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Biceps tenotomy vs. tenodesis: an ACS-NSQIP analysis of postoperative outcomes and utilization trends

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Background: While studies have assessed comparative rates of restoration of shoulder function and alleviation of symptoms, comparative systemic postoperative complication rates between biceps tenotomy and tenodesis have yet to be assessed. The purpose of the present study was to use a national administrative database to perform a comprehensive investigation into 30-day complication rates after biceps tenotomy versus tenodesis, thus providing valuable insights for informed decision-making by clinicians and patients regarding the optimal surgical approach for pathologies of the long head of the biceps tendon.

Methods: The National Surgical Quality Improvement Program database was queried to analyze postoperative complication rates and metrics associated with biceps tenotomy and tenodesis. Patient data spanning from 2012 to 2021 was extracted, with relevant variables assessed to identify and compare these two surgical approaches. Adjusted and unadjusted analyses were utilized to analyze patient demographics, comorbidities, operative times, lengths of stay, readmissions, adverse events, and yearly surgical volume, along with trends in usage, across cohorts.

Results: Of 11,527 total patients, 264 (2.29%), 6826 (59.22%), and 4437 (38.49%) underwent tenotomy, tenodesis with open repair, and tenodesis with arthroscopic repair, respectively. Tenotomy operative times ([mean ± SD]: 66.25 ± 44.76 minutes) were shorter than those for open tenodesis (78.83 ± 41.82) and arthroscopic tenodesis (75.98 ± 40.16). Conversely, tenotomy patients had longer hospital days (0.88 ± 4.86 days) relative to open tenodesis (.08 ± 1.55) and arthroscopic tenodesis (.12 ± 2.70). Multivariable logistic regression controlling for demographics and comorbidities demonstrated that patients undergoing tenodesis were less likely to be readmitted (adjusted odds ratio [AOR]: 0.42, 95% confidence interval [CI]: 0.17-0.98, $P = .050$) or sustain serious adverse events (AOR: 0.27, 95% CI: 0.13-0.57, $P < .001$), but equally likely to sustain minor adverse events (AOR: 0.87, CI: 0.21-3.68, $P = .850$), compared with patients undergoing tenotomy. Lastly, comparing utilization rates from 2012 to 2021 revealed a significant decrease in the proportion of tenotomy (from 6.2% to 1.0%) compared to open tenodesis (from 41.0% to 57.3%) and arthroscopic tenodesis (52.8% to 41.64%; $P_{trend} = .001$).

Conclusion: To our knowledge, this is the first large national database study investigating postoperative complication rates between the various surgical treatments for pathologies of the long head of the biceps tendon. Our results suggest that tenodesis yields fewer serious adverse events and lower readmission rates than tenotomy. We also found a shorter operative time for tenotomy. These findings support the increased utilization of tenodesis relative to tenotomy in recent years.

The long head of the biceps tendon (LHBT) is a frequent source of shoulder pain and dysfunction. Two primary surgical interventions for addressing LHBT lesions, which can arise secondary to diverse pathologies, such as trauma, subluxation, and inflammation, are tenotomy and tenodesis.[4,8,39,67] Tenotomy involves the surgical cutting and release of the tendon, an approach possible because, as some have claimed, it appears that LHBT has no function,[31,38,55,66] while tenodesis involves the surgical fixation of the tendon to a stable structure, often the humerus.[23,45] Both

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procedures aim to alleviate pain and improve shoulder function, but the decision between them remains a topic of debate among orthopedic surgeons.[50]

Historically, tenotomy has been favored for its simplicity, shorter operative time, and quicker return to activity.[22,24,37] However, this approach does have the potential for cosmetic deformities, such as the Popeye sign as well as fatigue, cramping, and resulting pain.[30,48] Conversely, tenodesis, though often resulting in fewer incidences of cramping, pain, and Popeye sign, tends to require a longer surgical time compared to tenotomy.[23] A recent case series focusing on outcomes of patients undergoing revision subpectoral tenodesis after failed primary tenodesis or tenotomy of the LHBT highlighted the challenges associated with revision surgeries; the authors emphasized the importance of selecting the most appropriate initial procedure to minimize the need for subsequent interventions.[56] Given the current state of evidence, there is a clear need for a highly powered comparison of tenotomy and tenodesis not limited to any one institution.

