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CLINICAL STUDY

# Comparison of decrease in elbow flexion strength in patients after tenotomy and tenodesis of the long head of the biceps brachii

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**ABSTRACT**

INTRODUCTION: The last two decades have been leading to the development of several types of surgical techniques and procedures to manage the LHB lesions. This paper analyses and compares the difference in muscle strength pre- and post-operatively in two most commonly used surgical procedures – LHB tenotomy and tenodesis.

METHOD: The study includes 68 patients who underwent surgery between 2016 and 2020. The patients who had met the prospective study inclusion criteria were divided into two groups based on type of surgery they had undergone (LHB tenotomy or tenodesis); each group consisted of 34. The muscle strength during elbow flexion was measured preoperatively and postoperatively using the Commander Echo Console ultrasound muscle testing device. All patients enrolled in the study had been assessed for elbow flexion strength preoperatively. The muscle strength was measured preoperatively and then 3 years postoperatively (12 to 60 months) on average.

CONCLUSION: The study confirmed that the patients who had undergone LHB tenodesis show a significantly lower decrease in elbow flexion strength and a significantly lower incidence of "Popeye" deformity than the patients after LHB tenotomy. Moreover, in the tenodesis group, it was possible to initiate rehabilitation earlier. The incidence of postoperative complications was almost identical in both groups of patients *(Tab. 10, Fig. 6, Ref. 40)*. Text in PDF *www.elis.sk*

KEY WORDS: LHB, tenotomy, tenodesis, Popeye deformity, muscle strength, elbow flexion.

## Introduction

The long head of the biceps (LHB) tendon is a tendon which performs a most comprehensive chain and scope of motions during shoulder movement. Consequently, the LHB tendon is subjected to heavy strain during movement.

Several fundamental studies aimed at clarifying the LHB function have been conducted, repeatedly concluding that LHB acts as a humeral head depressor and stabilizer during elbow flexion and supination (1).

More recent cadaveric studies analysed the LHB function as an important shoulder stabilizer for anterior, posterior and inferior glenohumeral components of stability as well as for rotational stability (2–4) while stabilizing the humeral head translation in the glenohumeral joint (5–7).

Various studies as well as electromyographic tests have shown that the biceps tendon and superior *labrum* bear the highest load in overhead sports, especially those requiring quick contraction immediately followed by relaxation of the shoulder during movement (8–10).

The anterior shoulder pain is largely caused by biceps tendon injuries resulting in tendinitis, instability and traumatic superior labral anterior posterior (SLAP) lesions.

The LHB injury may occur as a consequence of trauma, shoulder instability (11), rotator cuff tears, osteochondral lesions, and arthritis while high percentage of biceps tendon pathologies occur in association with subacromial impingement syndrome (12).

The two basic types of treatment of LHB pathologies are tenotomy and tenodesis.

Tenotomy is a complete cut through of the LHB tendon in its intraarticular portion, most commonly at its origin at the top of the glenoid labrum with subsequent slipping into the bicipital groove. Tenodesis is a complete cut through of the LHB tendon and release of its intra-articular portion with subsequent tendon re-fixation at a different site.

The surgeons need to make a decision on the type of surgery that is to be performed. Both methods, tenodesis and tenotomy give satisfactory outcomes (13–20). The treatment algorithm is based on the patient's age, sex, and activity.

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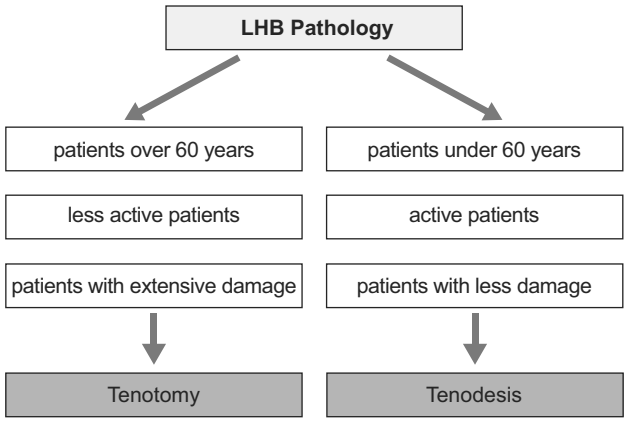


**Figure 1. Treatment algorithm in patients with the LHB pathology.**

The algorithms used at our department for indication of the respective type of surgical procedure are presented in Figure 1 of the paper (Fig. 1).

