducing the likelihood of reaching the MCID (odds ratio: 0.658; 95% confidence interval [0.465, 0.931]), a higher LHB score at 12 months significantly increased the probability (odds ratio: 1.402; 95% confidence interval [1.073, 1.834]) of reaching the MCID of the CMS at the 12-month FU.

A statistically significant difference in the proportion of patients achieving the MCID of the CMS was observed only at the 6-week FU between those undergoing isolated LHB tenodesis (4/4 patients) and those undergoing tenodesis with concomitant procedures (20/77 patients; $P = .002$). When comparing the subgroups of LHB tenodesis with and without rotator cuff repair, there was no significant difference in the proportion of patients achieving the MCID for the Constant score at 6 weeks ($P = .32$), 6 months ($P = .99$), 12 months ($P = .10$), or 24 months ($P = .28$).

Secondary functional outcome parameters: SSV

The SSV was assessable for all patients both preoperatively and at the initial postoperative evaluation, and for 74 patients, 68 patients and 64 of 81 patients after 6 months, 12 months, and 24 months, respectively. In concordance with the LHBS and CMS, the SSV did not exhibit any significant changes ($P > .05$) at the first postoperative FU (Fig. 5, Table II). However, there was a distinct and statistically significant improvement in the SSV observed between the 6-week and the 6-month FU ($P < .001$). Another significant enhancement was noted between the 6-month and 24-month FU assessments ($P = .001$).

At 6, 12, and 24 months, the MCID of the SSV was achieved by 78%, 88%, and 94% of patients, respectively. At the final FU, the SSV averaged 87.7 ± 14.9 points, which did not significantly differ from the score of the unaffected shoulder (87.7 ± 16.1 points; $P > .05$).

Supination torque

Supination torque measurements were successfully conducted for all patients both before the procedure and at the 6-week postoperative evaluation. Subsequently,

Table II Prospective outcome values from 6 weeks to 24 months after surgery

	Preoperative	6 weeks postoperative	6 months postoperative	12 months postoperative	24 months postoperative	Unaffected shoulder
	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)
CMS (pt.)	57.4 ± 18.3 (20-100)	51.8 ± 20.3 (11-98)	75.9 ± 16.6 (29-98)	81.5 ± 16.2 (37-100)	86.5 ± 13.0 (32-100)	90.0 ± 12.1 (34-100)
LHBS (pt.)	77.1 ± 12.7 (42-100)	77.6 ± 13.4 (25-100)	82.2 ± 15.6 (9-100)	88.0 ± 15.0 (40-100)	88.6 ± 15.2 (26-100)	95.5 ± 6.1 (74-100)
SSV (%)	47.2 ± 18.5 (10-85)	45.9 ± 22.2 (0-100)	74.5 ± 19.6 (10-100)	81.8 ± 17.7 (30-100)	87.7 ± 14.9 (50-100)	87.7 ± 16.1 (40-100)
Supination torque (Nm)	134.3 ± 70.3 (41-300)	100.9 ± 62.5 (0-300)	159.8 ± 72.9 (19-300)	158.3 ± 70.6 (41-300)	137.3 ± 66.5 (13-319)	154.5 ± 70.1 (16-319)

SD, standard deviation; *pt.*, points; *CMS*, Constant-Murley score; *LHBS*, long head of biceps brachii score; *SSV*, Subjective Shoulder Value.

assessments were performed in 59 patients, 46 patients, and 61 of 81 patients at 6 months, 12 months, and 24 months postoperatively, respectively. Initially, there was a nonsignificant ($P > .05$) trend of decreased supination torque following surgical intervention (Fig. 6). However, between the 6-week and 6-month FU periods, a notable and statistically significant improvement in strength was observed ($P < .001$), also significantly surpassing the baseline value ($P = .002$). Although, this significant improvement in strength was not sustained beyond the 12-month FU ($P = .001$), with no significant difference noted compared to the baseline value at the final strength assessment ($P > .05$, Table II).

