A Comparison of Forearm Supination and Elbow Flexion Strength in Patients With Long Head of the Biceps Tenotomy or Tenodesis

John R. Shank, M.D., Steven B. Singleton, M.D., Sepp Braun, M.D., Michael J. Kissenberth, M.D., Arun Ramappa, M.D., Henry Ellis, M.D., Michael J. Decker, Ph.D., Richard J. Hawkins, M.D., and Michael R. Torry, Ph.D.

Purpose: The purpose of this study was to compare the forearm supination and elbow flexion strength of the upper extremity in patients who have had an arthroscopic long head of the biceps tendon (LHBT) release with patients who have had an LHBT tenodesis. **Methods:** Cybex isokinetic strength testing (Cybex Division of Lumex, Ronkonkoma, NY) was performed on 17 patients who underwent arthroscopic LHBT tenotomy, 19 patients who underwent arthroscopic LHBT tenodesis, and 31 age-, gender-, and body mass index–matched control subjects. Subjects were considered fully recovered from shoulder surgery, were released for unrestricted activities, and were at least 6 months after surgery before testing. Subjects were tested for forearm supination and elbow flexion strength of both arms by use of a Cybex II NORM isokinetic dynamometer at 60°/s and 120°/s. Testing was performed on injured and uninjured arms as well as dominant and nondominant arms in control subjects. Both forearm supination and elbow flexion strength values were recorded. **Results:** Comparison between the involved and uninvolved upper extremities within each group by use of a paired *t* test showed a 7% increase in elbow flexion strength when the dominant and nondominant arms were compared at 60°/s. Neither the tenotomy nor tenodesis groups exhibited elbow flexion strength differences at 120°/s (all $P \geq .147$). Comparison between groups by use of 2 × 3 analysis of variance (speed × group) showed no statistical difference in either forearm supination or elbow flexion strength when we compared the tenotomy, tenodesis, and control groups. **Conclusions:** In asymptomatic patients who have had biceps tenotomy or tenodesis, no statistically significant forearm supination or elbow flexion strength differences existed in the involved extremity between the 2 study groups. **Level of Evidence:** Level III, case-control study.

Proximal long head of the biceps tendon (LHBT) release and tenodesis are 2 techniques used to treat symptomatic patients with proximal biceps pathology.[1] The concept of simple biceps tenotomy was initially proposed by Walch et al.[2] in 1991 as an associated procedure with repairs of massive rotator cuff tears. Arthroscopic biceps tenotomy has been shown to provide substantial pain relief in patients with a variety of proximal bicipital pathologies.[3-7] Subsequently, the functional outcome as measured by the American Shoulder and Elbow Surgeons scoringsystem has been shown to be very good with arthroscopic biceps tenotomy for the treatment of biceps tendon pathology.[6,7] Whereas tenotomy is technically simple, with it comes the risk of a "popeye" cosmetic deformity with distal tendon migration and possibly recurrent muscle spasm, fatigue, and discomfort with active elbow flexion and supination. Wolf et al.[8] in 2005 in a cadaveric analysis after biceps tenotomy showed that stump migration leading to cosmetic deformity occurred 40% of the time under physiologic loading. Furthermore, Kelly et al. in 2005 evalu-

From the Steadman Hawkins Clinic of the Carolinas (J.R.S., S.B.S., M.J.K., R.J.H.), Spartanburg, South Carolina; Department of Orthopaedics (A.R.), Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, Massachusetts; School of Kinesiology and Recreation (M.R.T.), Illinois State University, Normal, Illinois; and Biomechanics Research Laboratory, Steadman Philippon Research Institute (S.B., H.E., M.J.D., M.R.T.), Vail, Colorado, U.S.A.

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Address correspondence and reprint requests to Michael R. Torry, Ph.D., School of Kinesiology and Recreation, College of Applied Science and Technology, Campus Box 5120, Normal, IL 61761, U.S.A. E-mail: mtorry@ilstu.edu

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ated the functional outcome of patients after arthroscopic release of the biceps tendon.[7] Their results showed a 70% chance of the development of a popeye deformity and that 38% reported some fatigue discomfort after resistance exercises with no pain reported at rest. Moreover, several investigators suggest that biceps release may lead to a loss of upper extremity strength and, possibly, a loss in glenohumeral stability.[3,9-12] As a result, many reserve tenotomy for older, less active patient populations.