The purpose of this study was to compare the muscle strength in patients who had undergone tenodesis or tenotomy of the long head of the biceps. We hypothesized that the functional outcomes of patients undergoing tenodesis should be superior to those of the patients undergoing tenotomy.

## Materials and methods

In general, there are several basic goals to be pursued in LHB management, namely to relieve clinical subjective and objective symptoms, improve the range of motion, restore muscle strength, reconstruct associated pathologic affections, and prevent any further damage to LHB and the surrounding structures.

The surgeries of patients in the followed-up study group were performed in a semi-sitting position, specifically in a beach-chair position. The patient is seated at an angle ranging from 60° to 80°. The operated limb is positioned in a flexible Trimano support arm, which also allows us to perform intraoperative dynamic tests on the LHB tendon and improve our manipulation of the shoulder during biceps procedures, also in relation to the tension within the LHB tendon.

Tenotomy – a complete cut through of the LHB tendon can be performed at its origin at the top of the superior labrum or anywhere in its intraarticular portion, while its full release and subsequent slipping into the bicipital groove, where the LHB tendon gradually adheres to the surrounding soft tissues and base of the groove, are controlled from the arthroscopically visualised field of view. This procedure was performed in all patients included in our study group. Tenotomy frequently leads to the formation of "Popeye" deformity, which is a defect of the biceps muscle caused by the tendon sinking lower distally, thus shortening the biceps muscle.

Tenodesis – a complete cut through of the LHB tendon and its release anywhere in its intra-articular portion, with a subsequent tendon refixation. Currently, tenodesis with attaching the tendon to the humerus is preferred. At our department, tenodesis with reattaching the biceps tendon to the upper part of the bicipital groove in a drill hole in the humerus just behind the border of the cartilage, i.e., in the upper part of zone 1 of the bicipital groove, is predominantly performed. This procedure was conducted in all patients included in the presented study group.

The study focuses on comparing the muscle strength loss preoperatively and at least 12 months postoperatively in patients after tenodesis and tenotomy, with the mean follow-up period of muscle strength assessment of 30 months (12–60 months).

We approached all 176 patients who had undergone surgery between 2016 and 2020, of whom 68 patients (40 men and 28 women) agreed to participate in the prospective study. These 68 patients were evenly divided into two groups by type of performed procedure, Specifically, 34 patients underwent tenodesis while the remaining 34 patients underwent LHB tenotomy.

The selection of patients for the study was not limited by age since a change in muscle strength was assessed in each patient separately, the total reduction in muscle strength was expressed in percentage, not in absolute values.

In 49 patients, an additional procedure was performed during the surgery to address another pathology within the shoulder joint, whereas 19 patients underwent a stand-alone LHB surgery. In total, 40 men and 28 women were operated on (Fig. 1).

The study was approved by the Ethics Committee and all study subjects had given their informed consent in writing prior to initiating any study procedures.

The patients participating in the study underwent a full medical examination including an assessment of their medical history obtained, clinical examination of the shoulder joint focusing on most common pathologies of the glenohumeral joint and surrounding structures, paraclinical examinations, and subsequent measurements of isolated elbow flexion strength. In this study, we concentrated solely on the isolated elbow flexion strength, and we did not evaluate any other clinical indicators.

Elbow flexion strength was measured using the *Commander Echo Muscle Tester* by JTECH Medical, USA (Fig. 2). The muscle strength was measured for 5 seconds, thus the value obtained was not the peak muscle force, but rather its continuously sustained value. The measurement was repeated five times in each patient.

*Commander Echo Muscle Tester* is a wireless device transmitting the measured values to data collector that can be connected to a PC. The measuring device as such offers a high standard of measurement since the measured values are accurately transmitted, thus eliminating a potentially subjective reading of measured values. The device allows for quick and accurate quantification of muscle strength and identification of weaknesses in an isolated muscle group. Test protocols can be customised based on the number of tests, starting force, number of repetitions, and various measurement units for muscle strength measurements (21).