Sonographic results

Sonographic assessments were performed in all patients at the 6-week evaluation, in 59 patients at the 6-month FU, in 46 patients at the 12-month FU, and in 62 of 81 patients after 2 years. Of all evaluated patients at any time point, the presence of the ''empty sulcus'' sign, indicating structural tenodesis failure, was detected in only 2 patients (3.2%) throughout the entire observation period. These 2 patients experienced failure as early as 6 weeks postprocedure. Subsequent sonographic evaluations during FU visits did not reveal any additional cases of loop tenodesis failure. Concerning cosmetic outcomes, 1 of the 2 patients exhibited severe upper arm deformity according to observer assessment and moderate deformity based on the patient's self-evaluation, while the other patient displayed moderate deformity as per observer assessment and mild deformity according to the patient's self-assessment.

Complications and revision

None of the study patients experienced deep surgical site infection or any other postoperative complications. However, 3 patients required revision surgery for acromioclavicular joint resection within the FU period due to persistent pain at the acromioclavicular joint.

Discussion

This investigation presents prospective mid-term outcome data on the implant-less loop tenodesis technique for treating LHB lesions. Key findings include:

- The implant-free loop tenodesis procedure led to significant improvement of biceps-specific function in individuals undergoing shoulder arthroscopy.
- Improvement of the LHB score significantly contributed to clinically relevant improvement of the patient-reported global shoulder function.
- By enlarging the LHB tendon stump after tenotomy followed by autotenodesis through scar formation, the

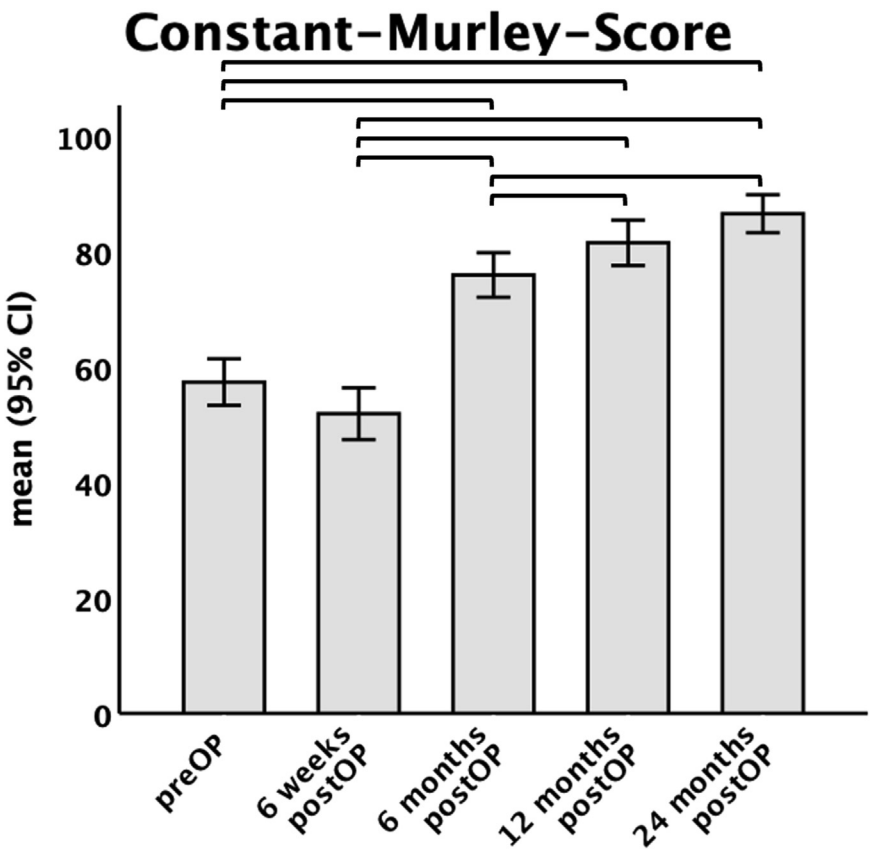

Figure 4 Changes in the Constant-Murley score during the follow-up period of 24 months. The error bars represent 95% confidence intervals. Significant differences ($P < .05$) are indicated by brackets.