Given these potential problems with tenotomy, some investigators have advocated LHBT tenodesis.[3,5,10,13] There are, however, a number of potential problems associated with tenodesis that should not be overlooked: longer surgical time, longer rehabilitation, anterior shoulder pain, recurrent muscle spasm, and symptomatic fixation or hardware. In addition, after a tenodesis, there is still a risk of a popeye deformity developing if there is either a failure of fixation or LHBT disruption. Thus tenodesis may be preferred in the younger, active patient because of cosmesis and strength.

To date, no studies have evaluated strength postoperatively in patients who have had an elective LHBT tenotomy. Concurrently, there are no published reports of normal strength parameters for isokinetic testing of the dominant and nondominant upper extremity in forearm supination. The goals of this study were the following: (1) to establish normal isokinetic strength data for forearm supination and elbow flexion, and (2) to compare this data group with data from 2 groups of patients who have had either an LHBT tenotomy or tenodesis. The null hypothesis for this experimental study states that forearm supination and elbow flexion strength will not be different between arms within each group or between each group.

METHODS

Over a 3-year period, 75 patients were enrolled in this study. Of these patients, 8 (6 tenodesis and 2 tenotomy) voluntarily withdrew their participation in the study or were lost to follow-up, leaving 17 patients (10 men and 7 women; 15.3 ± 8.6 months after surgery; mean age, 51.5 ± 9.9 years; mean body mass index [BMI], 26.5 ± 3.8) who underwent isolated arthroscopic biceps tenotomy, 19 patients (11 men and 8 women; 20.2 ± 7.9 months after surgery; mean age, 51.8 ± 12.8 years; mean BMI, 25.9 ± 3.1) who underwent isolated arthroscopic biceps tenodesis, and 31 matched control subjects (21 men and 10 women; mean age, 49.8 ± 12.2 years; mean BMI, 26.4 ± 2.1). There was additional pathology in all the cases. Nearly all subjects had subacromial impingement and underwent a subacromial decompression at the time of surgery. In all cases the biceps was degenerative and inflamed and therefore released or tendered. Two patients in each surgery group presented with cuff tears.

All patients were considered fully recovered from shoulder surgery as defined by being released to full, unrestricted activities. Surgical procedures were recommended based on clinical examination findings including tenderness over the proximal LHBT, provocative maneuvers, response to injection, and magnetic resonance imaging suggesting biceps pathology. For surgery, in brief, a small incision was made at the supra-pectoral and subdeltoid at the bottom of the groove with a 5-mm anchor double loaded, whip stitched, and secured down over the post in duplicate. To create the correct tension in the tenodesis group, the biceps was pulled taught with the elbow flexed and the excess excised.

Subject Preparation

After identification by the senior physician during their routine clinical visit, all patients were informed of the study by either the senior physician or attending fellow and were informed of their rights as volunteers for this project. Once they verbally volunteered, the subjects were directed to the Biomechanics Laboratory, where they were further instructed as to the study procedures, introduced and educated as to the testing equipment, and asked to sign an informed consent form that was approved by the Vail Valley Medical Center's Institutional Review Board. All testing was conducted in the Biomechanics Research Laboratory of the Steadman Philippon Research Institute by a single examiner and lasted approximately 45 minutes.

Experimental Protocol

Before testing, subjects were instructed on how to stretch the upper extremity. In addition, each subject was allowed ample time to sit within the Cybex machine (Cybex Division of Lumex, Ronkonkoma, NY) to familiarize themselves with the apparatus (Fig 1). This included several practice trials where the subject could become acquainted with the examination to be performed, as well as the speed at which each test was to be performed.