Muscle strength was measured in a seated position with knees bent at 90 degrees to minimize the exertion of lower body forces during testing. During the examination, the patient was seated (on a chair with hight adjusted to the patient´s body height), with the shoulder at 0 degrees adduction and elbow at 90 degrees flexion in order to measure, the isolated strength of the biceps as accu-

rately as possible (Fig. 3). Subsequently, the patient exerted maximum pressure on the mat for 5 seconds. Five measurements were always performed, and the mean value was calculated (Fig. 4) and subsequently recorded in kilograms. Then the values of each patient's muscle strength before and after surgery were compared and muscle loss determined separately for each group of patients (tenodesis group and tenotomy group).

All surgical procedures included in this study were performed by one surgeon. This helped to minimize variations in surgical technique and surgical procedures as there are multiple different ways how to perform biceps tenodesis or tenotomy.

We declare that the work has been reported in accordance with the criteria of the PROCESS (22).


**Figure 2. Commander Echo Console ultrasound muscle tester.**

*Statistical processing of data*

Data of 68 patients (34 with tenotomy and 34 with tenodesis) were processed. For numerical values (cardinal numbers), the number of subjects, arithmetic mean, standard deviation, median, minimum and maximum values are reported. Statistical processing of the data was carried out using nonparametric statistical tests that do not require normal distribution of data and presence of homoscedasticity. Variables from different groups were compared using the Mann–Whitney test; for pair comparisons of data before and after surgery the Wilcoxon matched-pairs signed-rank test was used. Categorical data were processed using a contingency table and a chi-square test. While nonparametric tests were employed for the analysis, for the sake of comprehensive reporting, fundamental statistical data are presented. In addition to the essential median and range (minimum – maximum) we include the arithmetic mean and standard deviation. It is important to note that the latter parameters are not used for interpretation of results of nonparametric tests. If the p value of test criterion of the statistical test was less than 0.05, the obtained differences between the tested groups were considered statistically significant and non-random, i.e., caused by the investigated factor. The statistical analysis was conducted with the use of InStat and Statistica software.

**Table 1. Comparison of age structure (years) at surgery by type of surgical procedure.**

| Group | n | $\bar{x}$ | sd | $x_m$ | min | max | p |
|---|---|---|---|---|---|---|---|
| Tenotomy | 34 | 58.0 | 2.3 | 58 | 54 | 62 | < 0.001 |
| Tenodesis | 34 | 43.2 | 4.1 | 43 | 36 | 50 | |

n – number if patients, $\bar{x}$ – arithmetic mean, sd – standard deviation, $x_m$ – median, min – minimum value, max – maximum value, p – value of the test criterion of the Mann–Whitney test

**Table 2. Comparison of age structure (years) at measurement by type of surgical procedure.**

| Group | n | $\bar{x}$ | sd | $x_m$ | min | max | p |
|---|---|---|---|---|---|---|---|
| Tenotomy | 34 | 61.0 | 2.9 | 61 | 56 | 66 | < 0.001 |
| Tenodesis | 34 | 46.1 | 4.2 | 46.5 | 38 | 54 | |

n – number of patients, $\bar{x}$ – arithmetic mean, sd – standard deviation, $x_m$ – median, min – minimum value, max – maximum value, p – value of the test criterion of the Mann–Whitney test

*Conclusions and results of statistical processing of data*

Table 1 shows a statistically significant difference in the age of patients with tenotomy ($x_m$ = 58 years) and tenodesis ($x_m$ = 43 years) at surgery ($p < 0.001$). The same statistically significant difference was detected in age structure at muscle strength measurement (Tab. 2) ($p < 0.001$), which basically corresponds with the time

**Figure 3. Patient position during the examination.**


**Figure 4. Commander Echo Console ultrasound muscle tester.**

elapsed from surgery. These findings confirmed the fact that our department complies with the aforementioned LHB treatment algorithm, according to which in patients older than 60 years, less active patients and patients with an extensive pathology, tenotomy is preferably indicated.