Table III Multivariate binary logistic regression: MCID for CMS after 12 months

Factor	Standard error	*P* value	OR	95% CI	
				Lower limit	Upper limit
Male sex	3.465	.079	0.002	0	2.041
Age	0.069	.607	0.965	0.842	1.105
BMI	0.177	.317	1.194	0.843	1.690
Preoperative CMS	0.177	.018	0.658	0.465	0.931
12-month postoperative LHBS	0.137	.013	1.402	1.073	1.834

MCID, minimal clinically important difference; *CMS*, Constant-Murley score; *OR*, odds ratio; *CI*, confidence interval; *BMI*, body mass index; *LHBS*, long head of biceps brachii.

technique effectively prevented tendon slippage through the bicipital groove, resulting in a low rate of structural tenodesis failure.

- Despite persistent impairments observed in elbow flexion and forearm supination torque measurements, surgical revision due to biceps-related issues was not necessary for any patient.

The findings of this study confirm our hypothesis that the presented surgical technique for arthroscopic implant-free tenodesis of the long head of the biceps tendon achieves satisfactory functional results by blocking the tendon stump above the bicipital groove without relying on implants, solely by enhancing the autotenodesis phenomenon.

The concept of autotenodesis was initially recognized by Walch et al[34] following arthroscopic surgeries in the 1990s, when approximately half of the patients undergoing tenotomy of LHB tendon did not experience upper arm deformity postprocedure. It was subsequently theorized that following tenotomy, the tendon autotenodes within the lower bicipital groove due to its physiological anatomy. Specifically, the tendon's diameter near its origin is wider than the intertubercular tendon portion, facilitating self-locking of the LHB tendon at the entrance of the bicipital

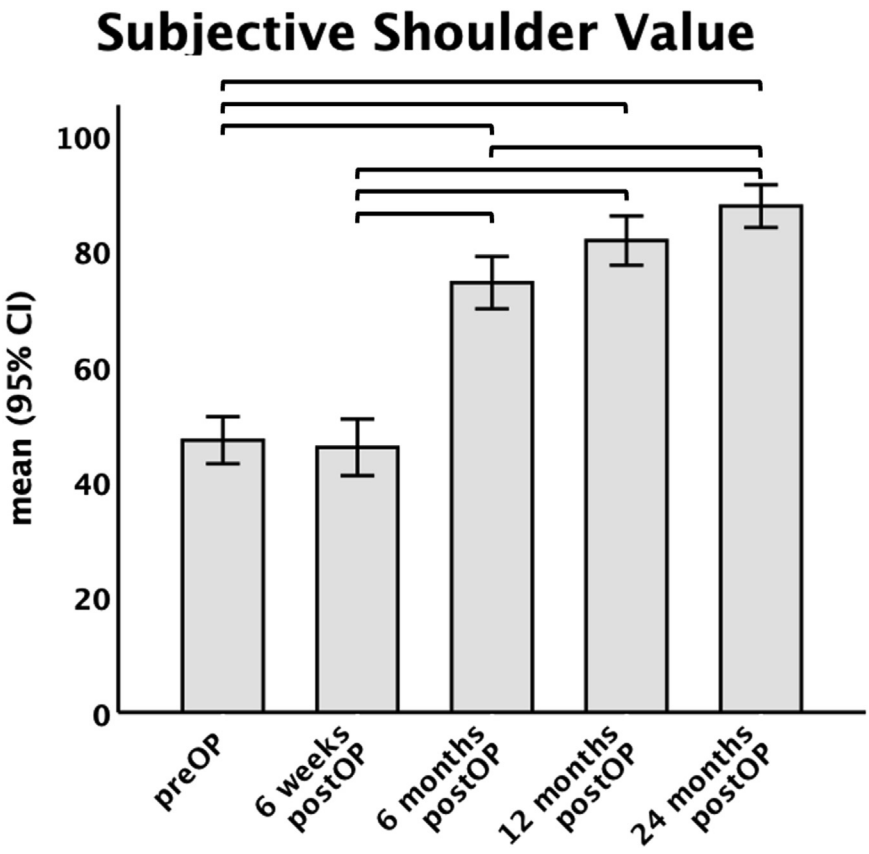

Figure 5 Increase of the Subjective Shoulder Value (SSV) during the follow-up period of 24 months. The SSV represents the condition of the affected shoulder compared to a fully functional shoulder as a percentage. The error bars represent 95% confidence intervals (CI). Significant differences ($P < .05$) are indicated by brackets.