The existing literature is conflicted regarding even basic characteristics of the two approaches. While some studies report tenotomy as having shorter operative times,[23,28] surprisingly, a comparable number report no significant difference in operative time.[47,60] Based on previous work on smaller scales that has investigated orthopedic-specific complications, such as pain, cramping, and Popeye deformity, tenotomy tends to have higher complication rates,[1,11,23,39,47,50] although, as with operative time, some disagree and deny any difference in complication rates.[28] Similar disagreements exist for yet another outcome, range of motion (ROM), with Ge et al[23] claiming improved ROM with tenodesis, in contrast to the findings of Hartland et al.[28] However, several studies note similar functional outcomes between the two procedures with differences being largely cosmetic in nature, thus further necessitating viewing these procedures through a different lens.[1,10,16,29] Thus, there is a clear discrepancy in the current literature regarding the optimal approach for pathologies of the LHBT. Taken together, these inconsistencies between different studies support the value of comparing these approaches using a single, unified, and large data source.

There are a plethora of studies investigating orthopedic-specific complications, such as pain, cramping, and functional outcomes, for both of these approaches. While there appears to be a growing consensus that tenodesis is associated with fewer orthopedic-specific complications, prior studies have not utilized a national database to assess incidence of systemic complications. By taking advantage of the large volume of the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database, which houses over a decade's worth of aggregated data, this study hopes to alleviate any confounding variables and yield the highest-powered assessment of tenotomy and tenodesis to date. Thus, the purpose of the present study was to leverage the power of a large national database to observe procedure volumes on a scale not assessed before as well as to investigate systematic complications, more traditional orthopedic-specific complications, readmission rates, and procedure utilization rates. Secondarily, we sought to provide surgeons with objective evidence on the risk of adverse events following tenotomy versus tenodesis to better gauge the risks of either procedures, and ultimately, best guide the choice of surgical approach. We hypothesize that tenotomy will be associated with shorter surgical times, lower readmission rates, and fewer systematic complications, along with a demonstrated increase in utilization over the past decade.

Materials and methods

Study design and population data

This was a retrospective cohort study conducted utilizing prospectively collected data from the NSQIP database from 2012 to 2021. As all patient data are deidentified before uploading into the registry and no geographic links are available, the present study was exempted by our institutional review board. NSQIP's registry houses reliable, risk-adjusted data collected as individual cases by a given site's trained surgical clinical reviewer from a total of over 700 hospitals within the United States. The database captures over 150 data points per case, including preoperative risk factor, intraoperative variables of interest, and postoperative morbidity and mortality.[59] Due to its ongoing and rigorous internal auditing, systematic reviewing and reporting process, high interrater fidelity (approximately 98%), and extremely large sample size (over 9.6 million cases to date), the NSQIP registry represents both one of the most in-depth and accurate surgical outcome databases used in surgical research.[6,7,12,20,42,57,59,63] Overall, the NSQIP database has proven to be a high-fidelity source of information, which lends itself to the assessment of 30-day perioperative outcomes[2,12,13,26,61] and is an excellent source for comparing tenotomy and tenodesis due to its nearly unrivaled patient size, highly accurate data collection process, and extensive patient demographics and comorbidities.

Inclusion criteria and outcome variables

All patients in the present study were $\geq$18 years. All patients received a unilateral, primary shoulder procedure for LHBT pathology of either tenotomy, open tenodesis, or arthroscopic tenodesis and were identified using the Current Procedural Terminology (CPT) codes 23405 (tenotomy of the biceps tendon), 23430 (open tenodesis of long tendon of biceps), and 29828 (arthroscopic biceps tenodesis). Baseline patient demographics and comorbidities collected and analyzed included the following parameters: age, sex, body mass index , American Society of Anesthesiologists (ASA) classification, race, ethnicity, diabetes mellitus, smoking status, severe chronic obstructive pulmonary disease, steroid/immunosuppressant use (for chronic conditions), congestive heart failure (CHF), hypertension requiring medication, functional health status, ascites, and dialysis. In accordance with previously published literature, adverse events were categorized as serious or minor.[5,6,14,15,20,42,43,61] Serious adverse events included death, reoperation, pulmonary complications (consisting of ventilator use for > 48 hours or unplanned intubation), pneumonia, cardiac complications (myocardial infarction or cardiac arrest), renal complications (progressive renal insufficiency or acute renal failure), thromboembolic complications (deep vein thrombosis or pulmonary embolism), deep wound complications (joint space infection, wound disruption/dehiscence, and deep incisional surgical site infection [SSI]), and sepsis. Of note, deep SSI is coded in the NSQIP database as infection related to the surgical incision, whereas joint space infections refer to infections of the deep joint spaces. Minor adverse events were defined as superficial SSIs or urinary tract infections. Finally, total operation time, total length of hospital stay, days from operation to discharge, unplanned readmissions (to inpatient acute care, outpatient services, emergency department, or observation services spanning at least two overnight stays), and annual procedure volumes were also assessed. Trends in relative procedure rates were also investigated.