**Table 3. Verification of the proportionality of representation of both sexes by type of surgical procedure.**

| Group | Men | Women | Total | $\chi^2$ | d.f. | p |
|---|---|---|---|---|---|---|
| Tenotomy | 15 (20) | 19(14) | 34 | | | |
| Tenodesis | 25(20) | 9(14) | 34 | 6.071 | 1 | 0.012 |
| Total | 40 | 28 | 68 | | | |

$\chi^2$ – chi–square test characteristics, d.f. – degrees of freedom, p–value of the test criterion of chi–square test

**Table 4. Time elapsed since surgery (months) in dependence on its type.**

| Group | n | $\bar{x}$ | sd | $x_m$ | min | max | p |
|---|---|---|---|---|---|---|---|
| Tenotomy | 34 | 37.1 | 13.5 | 34.5 | 12 | 60 | 0.508 |
| Tenodesis | 34 | 34.9 | 13.8 | 34.5 | 12 | 60 | |

n – number of patients, $\bar{x}$ – arithmetic mean, sd – standard deviation, $x_m$ – median, min – minimum value, max – maximum value, p – value of the test criterion of the Mann–Whitney test

**Table 5. Tenotomy: comparison of preoperative and postoperative muscle strength.**

| Strength (kg) | Measurement | n | $\bar{x}$ | sd | $x_m$ | min | max | p |
|---|---|---|---|---|---|---|---|---|
| Maximum | Pre | 34 | 17.74 | 4.35 | 17.25 | 11.5 | 28.9 | < 0.001 |
| | Post | 34 | 15.17 | 4.34 | 14.85 | 8.8 | 26.1 | |
| Minimum | Pre | 34 | 15.47 | 4.24 | 15.15 | 8.0 | 26.5 | < 0.001 |
| | Post | 34 | 12.97 | 4.22 | 12.30 | 5.8 | 23.7 | |
| Mean | Pre | 34 | 16.60 | 4.26 | 16.40 | 10.0 | 27.7 | < 0.001 |
| | Post | 34 | 14.07 | 4.24 | 14.15 | 7.5 | 24.9 | |

n – number of patients, $\bar{x}$ – arithmetic mean, sd – standard deviation, $x_m$ – median, min – minimum value, max – maximum value, p – value of the test criterion of the Mann–Whitney test

**Table 6. Tenodesis: comparison of pre– and postoperative muscle strength (kg).**

| Strength (kg) | Measurement | n | $\bar{x}$ | sd | $x_m$ | min | max | p |
|---|---|---|---|---|---|---|---|---|
| Maximum | Pre | 34 | 28.52 | 8.19 | 30.55 | 11.7 | 39.7 | < 0.001 |
| | Post | 34 | 26.85 | 7.99 | 29.05 | 11.2 | 38.0 | |
| Minimum | Pre | 34 | 26.28 | 7.91 | 28.30 | 10.1 | 36.7 | < 0.001 |
| | Post | 34 | 24.38 | 8.00 | 25.70 | 8.4 | 35.8 | |
| Mean | Pre | 34 | 27.40 | 8.03 | 29.60 | 10.9 | 38.2 | < 0.001 |
| | Post | 34 | 25.62 | 7.98 | 27.20 | 9.8 | 36.6 | |

n – number of patients, $\bar{x}$ – arithmetic mean, sd – standard deviation, $x_m$ – median, min – minimum value, max – maximum value, p – value of the test criterion of the Mann–Whitney test

Interestingly, there is unequal representation of men and women in the group (Tab. 3), with a statistically significant difference between them (p = 0.012). Tenotomy was performed in 15 men and 19 women, while tenodesis in 25 men and 9 women.

In Table 3, the values in the brackets below the number of patients reported give the so-called expected value which is anticipated by the statistical test in case of equal representation of men and women by procedure, which is not the case in our study. Table 6 clearly indicates that the number of men treated with tenodesis (n = 25) was higher than expected, whereas the number of men treated with tenotomy (n = 15) was lower than 20 which represents the expected value. In case of women, this ratio is symmetrically opposite to that in men. These findings are again consistent with our applied LHB treatment algorithm. Although both methods yield satisfactory outcomes (16–19), tenotomy is after all a simple and less invasive procedure that can be performed in a relatively short time and leads to excellent postoperative pain relief (23, 24).

As to the verification of time elapsed since surgery (months) relative to type of procedure, namely tenotomy versus tenodesis (Tab. 4), we can claim that no statistically significant difference was found between the two groups of patients (p = 0.508).