Strength Testing

Supination and elbow flexion isokinetic strength was measured at 60°/s and 120°/s with a Cybex

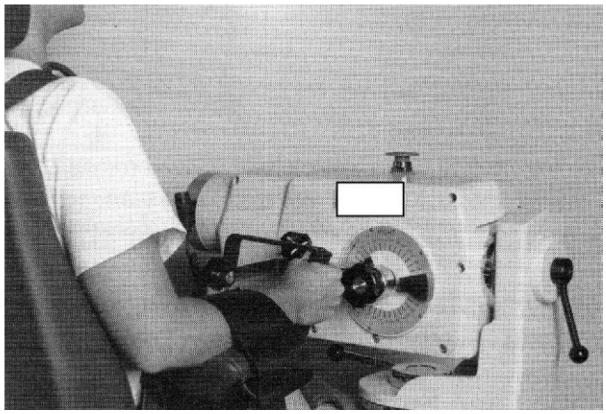

FIGURE 1. Experimental test setup for maximal supination-pronation strength testing.

NORM dynamometer according to the following protocol and Cybex testing guidelines.[14]

Forearm Supination Testing: Subjects were instructed to sit in the Cybex testing chair with their forearm strapped to a pad, their shoulder in adduction and neutral external/internal rotation, and their elbow flexed to 90°. The forearm was in a neutral position with respect to supination/pronation. These start positions were standardized with a handheld goniometer as well as the chair-positioning calibration scales provided on the Cybex apparatus itself. The strap was used to help standardize body position and limit extraneous movement or its associated muscle activity from influencing supination or pronation measures per the recommendation of the Cybex operator's manual.[14] The subjects were given several practice trials of supination and pronation at the different test speeds to make sure that they were properly positioned and adequately warmed up. They were allowed to practice as long as needed to become well acquainted with the test situation, the range-of-motion boundaries, and the test speeds to be encountered. On the basis of subject feedback and comfort level, ample time was taken (approximately 5 minutes) after practice trials to mitigate possible fatigue effects before testing. Testing the subject's supination strength at 60°/s and 120°/s as well as arm (dominant *v* nondominant, injured *v* uninjured) was counterbalanced by subject for all groups to avoid order bias in the data. Range of motion for each test speed was set between the subject's maximum supination and pronation for each arm. Testing consisted of 1 set of 5 repetitions at each speed condition. Subjects paused for 5 seconds between each of the 5 repetitions, to ensure that they did not influence the next repetition with the momentum of their movement. Subjects were allowed to rest for 2 minutes between each speed condition. After testing the first arm, the subjects were allowed a short break while we repositioned them in the chair to test their other arm with the same procedures. To help eliminate subject positioning bias, simple measurements were made between the Cybex machine's center of rotation and the force application at the subject's middle metacarpal-phalangeal joint, which was assumed to be the center of pressure applied to the torque handle by the subject.

Elbow Flexion Testing: The same chair position was used for elbow flexion and extension testing, with the forearm in the neutral supination/pronation position. A strap was placed across the chest, securing the arm to the side, to again standardize body position and limit extraneous muscle activity from influencing elbow flexion or extension measures during the effort. Subjects were first tested in degrees for maximum range of motion in elbow flexion and extension. Again, subjects were given several practice trials to make sure they were adequately warmed up and comfortable with the testing procedure.

Data Analysis

Subjects were classified into 3 groups: those with normal shoulders (control subjects), those having proximal biceps release (tenotomy), and those having proximal biceps tenodesis. Peak strength scores (torque in newton meters) were averaged for all trials of each condition. The difference in torque between the dominant and nondominant extremities in supination and pronation for the normal shoulders was used as a control. Elbow flexion and extension for the normal shoulders were also used as a control and were compared with the known normal data from other isokinetic studies. The difference in torque between the surgical shoulder (biceps release or biceps tenodesis) and the other, nonsurgical shoulder was calculated and used as the criterion measure. Therefore the nonsurgical shoulder served as the control. Torque differences between the 3 groups of patients were compared statistically by use of an analysis of variance.

Maximal torque values were compared across groups with an analysis of variance with a Bonferroni adjustment. Within-group/between-arm comparisons were conducted with paired t tests with a P value of .05.