Statistical analysis

All statistical analyses were performed in SPSS Statistical Software (version 28; IBM, Armonk, NY, USA) with a significance level of $\alpha = 0.05$. Baseline demographics, comorbidities, operative times, lengths of stay (in days) from operation to discharge, and 30-day complications were compared between the cohorts using Fisher's exact test, Chi-squared test, or one-way analysis of variance with Tukey's honestly significant difference post hoc test, as appropriate. Additionally, multivariable logistic regression models were utilized to compare rates of perioperative complications (readmissions, serious adverse events, and minor adverse events), while controlling for patient-specific demographics and comorbidities. To facilitate the evaluation of perioperative outcomes surrounding tenotomy relative to the overall tenodesis approach, both open and arthroscopic tenodesis were considered as a single comparison group in all adjusted analyses. The Cochran-Armitage trend test was utilized to assess the relative usage of the various procedures over the study time course.[3]

Results

Patient demographics and comorbidities

There were a total of 11,527 patients included in this study (264 [2.29%] tenotomy, 6826 [59.22%] open tenodesis, and 4437 [38.49%] arthroscopic tenodesis). The unadjusted baseline demographics are presented in Table I. Relative to patients undergoing open or arthroscopic tenodesis, patients undergoing tenotomy tended to be older (tenotomy: 52.43 ± 15.31 years; open tenodesis: 44.46 ± 12.96 years; arthroscopic tenodesis: 48.54 ± 13.41 years; $P < .001$), less frequently Black (tenotomy: 8.3%; open tenodesis: 11.2%; arthroscopic tenodesis: 10.2%; $P = .005$), or not Hispanic (tenotomy: 77.4%; open tenodesis: 66.5%; arthroscopic tenodesis: 65.2%; $P < .001$), and more often ASA class 3 or higher (tenotomy: 36.0%; open tenodesis: 14.9%; arthroscopic tenodesis: 21.9%; $P < .001$). Additional baseline demographics, along with investigated comorbidities, are included in Table I.

Operative elements, readmissions, and serious/minor adverse events

Tenotomy had a significantly shorter mean operative time than did both tenodesis approaches (tenotomy: 66.25 ± 44.76 minutes; open tenodesis: 78.83 ± 41.82 minutes; arthroscopic tenodesis: 75.98 ± 40.16 minutes; $P < .001$), but longer average length of hospital stays (tenotomy: 0.88 ± 4.86 days; open tenodesis: .07 ± 2.94 days; arthroscopic tenodesis: .07 ± 4.27 days; $P < .001$) as well as more days between operation and discharge (tenotomy: .90 ± 4.65 days; .08 ± 1.55, .07 ± 4.27; $P < .001$; Table II). Additionally, the rates for readmissions within 30 days of the operation were highest among patients undergoing tenotomy (tenotomy 2.6%; open tenodesis: 0.6%; arthroscopic tenodesis: 0.6%; $P < .001$). Patients undergoing tenotomy experienced serious adverse events at the highest rate of all the procedures analyzed (7.58%), followed by arthroscopic tenodesis (1.10%) and open tenodesis (0.91%; $P < .001$). No significant differences in minor adverse events were noted. More detailed breakdowns specifying various classifications of adverse events are available in Table II.

A multivariable logistic regression controlling for patient demographics (age, sex, race, body mass index, and functional health status) and comorbidities (ASA class, smoking status, CHF, hypertension, and diabetes) yielded similar results to the initial unadjusted analyses. More specifically, those patients undergoing either tenodesis procedures had a significantly lower adjusted odds ratio (AOR) or risk of experiencing readmission for any reason (AOR: 0.42, 95% confidence interval [CI]: 0.17–0.98; $P = .050$) or enduring serious adverse events (AOR: 0.27, 95% CI: 0.13–0.57; $P < .001$) relative to patients undergoing tenotomy. The AOR of experiencing minor adverse events was not significant between the two groups. Further adjusted risk factors for readmission as well as serious and minor adverse events observed included Black or African American race, ASA class 2, ASA class 3, smoking status, hypertension, diabetes mellitus, CHF, functional status, and steroid use and are reported in Table III.