Tables 5 and 6 indicate that in each procedure (tenotomy and tenodesis), the difference in preoperative and postoperative muscle strength values is of extreme statistical significance (p < 0.001). The median values naturally differ relative to the type of procedure, with higher numerical values in case of tenodesis. In summary, the median of the mean muscle strength in case of tenotomy before surgery ($x_m$ = 16.4 kg) is significantly higher than that after surgery ($x_m$ = 14.15 kg) (Table 8). The same level of statistical significance applies to tenodesis, where the median of the mean muscle strength before surgery ($x_m$ = 29.60 kg) is higher than the median of the mean muscle strength after surgery ($x_m$ = 27.2 kg). Despite different values of strength in tenotomy and tenodesis, we may conclude that the "shift" in the decrease in value after treatment is in a similar range in both types of treatment, namely 2.25–2.4 kg, and can therefore be considered very similar. It should be emphasised that regarding the numerical values of muscle strength (maximum, minimum and mean) obtained preoperatively, a direct mutual statistical comparison of the effectiveness of methods is not feasible. This is due to the fact that muscle strength values in tenotomy (median values from 15.15 to 17.25) are almost by 50% lower than the median values measured preoperatively in tenodesis (28.3 and 30.55) (Tabs 5 and 6). In conclusion, both methods are deemed almost equally beneficial.

In connection with the procedures, it should be highlighted that not all patients underwent a stand-alone procedure but were treated with additional concomitant procedures (rotator cuff repair, SAD, or combination of procedures). In this context, we statistically verified the degree of difference in the observed mean strength between the patients with a stand-alone procedure and patients in whom also

a concomitant procedure was performed. The calculations were made both for tenotomy and for the subgroup of patients who underwent tenodesis. The results are presented in Table 7. In the case of tenotomy, the median values of mean strength differ by 4.6 kg in favour of stand-alone procedures (p = 0.032), which is clearly also statistically significant. In the case of tenodesis, the difference between the median of both groups is 2.4 kg, however in favour of concomitant procedures. Thus, this difference is smaller and according to the statistical test statistically nonsignificant (p = 0.460). Our findings suggest that in cases with concomitant procedures performed together with tenotomy, statistically significantly worse outcomes in terms of mean muscle strength are achieved. That is why in terms of mean elbow flexion strength loss, tenodesis can be considered preferrable to tenotomy, regardless of the incidence of "Popeye" deformity which occurs more often after tenotomy.

**Table 7. Comparison of mean postoperative muscle strength (kg) between the groups of patients by type of surgical procedure.**

| Group | Procedure | n | $\bar{x}$ | sd | $x_m$ | min | max | p |
|---|---|---|---|---|---|---|---|---|
| Tenotomy | Isolated | 7 | 17.66 | 4.91 | 17.40 | 10.8 | 24.9 | 0.032 |
| | Concomitant | 27 | 13.14 | 3.59 | 12.80 | 7.5 | 20.8 | |
| Tenodesis | Isolated | 12 | 26.97 | 8.76 | 29.60 | 9.8 | 36.6 | 0.460 |
| | Concomitant | 22 | 24.88 | 7.64 | 27.20 | 11.8 | 36.4 | |

n – number of patients, $\bar{x}$ – arithmetic mean, sd – standard deviation, $x_m$ – median, min – minimum value, max – maximum value, p – value of the test criterion of the Mann–Whitney test

## Results

In the group of 68 patients, a rotator cuff repair was performed in 14 patients, subacromial decompression in 15 patients, shoulder stabilization with anterior labrum refixation in 4 patients, a combination of procedures in 16 patients, and in 19 patients a stand-alone LHB procedure was carried out. We operated on 40 men and 28 women. The mean values of recorded pre- and post-operative measurements were organized in tables. Basic information on the distribution of patients into groups with detailed demographic description is presented (Tab. 8).

Assessments of patients and the mean values obtained by measurements in patients after tenodesis show that the mean decrease in muscle strength is 1.35 kg, which represents a mean decrease by 5.5%, with the lowest decrease in muscle strength recorded in the group of patients after a stand-alone procedure and the highest decrease in muscle strength recorded in the group of patients with the procedure combined with rotator cuff repair (Tab. 9).

Assessments of patients and the mean values obtained by measurements in patients after tenotomy show that the mean decrease in muscle strength is 2.65 kg, which represents a mean decrease by 14.5%, with the lowest decrease in muscle strength recorded in the group of patients after a stand-alone procedure and the highest decrease in muscle strength recorded in the group of patients with multiple procedures combined (Tab. 10).

The difference in the decrease in muscle strength is 8.55% in favour of tenodesis and against LHB tenotomy, which is a significant percentage difference.