RESULTS

There was no statistical difference between mean age and BMI in the control, tenotomy, and tenodesis

TABLE 1. *Mean Values for Isokinetic Flexion at 60°/s*

	Angle of Measurement of PFT (°)	PFT at 60°/s (Nm) Surgical Arm or Dominant Arm	PFT at 60°/s (Nm) Nonsurgical Arm or Nondominant Arm	β	Sample Size
Tenotomy (n = 17)					
Mean	89	19.04	22.12	0.21	94
SD	4.64	9.96	10.91		
Tenodesis (n = 19)					
Mean	89.26	20.22	18.94	0.08	674
SD	3.81	12.15	10.24		
Control (n = 31)					
Mean	88.48	23.64	22.15	0.08	1,498
SD	6.59	17.3	16.09		
ANOVA β		0.05	0.04		
Sample size		2,259	406		

NOTE. A post hoc power analysis (β) was used for within-group comparisons. Sample size was based on the minimal detectable difference between surgical/dominant arm and nonsurgical/nondominant arm, and SD was based on residual analysis and α of 0.80. ANOVA β was based on the minimal detectable difference between the 3 groups, and SD was based on residual analysis and α of 0.80.

Abbreviations: PFT, peak flexion torque; ANOVA, analysis of variance.

groups (all $P \geq .054$) or in time (in months) ($P = .68$) after surgery between the surgical groups. The mean strength testing follow-up was 1.4 years (18.7 months), with a range of 6.5 to 37.2 months.

Within-Group Comparisons

The control group showed a 7% ($P = .002$) increase in elbow flexion strength in the dominant arm compared with the nondominant arm at 60°/s (Table 1). However, there was no difference in elbow supination between dominant and nondominant arms ($P = .312$) at 60°/s or 120°/s ($P = .065$) in this group.

The biceps tenotomy group showed a 13% ($P = .014$) deficit in elbow flexion strength in the surgical arm compared with the nonsurgical arm at 60°/s (Table 1). There was no difference in elbow flexion strength at 120°/s when the surgical and nonsurgical arms of the tenodesis group were compared ($P = .277$) (Table 2). Neither the tenotomy nor the tenodesis group exhibited elbow flexion strength differences at 120°/s (all $P \geq .147$).

In both the tenotomy and tenodesis groups, the surgical arm was 15% and 13% weaker, respectively, in elbow supination compared with the nonsurgical arm at 60°/s ($P = .0143$ and $P = .0006$, respectively) (Table 3), and the 2 surgical groups were 17% and 15% weaker, respectively, in elbow supination compared with the nonsurgical arm at 120°/s ($P = .005$ and $P = .028$, respectively) (Table 4).

Between-Group Comparisons

When comparing across the control (dominant arm), tenotomy (surgical arm), and tenodesis (surgical arm) groups, we found that the tenotomy group exhibited strength scores that were weaker than those in the control and tenodesis groups; however, these differences were not significant at either 60°/s ($P = .29$) or 120°/s ($P = .45$). This trend also remained when comparing the control group's nondominant arm with the surgical arms of the tenotomy and tenodesis groups at 60°/s ($P = .41$) and 120°/s ($P = .69$).

There were no differences between the control (dominant arm), tenotomy (surgical arm), and tenodesis (surgical arm) groups with elbow supination at 60°/s ($P = .96$) or 120°/s ($P = .40$).

Across all groups, there was a correlation ($r = 0.43$, $P = .0003$) between age and strength, with younger patients showing 18.4% of the variance of flexion strength explained by age alone.

DISCUSSION

The functional role of the LHBT at the shoulder has long been and remains today poorly understood. LHBT abnormalities have been classified into 3 categories: (1) LHBT degeneration (tendonitis or tendinosis, hypertrophy, partial or complete tearing), (2) LHBT anchor disorders (SLAP lesions), and (3)

TABLE 2. *Mean Values for Isokinetic Flexion at 120°/s*

	Angle of Measurement of PFT (°)	PFT at 120°/s (Nm) Surgical Arm or Dominant Arm	PFT at 120°/s (Nm) Nonsurgical Arm or Nondominant Arm	β	Sample Size
Tenotomy (n = 17)					
Mean	89.71	13.53	20.29	1	N/A
SD	4.74	9.76	9.99		
Tenodesis (n = 19)					
Mean	89.74	14.01	13.97	0.11	>100,000
SD	3.83	7.43	5.74		
Control (n = 31)					
Mean	87.65	16.15	15.18	0.08	1,106
SD	5.35	12.25	11		
ANOVA β		0.08	0.05		
Sample size		406	890		

NOTE. A post hoc power analysis (β) was used for within-group comparisons. Sample size was based on the minimal detectable difference between surgical/dominant arm and nonsurgical/nondominant arm, and SD was based on residual analysis and α of 0.80. ANOVA β was based on the minimal detectable difference between the 3 groups, and SD was based on residual analysis and α of 0.80.