groove after proximal tenotomy and preventing distalization of the tendon stump, which is even enhanced by degenerative hypertrophy observed in diseased tendons.[1] Additionally, small connective tissue bridges known as ''vincula'' have been identified,[12] extending from the proximal humerus into the peritendineum of the LHB tendon, providing primary stability to the tenotomized tendon, albeit with inconsistent biomechanical stability under load.[12] Following primary self-entrapment by these mechanisms, the tendon is subsequently stabilized by scar tissue formation, a process validated through histologic analysis in a rabbit shoulder model,[21] ultrasound evaluations,[14,36] and magnetic resonance graphic analyses[22] in clinical trials.

Despite the support for autotenodesis provided by these studies, recent meta-analyses indicate a 3-fold higher prevalence of cosmetic deformity of the upper arm[24] and worse functional outcomes[24,27] following arthroscopic tenotomy compared to modern arthroscopic tenodesis techniques. Consequently, tenodesis is now considered the gold standard treatment for LHB pathologies, particularly in highly active individuals. While most common tenodesis techniques necessitate the use of an implant for stable tendon-to-bone fixation, various complications have been reported following implant-using tenodesis techniques, including infections,[26] continuing anterior shoulder pain,[13] and even humerus fractures.[28]

This article presents mid-term data on an implant-less tenodesis technique. First, the complication rate in our cohort was remarkably low, with no patients requiring revision surgery due to biceps-related issues. This aligns with existing evidence, underscoring the reduced risk of reoperation associated with arthroscopic compared to open tenodesis[7] and soft tissue tenodesis compared to implant-based methods.[26]

Additionally, the functional results of the present study demonstrated consistent improvement throughout the study duration. Notably, the improvement in outcome scores persisted over the entire FU period. The results based on the Constant score (81.5 $\pm$ 16.2 after 12 months; 86.5 $\pm$ 13.0 after 2 years) were comparable to those reported in clinical studies[9,15,17,33] and meta-analyses[24,27] using anchor tenodesis techniques. However, as biceps-dependent complaints are not adequately represented in the Constant score, the LHB score provided valuable insight into postoperative biceps function in our study. Mean LHB scores ranging