Procedural usage trends

Both the overall annual volume, along with incidence and percentage of outpatient surgeries for each approach to treating pathologies of the LHBT, were investigated from 2012 to 2021. While the utilization of both tenodesis approaches increased markedly over the study period of slightly over a decade (Fig. 1, *A*), that of tenotomy remained about the same. The relative usage of the tenotomy approach compared to the overall treatment approaches decreased significantly from 6.2% in 2012 to 1.0% in 2021, compared to open tenodesis (41.0% in 2012 to 57.3% 2021) and arthroscopic tenodesis (52.8% in 2012 to 41.64% in 2021) over the study course (slope [standard error]: −0.72% [0.75]; $P_{trend} = .001$; Fig. 1, *B*). Additionally, the percentage of open tenodesis performed has trended down in recent years from 64.80% in 2018 to 57.33% in 2021, with arthroscopic tenodesis gaining the resultant preference, increasing from 33.77% in 2018 to 41.64% in 2021. At the same time, tenotomy utilization in the outpatient setting has also declined (Fig. 2, *A*) from 4.62% in 2012 to 0.89% in 2021. The decreasing usage of tenotomy in the outpatient setting represents a statistically significant decline relative to the outpatient load of the total of all three procedures (slope [standard error]: −0.62% [0.68]; $P_{trend} = .004$; Fig. 2, *B*).

Discussion

By employing the NSQIP database, the present study investigated perioperative complications along with utilization trends between tenotomy and open and arthroscopic tenodesis procedures over the years (2012–2021). Overall, our study revealed that although tenotomy was associated with shorter operative times than open and arthroscopic tenodesis, these patients experienced longer hospital stays, higher readmission rates, and more serious adverse events, with comparable rates of minor adverse events. Notably, these noted differences remained significant following adjusted multivariable logistic regression controlling for differences in baseline demographics and comorbidities between cohorts. These findings should allow surgeons to gauge patient risk before performing these procedures, as well as aid them in providing the best counsel and approach for their patients. To our knowledge, this represents the first study of its kind that directly compares patient demographics, comorbidities, complication rates, various operative elements, and utilization trends for these surgical approaches. This study also represents the highest-powered assessment of these procedures to date and seeks to provide surgeons with further data to consider when deciding which procedure to perform.[52,58]

While this is the first study to assess rates of systemic complication, previous literature has suggested that tenotomy results in a higher rate of orthopedic-specific complications, including the Popeye deformity, cramping, and pain.[11,16,39,45,47,49,50,60] Numerous studies, including a systematic review by Hartland et al,[28] featuring 11 randomized clinical trials and 860 patients, found tenodesis resulted in a significantly lower rate of Popeye deformity with an odds ratio (OR) of 0.29. In a similar vein, a systematic review by

Table I
Baseline demographics and comorbidities for patients undergoing tenotomy and tenodesis (open v arthroscopic) from 2012-2021.