Abbreviations: PFT, peak flexion torque; ANOVA, analysis of variance; N/A, not applicable.

LHBT instability (subluxation or dislocation). Given the relative agreement among investigators about lesions of the LHBT, there is still disagreement and controversy about the proper treatment of these problems.[1,3,9,10,15-17]

Two recognized functions of the biceps muscle are elbow flexion and forearm supination. Several investigators have looked at elbow flexion and supination strength in patients who have had an LHBT tenodesis, and have made comparisons with patients who have sustained a prior proximal biceps rupture. Soto-Hall and Stroot in 1960 evaluated elbow flexion and shoulder abduction strength in patients who had sustained a spontaneous LHBT rupture and compared the results with normal individuals. They noted a 17% loss of shoulder abduction strength and a 20% loss of elbow

TABLE 3. *Mean Values for Isokinetic Supination at 60°/s*

	Angle of Measurement of PST (°)	PST at 60°/s (Nm) Surgical Arm or Dominant Arm	PST at 60°/s (Nm) Nonsurgical Arm or Nondominant Arm	β	Sample Size
Tenotomy (n = 17)					
Mean	46.18	6.08	7.2	0.21	95
SD	5	4.56	3.19		
Tenodesis (n = 19)					
Mean	42.68	6.45	7.49	0.38	52
SD	6.34	2.51	2.73		
Control (n = 31)					
Mean	44.03	6.31	6.52	0.19	>5,000
SD	4.48	6.83	5.81		
ANOVA β		0.04	0.05		
Sample size		>20,000	2,913		

NOTE. A post hoc power analysis (β) was used for within-group comparisons. Sample size was based on the minimal detectable difference between surgical/dominant arm and nonsurgical/nondominant arm, and SD was based on residual analysis and α of 0.80. ANOVA β was based on the minimal detectable difference between the 3 groups, and SD was based on residual analysis and α of 0.80.

Abbreviations: PST, peak supination torque; ANOVA, analysis of variance.

TABLE 4. *Mean Values for Isokinetic Supination at 120°/s*

	Angle of Measurement of PST (°)	PST at 120°/s (Nm) Surgical Arm or Dominant Arm	Nonsurgical Arm or Nondominant Arm	β	Sample Size
Tenotomy (n = 17)					
Mean	43.88	3.43	4.17	0.21	85
SD	3.71	2.34	2.55		
Tenodesis (n = 19)					
Mean	41.63	3.38	4	0.36	69
SD	2.31	1.68	2.01		
Control (n = 31)					
Mean	44.29	4.12	4.45	0.08	875
SD	4.51	3.68	3.28		
ANOVA β		0.04	0.05		
Sample size		>18,000	4,387		

NOTE. A post hoc power analysis (β) was used for within-group comparisons. Sample size was based on the minimal detectable difference between surgical/dominant arm and nonsurgical/nondominant arm, and SD was based on residual analysis and α of 0.80. ANOVA β was based on the minimal detectable difference between the 3 groups, and SD was based on residual analysis and α of 0.80.

Abbreviations: PST, peak supination torque; ANOVA, analysis of variance.