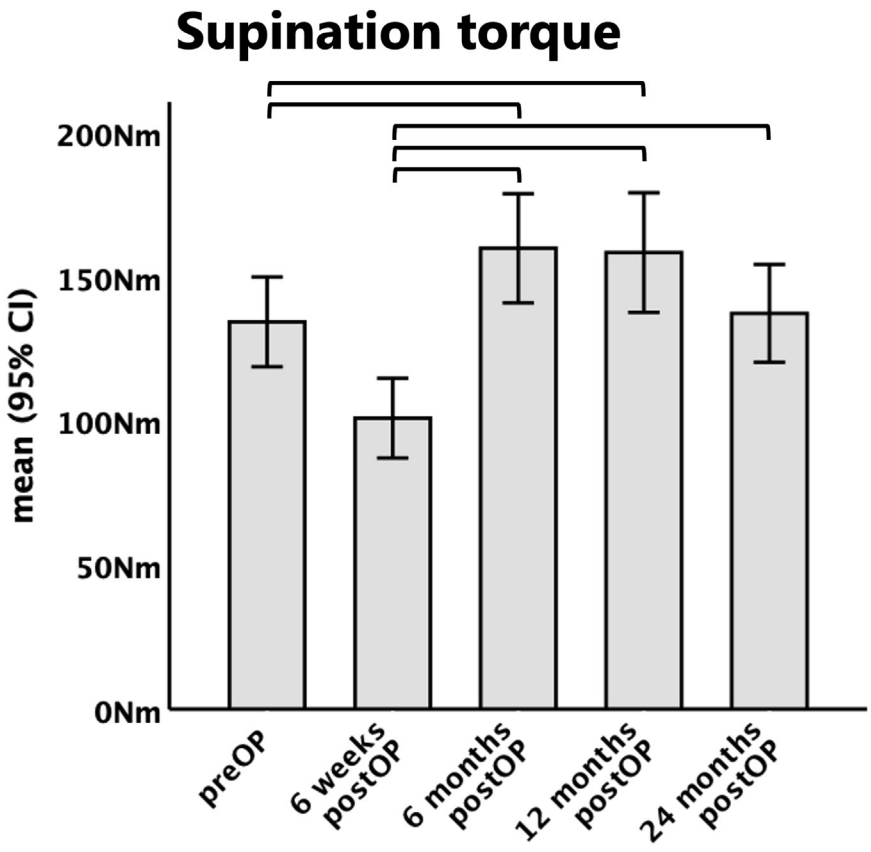

Figure 6 Changes in supination torque (Nm) were measured using a shovel handle attached to a hydraulic dynamometer. The increase in torque did not persist over the entire study period. The error bars represent 95% confidence intervals (CI). Significant differences ($P < .05$) are indicated by brackets.

from 73 to 91 points have been reported in previous studies evaluating different established tenodesis techniques.[9,30,31,33] Comparing the recent data of loop tenodesis (88.6 ± 15.2 points after 24 months) to these results and to a previously described comparable study cohort[17] of knotless suprapectoral anchor tenodesis patients (88 ± 10 points after a mean of 36.4 months),[17] we found comparable outcomes.

These satisfactory functional outcomes and minimal rates of high-grade cosmetic deformities demonstrate the robust primary fixation achieved by the loop tenodesis technique. In contrast to Karataglis et al,[14] who reported a 17.3% sonographic failure rate of biceps autotenodesis at 2 years post simple tenotomy, our study found structural failure of the tenodesis with a sonographic empty sulcus sign in only 2 patients. These data support the classification of the loop tenodesis as a reliable tenodesis procedure, as our failure rates are comparable to those reported with other standard tenodesis techniques in the literature, ranging between 5% and 10%.[6,17,26] Considering that most of the included patients suffered from rotator cuff tears and concomitant lesions of the biceps reflex pulley, this low rate of structural failure of the tenodesis demonstrates that safe locking of the tendon loop at the traverse humeral ligament is possible even with higher grade defects of the biceps pulley complex.

Nevertheless, our study exhibited mild examiner-dependent Popeye deformities in notably more patients than only those exhibiting structural tenodesis failure on ultrasound examinations. While Scheibel et al[30] observed a correlation between the examiner-dependent grade of upper arm deformity and the structural integrity of the tenodesis, prior studies have highlighted inconsistencies between the structural integrity of LHB tenodesis and the occurrence of mild Popeye deformities.[23] A possible explanation might be that apart from anchor pullout and failure at the tendon-anchor interface, elongation of the tendon has been identified as a potential cause of upper arm deformity.[10] It is plausible that secondary elongation of the tendon due to primary autotenodesis with insufficient tension may occur when loading is initiated between the 6-week and 6-month FU. Subsequently, limited muscle distalization causes in mild manifestation of Popeye deformity without structural failure of the construct, as seen in our patient cohort in this time interval. In line with this, Scheibel et al[30] reported an increased rate of distalization following the more flexible soft tissue tenodesis compared to bone anchor tenodesis procedures.