Not only did the patients with tenodesis experience an objectively smaller decrease in muscle strength, but they also reported a diminished subjective feeling of weakness during flexion in the elbow joint diminished and were capable of virtually identical sports and workload. At the same time, due to the absence of the development of "Popeye" deformity, they subjectively felt significantly better about the appearance of the shoulder, which increased the level of their satisfaction with the surgical procedure.

The incidence of the "Popeye" deformity in the tenotomy group was 52.9% (18 patients) as compared to the group after

**Table 8. Demographic data of patients included in the study.**

| | **Tenodesis** | **Tenotomy** |
|---|---|---|
| Number | 34 | 34 |
| Sex – male / female | 25:9 | 15:19 |
| Mean age at surgery | 43.2 | 58 |
| Mean age at measurement | 46.5 | 61.1 |
| Mean time elapsed since surgery | 2.9 | 3.1 |
| Isolated procedure | 12 | 7 |
| Concomitant procedures | 22 | 27 |
| Rotator cuff repair | 8 | 6 |
| SAD | 4 | 11 |
| Combination of procedures | 6 | 10 |
| Stabilization | 4 | 0 |

**Table 9. Results of elbow flexion strength measurements in patients before and after LHB tenodesis.**

| Muscle strength values obtained by measurements after **tenodesis** – 34 patients | | |
|---|---|---|
| | Preoperative | Postoperative |
| Mean maximum strength | 38.2 kg | 36.6 kg |
| Mean minimum strength | 10.9 kg | 9.8 kg |
| Mean strength | 24.55 kg | 23.2 kg |
| **Mean decrease in muscle strength 1.35 kg** | | |
| **In percentage** | **100%** | **94.5%** |
| **Decrease in percentage** | **5.5%** | |

**Table 10. Results of elbow flexion strength measurements in patients before and after LHB tenotomy.**

| Muscle strength values obtained by measurements after **tenotomy** – 34 patients | | |
|---|---|---|
| | Preoperative | Postoperative |
| Mean maximum strength | 27.7 kg | 24.9 kg |
| Mean minimum strength | 10.0 kg | 7.5 kg |
| Mean strength | 18.85 kg | 16.2 kg |
| **Mean decrease in muscle strength 2.65 kg** | | |
| **In percentage** | **100%** | **85.95%** |
| **Decrease in percentage** | **14.05%** | |

tenodesis where no development of "Popeye" deformity was observed. The incidence of "Popeye" deformity in patients after tenotomy was significantly higher.

The mean age of patients who underwent tenodesis was 43.2 years, whereas in patients after tenotomy, the mean age was 58 years (Tab. 8).

Figure 5 shows the values of decrease in elbow flexion strength in kg measured in patients before and after LHB surgery, with the mean decrease in muscle strength being 1.35 kg in the tenodesis group and 2.65 kg in the tenotomy group.

Figure 6 shows the values of decrease in elbow flexion strength in percentage measured in patients before and after LHB surgery, with the mean decrease in flexion elbow strength being 5.5% in the tenodesis group and 14.05% in the tenotomy group.

## Discussion

Though there is a plethora of articles on tenotomy and tenodesis available, some of them contradict each other and describe various surgical techniques. The primary goal of surgical treatment in patients with LHB pathology is to maximize the patient´s postoperative wellbeing with respect to the LHB tendon pathology and to minimize the adverse postoperative complications.

Apart from the isolated assessment of elbow flexion strength, in the followed-up group of patients, also the LHB score and Constant–Murley score (CMS) were obtained. Due to the heterogeneity of concomitant procedures and high number of patients in the study group, our study was not aimed to statistically analyse the mentioned scoring systems, rather to focus on assessing the isolated elbow flexion, while in addition to measuring its absolute strength to measure also the endurance strength during repeated elbow flexion against resistance. When evaluating the LHB score and CMS, we found an improvement in postoperative scores after both types of surgery. However, both scoring systems identified a greater weakening of muscle strength and a more frequent development of "Popeye" deformity in the tenotomy group. The mean CMS score in the tenodesis group improved from 49 (95% confidence interval [CI], 45–53) to 84 (95% CI [CI], 79–88). In the tenotomy group, the mean CMS improved from 42 (95% [CI], 39–46) to 78 (95% [CI], 74–82).

All operations in the followed-up study group were performed by one surgeon.