	Total	Tenotomy (23405)	Tenodesis (open) (23430)	Tenodesis (arthroscopic) (29828)	*P* value*
	N = 11,527 (%)	N = 264 (%)	N = 6826 (%)	N = 4437 (%)	
Mean age	46.21 ± 13.37	52.43 ± 15.31	44.46 ± 12.96	48.54 ± 13.41	<.001 for all comparisons†
Age group					<.001†
18-24	536 (4.60)	15 (5.7)	376 (5.5)	145 (3.30)	
25-34	1831 (15.90)	23 (8.7)	1230 (18.0)	578 (13.0)	
35-44	3046 (26.40)	35 (13.2)	1991 (29.20)	1020 (23.0)	
45+	6114 (53.00)	191 (72.1)	3229 (47.3)	2694 (60.7)	
Sex					<.001†
Female	3173 (27.5)	125 (47.20)	1627 (23.8)	1421 (32)	
Male	8359 (72.5)	140 (52.8)	5201 (76.2)	3018 (68)	
Mean BMI	29.78 ± 6.31	30.37 ± 8.38	29.64 ± 5.87	29.95 ± 6.77	.015†
BMI group					<.001†
Normal (<24.9 kg/m^2)	1817 (15.80)	56 (21.1)	1031 (15.1)	730 (16.4)	
Overweight (25-29.9 kg/m^2)	4525 (39.20)	79 (29.8)	2824 (41.4)	1622 (26.5)	
Obese (30+ kg/m^2)	4976 (43.1)	125 (47.2)	2848 (41.7)	2003 (45.10)	
ASA category					<.001†
1 (No disturb)	2314 (20.1)	26 (9.8)	1492 (21.9)	796 (17.9)	
2 (Mild disturb)	7123 (61.8)	143 (54.0)	4314 (63.2)	2666 (60.0)	
3 (Severe disturb)	2077 (18.0)	95 (36.0)	1014 (14.9)	968 (21.9)	
Race					.005†
Black	1242 (10.80)	22 (8.3)	767 (11.2)	453 (10.2)	
White	8019 (69.5)	183 (69.1)	4785 (70.1)	3051 (68.7)	
Other/Unknown	2235 (19.4)	60 (22.6)	1260 (18.5)	915 (20.6)	
Ethnicity					<.001†
Hispanic	679 (5.9)	10 (3.8)	409 (6.0)	260 (5.9)	
Not Hispanic	7642 (66.30)	205 (77.4)	4544 (66.5)	2893 (65.2)	
Unknown	3212 (27.9)	50 (18.9)	1875 (27.5)	1287 (29)	
Diabetes mellitus	1050 (9.10)	44 (16.6)	501 (7.3)	505 (11.4)	<.001†
Current smoker (within 1 yr)	2000 (17.30)	41 (15.5)	1220 (17.9)	739 (16.6)	.176
Severe COPD	168 (1.50)	18 (6.8)	83 (1.20)	67 (1.5)	<.001†
Steroid use (chronic condition)	177 (1.50)	7 (2.6)	90 (1.3)	80 (1.8)	.041†
CHF	10 (0.10)	0 (0)	6 (0.10)	4 (0.1)	.888
Hypertension requiring medication	3104 (26.9)	109 (41.1)	1648 (24.1)	1347 (30.3)	<.001†
Functional status					.002†
Independent	11,391 (98.80)	257 (97)	6739 (98.7)	4395 (99)	
Partially or totally dependent	30 (0.30)	3 (1.1)	12 (0.2)	14 (0.3)	
Ascites	1 (0)	0 (0)	1 (0)	0 (0)	.709
Dialysis	9 (0.10)	3 (1.1)	2 (0)	4 (0.1)	<.001†

BMI, body mass index; *ASA*, American Society of Anesthesiologists; *COPD*, chronic obstructive pulmonary disease; *CHF*, congestive heart failure.
**P* values were calculated using the Chi-square test for categorical variables and one-way analysis of variance tests for continuous variables.
†Indicates significant *P*-value.

Kooistra et al[40] of 25 studies consisting of 2191 patients found again that tenodesis was associated with lower odds of developing a Popeye deformity (OR, 0.32). In alignment with a majority of the literature, we found that tenotomy was associated with overall higher rates of systemic complications than tenodesis. Of serious adverse events, tenotomy patients experienced a higher rate of death (0.38%) as compared to tenodesis patients (0%). Similar to the present study's results, a prior retrospective case series of 337 tenodesis surgeries found no instances of death.[62] The present study featured a much larger sample size, and is thus, more likely to capture even rare instances of mortality associated with these procedures. Notably, however, the few deaths noted with tenotomy in the present study could be attributed to unrelated underlying comorbidities. Tenotomy patients also experienced higher rates of pulmonary complications (1.52%) relative to their tenodesis counterparts (.04%). While, to date, no direct comparison of pulmonary complications between tenotomy and tenodesis has been noted in the literature, the rates of pulmonary complications in arthroscopic shoulder surgeries have been reported to be 0.3%, comparable to the findings of the present study.[53] Similarly, tenotomy patients experienced cardiac complications (0.76%) at higher rates than tenodesis patients (.04%). Again while there exists a paucity of studies querying cardiac complication rates between these specific procedures, a study of patients undergoing shoulder arthroscopy with and without concomitant biceps tenodesis found that .04% of patients without tenodesis, compared to less than .15% and .31% with arthroscopic and open tenodesis, respectively, experienced cardiac complications.[65] Notably, sepsis rates also differed in the present study, with a rate of 2.65% for tenotomy, compared to 0.25% with the tenodesis approach. This closely mirrored prior work that found an infection rate of .28% for tenodesis.[51] Furthermore, multivariable logistic regression controlling for baseline differences in demographics and comorbidities also revealed a significantly decreased OR of tenodesis patients experiencing serious adverse events, relative to tenotomy patients (AOR, 0.27). The overall lower complication rates in tenodesis tracks well with the established literature, building on work by Gill et al[24], which found a 13% complication rate after tenotomy compared to 2% after tenodesis.[51] In contrast, the difference in OR of minor adverse events was not significant between the two groups. The observed differences in systemic complications were surprising and, perhaps, counterintuitive. While multivariable logistic regression was used to control for any baseline differences between the cohorts and comorbidities, these findings must be viewed critically. Perhaps cutting a tendon, as in tenotomy, rather than cutting and reattaching, as in tenodesis, predisposes to the recruitment of more inflammatory mediators,