Nevertheless, it must also be noted that the proportion of patients who self-detected an upper arm deformity was significantly lower than the rate of upper arm deformities detected by the investigators. This is consistent with related literature, which has found that mild forms of humeral deformity are more of a problem for the surgeon and less of a problem for the patient, as they rarely lead to dissatisfaction with the surgical outcome.[8]

The present investigation reveals some limitations, particularly those inherent with the design of an interventional single-armed case series lacking a suitable control group. However, we were able to compare the present patients undergoing loop tenodesis to comparable historical patient collectives undergoing tenotomy[16] or knotless anchor tenodesis,[17] as an identical study design was selected for the present trial. Second, including patients with concomitant rotator cuff tears in studies investigating treatment techniques for lesions of the long head of the biceps presents specific challenges and potential sources of bias. First, the presence of rotator cuff lesions and their treatment—often performed concurrently with LHB tenodesis—can significantly affect functional outcome data. Rotator cuff lesions may confound results, as improvements in pain and shoulder function may be attributable not only to LHB tenodesis but also to rotator cuff repair, making it difficult to isolate the efficacy of LHB treatment alone in the established shoulder function patient-reported outcome measures. However, since simultaneous treatment of the LHB tendon lesions during arthroscopic rotator cuff surgery is much more common than isolated LHB treatments,[25] this scenario is more likely to represent clinical practice. To reduce the potential bias of concomitant procedures, we selected the disease-specific LHB score as the primary outcome parameter, which has proven a valuable tool in comparable studies investigating LHB tenotomy and tenodesis[9,17,33] as a concomitant procedure in shoulder arthroscopy. Finally, it is important to acknowledge that potential variability in FU treatment protocols could not be eliminated in the study, primarily because nearly all patients underwent concomitant procedures, necessitating individualized postoperative FU treatment plans. Nevertheless, adapting postoperative treatment to concomitant procedures reflects everyday clinical practice.

Conclusion

The implant-free loop tenodesis procedure for the treatment of pathologies of the LHB demonstrates improvement in biceps-related function, resulting in consistently satisfactory patient-reported outcomes and a high rate of construct integrity within the first 2 years postoperatively. However, to further validate its efficacy and compare it with conventional techniques such as tenotomy and tenodesis, a randomized controlled trial design is warranted.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: Stefan Greiner reports a relationship with Arthrex Inc. that includes consulting or advisory. The other authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ahmad CS, DiSipio C, Lester J, Gardner TR, Levine WN, Bigliani LU. Factors affecting dropped biceps deformity after tenotomy of the long head of the biceps tendon. Arthroscopy 2007;23:537-41. https://doi.org/10.1016/j.arthro.2006.12.030
2. Ahmed AF, Toubasi A, Mahmoud S, Ahmed GO, Al Ateeq Al Dosari M, Zikria BA. Long head of biceps tenotomy versus tenodesis: a systematic review and meta-analysis of randomized controlled trials. Shoulder Elbow 2021;13:583-91. https://doi.org/10.1177/1758573220942923
3. Chen C-H, Hsu K-Y, Chen W-J, Shih C-H. Incidence and severity of biceps long-head tendon lesion in patients with complete rotator cuff tears. J Trauma Acute Care Surg 2005;58:1189-93. https://doi.org/10.1097/01.TA.0000170052.84544.34
4. Coda RG, Cheema SG, Hermanns CA, Tarakemeh A, Vopat ML, Kramer M, et al. A review of online rehabilitation protocols designated for rotator cuff repairs. Arthrosc Sports Med Rehabil 2020;2:277-88. https://doi.org/10.1016/j.asmr.2020.03.006
5. Creech MJ, Yeung M, Denkers M, Simunovic N, Athwal GS, Ayeni OR. Surgical indications for long head biceps tenodesis: a systematic review. Knee Surg Sports Traumatol Arthrosc 2016;24:2156-66. https://doi.org/10.1007/s00167-014-3383-9
6. Degenhardt H, Pogorzelski J, Themessl A, Muench LN, Wechselberger J, Woertler K, et al. Reliable clinical and sonographic outcomes of subpectoral biceps tenodesis using an all-suture anchor onlay technique. Arthroscopy 2022;38:729-34. https://doi.org/10.1016/j.arthro.2021.08.033
7. Deng ZJ, Yin C, Cusano J, Abdul-Rassoul H, Curry EJ, Novikov D, et al. Outcomes and complications after primary arthroscopic suprapectoral versus open subpectoral biceps tenodesis for superior labral anterior-posterior tears or biceps abnormalities: a systematic review and meta-analysis. Orthop J Sports Med 2020;8:2325967120945322. https://doi.org/10.1177/2325967120945322
8. van Deurzen DFP, Garssen FL, Wessel RN, Kerkhoffs GMMJ, van den Bekerom MPJ, van Wier MF. The Popeye sign: a doctor's and not a patient's problem. J Shoulder Elbow Surg 2021;30:969-76. https://doi.org/10.1016/j.jse.2020.10.040
9. Franceschetti E, Giovannetti de Sanctis E, Palumbo A, Paciotti M, La Verde L, Maffulli N, et al. The management of the long head of the biceps in rotator cuff repair: a comparative study of high vs. subpectoral tenodesis. J Sport Health Sci 2023;12:613-8. https://doi.org/10.1016/j.jshs.2020.08.004