flexion strength in "recent" ruptures. However, in "late" ruptures they observed no appreciable weakness of elbow flexion or shoulder abduction strength.[15] In 1985 Warren reported that patients with chronic proximal biceps ruptures exhibited no change in elbow flexion strength with Cybex testing. However, he reported a 10% loss of strength of forearm supination.[16] Comparatively, the data from both of these studies[15,16] are within 1 SD of the strength data reported in the present study, suggesting good agreement among previous studies and the methods producing the data provided herein. Subsequently, Mariani et al. in 1988 studied patients who presented with LHBT spontaneous rupture who had either a surgical repair of a proximal LHBT rupture or a tenodesis and compared this with a group treated nonsurgically.[17] The authors attempted to contrast these modes of treatment relative to the uninvolved extremity to determine whether there were permanent losses in strength in the non–surgically treated group. These authors reported that the nonsurgical group lost a mean of 21% of supination strength and 8% of elbow flexion strength compared with the uninvolved side.[17] Conversely, Phillips et al. in 1993 noted no difference with Cybex testing of elbow flexion and manual muscle testing of supination strength in comparing 2 groups of patients with proximal biceps ruptures, one treated operatively and the other treated nonoperatively.[18] Again, these data in both magnitude and differences are in good agreement with the data provided in this study.

Pagnani et al. and Rodosky et al. have suggested that the LHBT may play a role in stabilizing the humeral head.[19,20] Kumar et al. have reported that the LHBT may prevent superior migration of the humeral head and that cutting the tendon may lead to decreases in the acromiohumeral interval and concomitant shoulder dysfunction.[21]

Several other authors have attempted to confirm an active role of the LHBT in stabilizing the shoulder joint during motion.[12,22] These investigators, however, have not shown a significant contribution of the LHBT to shoulder function and regard the function of the LHBT at the shoulder to be minimal. The electromyographic data of Levy et al. and Yamaguchi et al. show that the LHBT is not active in isolated shoulder motion when the forearm and the elbow are controlled.[12,22] These studies would suggest that any function attributed to the LHBT at the shoulder is achieved in a passive role as, for example, in proprioception. This conclusion seems also to be supported by the earlier work of Glousman et al.[23] and Jobe et al.[24] Walch et al.[2] have reported that there is minimal, if any, superior humeral head migration after isolated rupture or release of the LHBT.

Given the results of our study, one may select either LHBT tenotomy or tenodesis for treatment of the symptomatic LHBT and recognize that a patient's strength in forearm supination and elbow flexion will not be statistically different after surgery based on this selection. Tenotomy is clearly the less technical surgical option and is associated with an easier postoperative course. Nonetheless, in patients with whom supination strength concerns are paramount, it may still be reasonable to recommend consideration of tenodesis over tenotomy of the LHBT. In addition, all patients should be properly counseled regarding the chance of a popeye deformity developing and, perhaps, be given the option of a tenodesis if he or she determines it would be cosmetically unacceptable.

Limitations

Within the scope of this study, limitations are acknowledged. The subjects were studied retrospectively, and their time after surgery adds variation to the results. Selecting a more time-constrained postoperative testing period may provide different results. In addition, we studied the value of peak strength and not an "exercise to fatigue"–type test. Patients with tenotomy may in fact show greater deficits or pain and cramping with fatigue because, clinically, those having had a tenotomy will complain of cramping and early fatigue under repetitive strenuous conditions. We did not collect subjective scores, and the results of this study are provided in relation to strength deficits only and do not represent surgical complications or patient satisfaction. Relatively low subject numbers were used in each group. We have provided post hoc power and sample size estimation for each of the comparisons made. This provides the readership a sense of the sample required to make the noted comparison significant. Because of the low group/subject numbers, we did not attempt to stratify across genders, and known upper extremity strength differences exist between male and female patients; furthermore, controlling for BMI as conducted in this study may not represent an adequate control because BMI is only a global assessment of body habitus and may not account for differences in muscle mass versus fat, as well as bone mass, among other body composites that can affect BMI across individuals. Lastly, no outcomes of the procedure for pain, VAS, shoulder outcomes, and so on were conducted, and although no subject complained of pain during the testing, this should be taken into account when considering these findings.

CONCLUSIONS

In this study we have compared forearm supination and elbow flexion strength in operatively treated groups undergoing either LHBT tenotomy or tenodesis with a gender-, age-, height-, and weight-matched control group. When considering within-group comparisons, we noted a 13% flexion strength deficit in the tenotomy group at 60°/s when comparing surgical and nonsurgical arms; this difference was not observed in the tenodesis group. However, the across-group comparisons exhibited no statistically significant strength differences between the involved limbs in the tenotomy and tenodesis groups and the dominant limbs in the control group in either forearm supination or elbow flexion.

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