Table II
Comparison of operation times, lengths of stay, and perioperative outcomes among patients undergoing tenotomy and tenodesis (open v arthroscopic).

	Total	Tenotomy (23405)	Tenodesis (open) (23430)	Tenodesis (arthroscopic) (29828)	*P* value
	N = 11,527 (%)	N = 264 (%)	N = 6826 (%)	N = 4437 (%)	
Total operative time	77.44 ± 41.31	66.25 ± 44.76	78.83 ± 41.82	75.98 ± 40.16	<.001 for all comparisons*
Length of hospital stay	0.09 ± 3.57	0.88 ± 4.86	.07 ± 2.94	.07 ± 4.27	<.001 for tenotomy vs. tenodesis (open) & tenotomy vs. tenodesis (arthroscopic); .998 for tenodesis (open) vs. tenodesis (arthroscopic)*
Days from operation to discharge	0.12 ± 2.18	0.90 ± 4.65	.08 ± 1.55	.12 ± 2.70	<.001 for all comparisons*
Any readmission	71 (0.62)	7 (2.65)	38 (0.56)	26 (0.59)	<.001 for all comparisons*
Serious adverse events	129 (1.12)	20 (7.58)	62 (0.91)	49 (1.10)	<.001*
Death	2 (0)	1 (0.38)	1 (0.0)	0 (0.0)	.045*
Return to operating room	35 (0.30)	4 (1.52)	20 (0.29)	11 (0.25)	.008*
Pulmonary complications	7 (0.06)	4 (1.52)	2 (0)	3 (0.07)	.01*
Pneumonia	9 (0.08)	1 (0.38)	2 (0)	6 (0.14)	.189
Cardiac complications	7 (0.06)	2 (0.76)	2 (0)	3 (0.07)	.01*
Renal complications	2 (0)	0 (0)	2 (0)	0 (0.0)	.951
Thromboembolic complications	22 (0.19)	0 (0)	13 (0.19)	9 (0.20)	.599
Deep wound complications	10 (0.09)	1 (0.38)	7 (0.10)	2 (0.05)	.207
Sepsis	35 (0.30)	7 (2.65)	13 (0.19)	15 (0.34)	<.001 for all comparisons*
Minor adverse events	65 (0.56)	2 (0.76)	34 (0.50)	29 (0.65)	.660
Superficial SSI	45 (0.39)	1 (0.38)	26 (0.38)	18 (0.41)	.723
Urinary tract infection	20 (0.17)	1 (0.38)	8 (0.12)	11 (0.25)	.372

SSI, surgical site infection.
P values were calculated using the Chi-square test for categorical variables or Fisher's exact test depending on sample size and one-way analysis of variance tests for continuous variables. Groups were combined for Fisher's exact test.
*Indicates significant *P*-value.

causing an overall more inflamed and reactive state within the body and predisposing patients to higher infection rates and more complications. There may also be a slant toward less experienced surgeons pursuing the tenotomy approach, as it is shorter and less complicated. Lesser surgical experience could, perhaps, translate to less experience managing patients appropriately, also resulting in higher complication rates. Lastly, as patients undergoing tenotomy tended to be older and less healthy, it is likely that these patients were fated to have worse outcomes regardless of their grouping.