10. Frank RM, Bernardoni ED, Veera SS, Waterman BR, Griffin JW, Shewman EF, et al. Biomechanical analysis of all-suture suture anchor fixation compared with conventional suture anchors and interference screws for biceps tenodesis. Arthroscopy 2019;35:1760-8. https://doi.org/10.1016/j.arthro.2019.01.026
11. Garrett WE, Swiontkowski MF, Weinstein JN, Callaghan J, Rosier RN, Berry DJ, et al. American Board of Orthopaedic Surgery practice of the orthopaedic surgeon: Part-II, certification examination case mix. J Bone Joint Surg Am 2006;88:660-7. https://doi.org/10.2106/JBJS.E.01208
12. 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;25:515-21. https://doi.org/10.1016/j.arthro.2008.10.026
13. 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. https://doi.org/10.1016/j.jse.2010.08.019
14. Karataglis D, Papadopoulos P, Boutsiadis A, Fotiadou A, Ditsios K, Hatzokos I, et al. Ultrasound evaluation of the distal migration of the long head of biceps tendon following tenotomy in patients undergoing arthroscopic repair of tears of the rotator cuff. J Bone Joint Surg Br 2012;94:1534-9. https://doi.org/10.1302/0301-620X.94B11.29499
15. 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;136:469-75. https://doi.org/10.1007/s00402-015-2391-7
16. 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;46:215-21. https://doi.org/10.1007/s00132-016-3358-2 [article in German].
17. Kerschbaum M, Scheuermann M, Gerhardt C, Scheibel M. Arthroscopic knotless suprapectoral tenodesis of the long head of biceps: clinical and structural results. Arch Orthop Trauma Surg 2016;136:1135-42. https://doi.org/10.1007/s00402-016-2466-0
18. Kerschbaum M, Voss A, Pfeifer C, Weiss I, Mayr A, Alt V, et al. Novel implant-free loop Tenodesis vs. simple Tenotomy of the long biceps tendon - a biomechanical investigation. BMC Musculoskelet Disord 2019;20:522. https://doi.org/10.1186/s12891-019-2919-z
19. Kerschbaum M, Weiss I, Mayr A, Pfeifer C, Nerlich M, Greiner S. The arthroscopic loop tenodesis procedure: an implant-free technique to treat long biceps tendon pathologies. Arthrosc Tech 2019;8:e503-6. https://doi.org/10.1016/j.eats.2019.01.009
20. Kilic AI, Zuk NA, Ardebol J, Pak T, Menendez ME, Denard PJ. Determining minimal clinically important difference and patient-acceptable symptom state after arthroscopic isolated subscapularis repair. JSES Int 2024;8:472-7. https://doi.org/10.1016/j.jseint.2024.01.014
21. Kim SH, Shin SH, Oh JH, Baek GH. Biomechanical and histological analysis after tenotomy of the long head of the biceps in the rabbit shoulder model. J Orthop Res 2012;30:416-22. https://doi.org/10.1002/jor.21546
22. Lee HJ, Jeong JY, Kim CK, Kim YS. Surgical treatment of lesions of the long head of the biceps brachii tendon with rotator cuff tear: a prospective randomized clinical trial comparing the clinical results of tenotomy and tenodesis. J Shoulder Elbow Surg 2016;25:1107-14. https://doi.org/10.1016/j.jse.2016.02.006
23. Lee HI, Shon MS, Koh KH, Lim TK, Heo J, Yoo JC. Clinical and radiologic results of arthroscopic biceps tenodesis with suture anchor in the setting of rotator cuff tear. J Shoulder Elbow Surg 2014;23:e53-60. https://doi.org/10.1016/j.jse.2013.06.004