Elbow flexion strength was measured using the *Commander echo muscle tester*. Stark et al found out that the assessment of strength by hand-held dynamometry almost correlates with isokinetic dynamometry. They have concluded that when compared to isokinetic devices, the features of hand-held dynamometry´s ease of use, portability, cost, and compact size make this instrument a reliable and valid tool for clinical testing of muscle strength (25).

In our study group, tenodesis was performed by fixation into the humerus, which is currently the preferred option. Tenodesis within the upper portion of the groove was introduced at the beginning of the 21st century and was followed by development of multiple techniques and materials (23, 26). At our department, tenodesis is predominantly performed with re-fixation in the upper portion of the bicipital groove in a drill hole in the humerus, just behind the border of the cartilage, i.e., in the upper part of zone 1 of the bicipital groove. This type of tenodesis is performed arthroscopically, with partial pulling out of the LHB tendon above the skin level, suture of the tendon and its subsequent push into the pre-drilled hole and fixation with a screw. Due to the preferences of the surgeon, subpectoral tenodesis was not used.

In our study group of patients, tenotomy was performed by releasing the LHB tendon from its upper attachment. There are several other LHB tenotomy methods and techniques seeking to minimize the development of "Popeye" deformity and postoperative cramping in the region of bicipital groove, e.g., loop tenotomy (26) or "anchor shape" technique (28). "Popeye" deformity is a common consequence of tenotomy and is not considered a complication in this type of surgery.

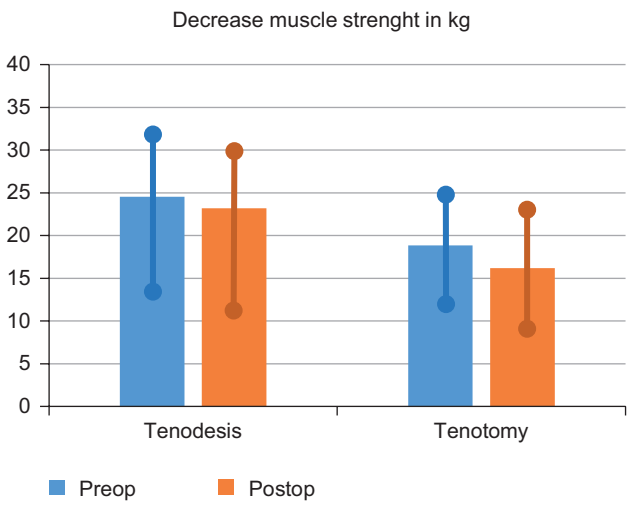


**Figure 5. Values of decrease in elbow flexion strength in kg measured in patients before and after LHB surgery.**

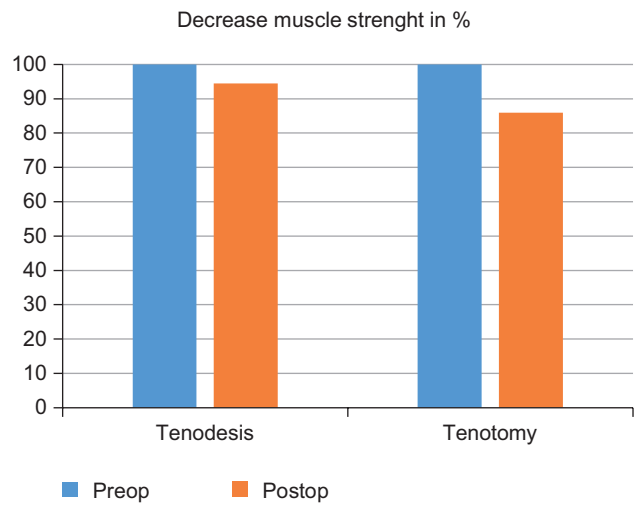


**Figure 6. Values of decrease in elbow flexion strength in percentage measured in patients before and after LHB surgery.**

Tenodesis and tenotomy are used not only as primary treatments for pathologic affections of LHB, but also as a solution to biceps problems if SLAP lesion refixation fails. In case of isolated SLAP II lesions in younger patients, SLAP lesion refixation is an option, but if re-fixation fails, tenodesis is subsequently performed (29). In older patients with failed SLAP lesion re-fixation , tenotomy is performed (30).