30-day readmission and reoperation rates were also investigated. Both variables differed significantly between groups. Tenotomy patients were readmitted at a significantly higher rate (2.65%) as compared to tenodesis patients (0.57%). Multivariable logistic regression demonstrated a persistent difference in readmission rates when controlling for patient demographics and comorbidities and showed that tenodesis patients exhibited a 0.42-fold decrease in odds of readmission as compared to tenotomy patients. Similarly, tenotomy patients underwent reoperations at a rate of 1.52% relative to their tenodesis peers at 0.28%. While, again, the literature is sparse in reporting direct comparisons of these metrics between tenotomy and tenodesis, an investigation of various treatments for pathologies of the proximal biceps tendon, including pooled results of tenotomy and tenodesis, found overall reoperation and readmission rates of 0.97% and 1.27%, respectively.[9] Another study comparing various methods of biceps tenodesis found a revision rate of 0% for proximal open tenodesis and 2.7% for open subpectoral tenodesis.[21] In contrast, a study of patients with concomitant partial rotator cuff repair and biceps tenotomy found a revision rate of 11%,[17] and it is much higher than rates reported for tenodesis. The data presented here, which to our knowledge represent the only direct comparison of readmission and reoperation rates between these procedures without concomitant rotator cuff repairs or other nonbiceps shoulder pathology, are particularly valuable, especially in the light of a systematic review's claims that an insufficient number of papers exist that directly evaluate revision surgery rates between the two procedures.[52]

Next, we found that the relative percentage of biceps tenotomy procedures has declined significantly relative to either tenodesis approach from 2012 to 2021, decreasing from 6.15% in 2012 to 1.03% in 2021. Interestingly, we also found a stark drop in the open tenodesis approach from 2018 to 2021, with a corresponding increase in the utilization of the arthroscopic tenodesis method from 2020 to 2021. On the whole, both tenodesis procedures have enjoyed widespread increased utilization relative to tenotomy. This aligns with existing literature, which has established an increase in the annual number of proximal biceps tendon procedures performed overall, along with a significant decrease in the incidence of tenotomy with a resultant increase in both open and arthroscopic tenodesis from 2007 to 2018.[9] Multiple interpretations could explain the changes in utilization trends. These changes could potentially have occurred due to overwhelming evidence that tenotomy is associated with higher odds of developing the Popeye deformity. An alternative explanation for the decline in usage of the tenotomy procedure lies in the differences in patient-reported outcome measures (PROMs) and functional scores comparing the two approaches. Leroux et al[45] demonstrated a significantly greater 2-year postoperative Constant Score for tenodesis as compared to tenotomy. Another systematic review by Na et al[50] similarly discovered that tenotomy resulted in lower Constant Scores. A systematic review by Vajda et al[60] found tenodesis to have superior 12-month forearm supination strength relative to tenotomy. Of note, however, several studies found no difference in PROMs, Constant Scores, or other metrics such as the elbow strength index.[39,47] In contrast, the results of the present study suggest that higher complication rates, in the form of serious adverse events and readmissions associated with the tenotomy approach may explain the decreased utilization of tenotomy relative to tenodesis. This massive dissonance between various studies in terms of reported

Table III
Adjusted analysis comparing postoperative complications between procedures, patient demographics, and baseline comorbidities.

	Readmission AOR	*P* value	SAE ARR	*P* value	MAE ARR	*P* value
Tenodesis (combined)	0.42 (0.17-0.98)	.050*	0.27 (0.13-0.57)	<.001*	0.87 (0.21-3.68)	.850
Female	1.10 (0.66-1.82)	.722	0.58 (0.34-0.98)	.042*	1.44 (0.84-2.48)	.190
Black or African American	0.87 (0.39-1.97)	.743	0.62 (0.26-1.43)	.261	0.48 (0.17-1.34)	.161
Hispanic	0.66 (0.44-0.98)	.037*	0.95 (0.71-1.28)	.751	1.24 (0.90-1.70)	.181
Age	0.99 (0.97-1.01)	.387	0.996 (0.977-1.01)	.703	0.99 (0.97-1.01)	.267
BMI	0.98 (0.95-1.02)	.295	0.99 (0.96-1.02)	.540	1.04 (1.001-1.08)	.047*
Current smoker	0.66 (0.33-1.31)	.234	0.78 (0.43-1.40)	.402	0.76 (0.37-1.57)	.452
ASA (Class 2)	2.40 (0.82-7.04)	.112	1.86 (0.88-3.94)	.103	1.29 (0.59-2.92)	.527
ASA (Class 3)	4.70 (1.42-15.57)	.011*	3.53 (1.43-8.72)	.006*	1.57 (0.56-4.41)	.392
Hypertension	1.29 (0.72-2.31)	.394	0.96 (0.56-1.61)	.835	1.58 (0.85-2.94)	.146
Diabetes mellitus	3.05 (1.70-5.45)	<.001*	1.80 (0.98-3.30)	.059	0.56 (0.21-1.49)	.243
Independent functional status	0.11 (0.03-0.40)	<.001*	0.17 (0.04-0.79)	.024*	0.09 (0.02-0.44)	.002*
Steroid use	2.03 (0.70-5.87)	.191	2.78 (0.97-7.98)	.058	2.05 (0.83-3.45)	.150

AOR, adjusted odds ratio; *SAE*, serious adverse event; *MAE*, minor adverse event; *ASA*, American Society of Anesthesiologists; *BMI*, body mass index; *AAR*, adjusted relative risk.
All *P* values adjusted for age, sex, race, ethnicity, body mass index, ASA, class, smoking status, hypertension, diabetes mellitus, steroid use, and functional status.
Reference: Tenodesis (Combined).
Reference: White.
Reference: ASA, class 1.
Reference: Independent.
*Indicates significant *P*-value.