24. Liu H, Song X, Liu P, Yu H, Zhang Q, Guo W. Clinical outcomes of arthroscopic tenodesis versus tenotomy for long head of the biceps tendon lesions: a systematic review and meta-analysis of randomized clinical trials and cohort studies. Orthop J Sports Med 2021;9:2325967121993805. https://doi.org/10.1177/2325967121993805
25. MacDonald P, Verhulst F, McRae S, Old J, Stranges G, Dubberley J, et al. Biceps tenodesis versus tenotomy in the treatment of lesions of the long head of the biceps tendon in patients undergoing arthroscopic shoulder surgery: a prospective double-blinded randomized controlled trial. Am J Sports Med 2020;48:1439-49. https://doi.org/10.1177/0363546520912212
26. McCrum CL, Alluri RK, Batech M, Mirzayan R. Complications of biceps tenodesis based on location, fixation, and indication: a review of 1526 shoulders. J Shoulder Elbow Surg 2019;28:461-9. https://doi.org/10.1016/j.jse.2018.09.005
27. Na Y, Zhu Y, Shi Y, Ren Y, Zhang T, Liu W, et al. A meta-analysis comparing tenotomy or tenodesis for lesions of the long head of the biceps tendon with concomitant reparable rotator cuff tears. J Orthop Surg 2019;14:370. https://doi.org/10.1186/s13018-019-1429-x
28. Parisien RL, Trofa DP, Kang HP, Swindell HW, Trasolini N, Li X, et al. Increased risk of humeral fracture with open versus arthroscopic tenodesis of the long head of the biceps brachii. Arthrosc Sports Med Rehabil 2020;2:e329-32. https://doi.org/10.1016/j.asmr.2020.04.010
29. Riedl M, Mayr A, Greiner S, Pfeifer C, Weiss I, Forchhammer L, et al. The loop tenodesis procedure-from biomechanics to first clinical results. J Clin Med 2021;10:432. https://doi.org/10.3390/jcm10030432
30. 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. https://doi.org/10.1177/0363546510390777
31. Schoch C, Geyer M, Drews B. Suprapectoral biceps tenodesis using a suture plate: clinical results after 2 years. Arch Orthop Trauma Surg 2017;137:829-35. https://doi.org/10.1007/s00402-017-2664-4
32. 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. https://doi.org/10.1097/JSA.0b013e3181824f1e
33. Uschok S, Herrmann S, Pauly S, Perka C, Greiner S. Combined arthroscopic tenodesis of the long head of biceps and rotator cuff repair in antero-superior cuff tears. Arch Orthop Trauma Surg 2016;136:1273-9. https://doi.org/10.1007/s00402-016-2498-5
34. Walch G, Edwards TB, Boulahia A, Nové-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;14:238-46. https://doi.org/10.1016/j.jse.2004.07.008
35. Xu S, Chen JY, Lie HME, Hao Y, Lie DTT. Minimal Clinically Important Difference of Oxford, Constant, and UCLA shoulder score for arthroscopic rotator cuff repair. J Orthop 2020;19:21-7. https://doi.org/10.1016/j.jor.2019.11.037
36. Zabrzynski J, Paczesny L, Lapaj L, Zabrzynska A, Szwedowski D. The surgical treatment of the long head of biceps tendon and the autotenodesis phenomenon: an ultrasound and arthroscopic study. Folia Morphol 2020;79:395-401. https://doi.org/10.5603/FM.a2019.0072