However, the arthroscopic examination of LHB has some limitations. Gilmer et al pointed out that diagnostic arthroscopy identified only 67% of LHB pathology and poor visualization resulted in underestimation of the LHB pathology (31). Another study has concluded that arthroscopy failed to fully diagnose up to 47% of extra-articular LHB lesions in the bicipital groove in patients presenting symptoms of LHB pathology, while arthroscopy also managed to visualize only approximately 55% of the LHB length (32). LHB examination by arthroscopy only has its pitfalls and limits as its length up to the superior border of the pectoral major tendon border is approximately 90 mm, whereas no more than 56 mm can be observed, i.e., approximately 62% (15).

We compared the results of our study and assessments of the study group with other conducted studies.

Our results regarding the decrease in elbow flexion strength in patients after tenodesis and after tenotomy do not significantly differ from the results of other studies carried out. The results are almost identical, e.g., when compared to those of the study by Koh et al (33) who demonstrated a 20% decrease in elbow flexion and supination strength after tenotomy. In our study, we used a state-of-the-art method of measuring muscle strength, with the statistically lowest measurement error; we repeated the measurements for each patient 5 times and then averaged the muscle strength, eliminating as much as possible the involvement of other muscle groups in the elbow flexion movement by the patient's position during examination.

The patients after tenotomy exhibit a significantly higher incidence of "Popey" deformity compared to patients after tenodesis. In our study group, the "Popeye" deformity was reported in 18 patients, i.e., in 52.9%. According to Alflatooni, it is 3% only (34), whereas Slenker states up to 43% (35) and according to MacDonald et al, the incidence of "Popeye" deformity is up to 3.5 times higher in the LHB tenotomy group than in the LHB tenodesis group (36). This author found no differences in the postoperative outcomes of the two types of surgery in terms of flexion and supination muscle strength, pain, or cramping, other than dropping down of the muscle belly. Similar results regarding the decrease in muscle strength were obtained by Friedman et al in their study (21).

Some other studies suggest that LHB tenotomy and tenodesis yield comparable postoperative clinical and functional outcomes, but tenodesis shows better results in preventing the development of "Popeye" deformity (37). Shank compared the elbow flexion and forearm supination strength on a group of 17 patients who underwent tenotomy and 19 patients who underwent tenodesis and found no differences between the two groups (38). Virtually identical weakening of muscle strength after tenotomy and tenodesis has been found by studies conducted by Kooistra et al (17) and Carvalha et al (18). Similar results regarding the decrease in muscle strength were obtained by the study by Friedman et al (21). In their retrospective study on 160 patients, Osbahr et al investigated the "Popeye" deformity, cramping and bicipital pain and found only small differences between patients receiving tenodesis and tenotomy, but they reported a higher rate of "Popeye" deformity (39). On the contrary, Aflatooni (33) and Ahmed (13) demonstrate a weakening of muscle strength, cramping and frequent biceps pain in the front of the shoulder after tenotomy. Abdulaziz et al revealed that in patients followed-up at one year after surgery, the difference in improvement in the Constant–Murley score between the tenodesis and tenotomy groups was negligible, which is also confirmed by our results; however, after two years, the difference in CMS between the two groups became greater in favour of the tenodesis group, while no significant difference was detected in other functional outcomes, pain, or elbow flexion and forearm strength indices (20).

Nonetheless, this does not mean that tenotomy, which is regarded as a simpler procedure while showing almost identical functional outcomes in many studies, is the method of choice in most patients. The patient should be always treated on a case-by-case basis, considering factors such as the patient's age, clinical findings, local findings in the shoulder during surgery, and naturally also the requirements of the patient and the shoulder load during sports or at work.

Potential differences in the outcome of surgery, such as the development of biceps belly deformity, muscle strength, and postoperative cramping, shall be considered in the choice and proper indication of surgery. The algorithm for the indication of surgical treatment is included in Figure 1. When focusing on what almost all studies have in common, the consensus is that tenodesis is a preferable procedure to avoid "Popeye" deformity, which is much more common after tenotomy (19, 35, 36, 40).

Tenotomy and tenodesis are very good techniques of surgical treatment relieving the patients' symptoms, reducing pain, and improving the functional outcomes of the shoulder.

Regarding the weakening of elbow flexion strength in our study group, tenodesis has yielded significantly better outcomes with an 8.55% reduction in muscle strength weakening compared to tenotomy. Tenodesis is the method of choice in younger and physically active patients, both for primary indications and revision surgeries of failed SLAP lesion re-fixation, and when aiming to prevent the development of "Popeye" deformities.

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