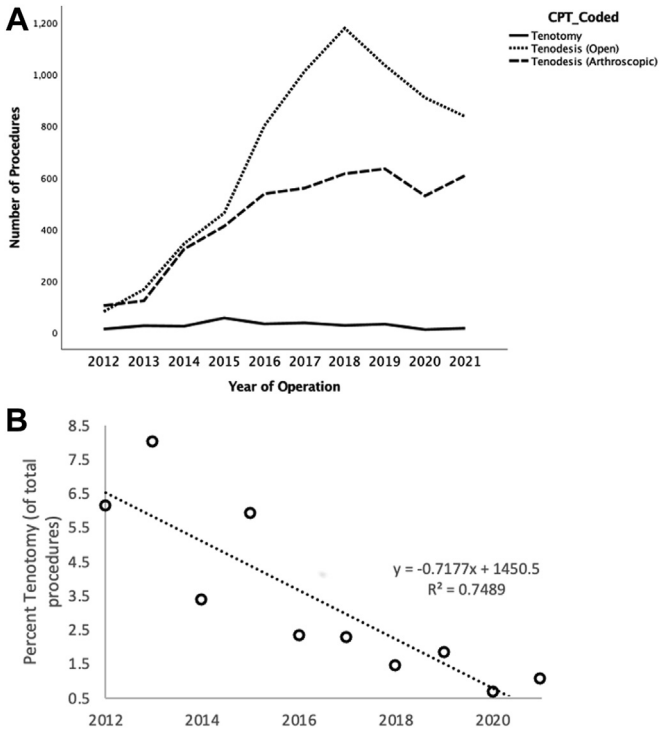

Figure 1 (**A**) Utilization trends for biceps tenotomy, tenodesis (open), tenodesis (arthroscopic) from 2012 to 2021. (**B**) The relative utilization of tenotomy (defined as the percent of total tenotomy, open tenodesis, and arthroscopic tenodesis cases performed that were tenotomy) has decreased markedly over the study period (equation: $y = -0.72x + 1450.5$, $R^2 = 0.750$; $P = .001$). *CPT*, current procedural terminology.

PROMs and other metrics motivated the present study's evaluation of systemic postoperative complications to add further evidence on the relative risks of either procedure as well as to understand if an unofficial preference for procedure had already been reached by observing utilization trends over the past decade. An additional undeniable consideration is the cost difference between the two procedures. More time in the operating theater invariably costs more. According to a study querying the State Ambulatory Surgery and Services Databases from 6 states, each additional minute in a tenodesis procedure added $37.[46] This, combined with higher reimbursement rates for either open or arthroscopic tenodesis compared to tenotomy, provides a concrete rationale for the observed changes in utilization rates.[9] Lastly and perhaps most importantly, is the underlying cost associated with both procedures. The advent of new technologies increases the ease of the surgery for the surgeon but, invariably, results in a higher cost, some of which is passed on to the patient.[32]

Limitations

While the present study does benefit from the largest sample size for the assessment of tenotomy versus tenodesis procedures as well as an extended time range, it is limited by certain constraints due to the nature of the NSQIP database. First and foremost, the NSQIP dataset is limited to reporting only 30-day outcomes, thus potentially underestimating the true complication rate.[13,26] Second, the database is further limited by a lack of data regarding surgeon experience and hospital-specific volume, both of which are factors that contribute to patient outcomes along with complication rates.[19,25,33–36,44,54] Additional noncollected, yet useful, measures include patient-specific preoperative parameters, such as measures of bone loss, radiographic measurements, PROMs, and details regarding the procedure itself other than operative time (e.g., instruments used, number and type of anchors, screws, suture, etc.). Third, using a CPT-based approach to delineate procedure type also does not distinguish between the various sites of tendon reattachment in the tenodesis procedure, which may influence outcomes. Fourth, potential social determinants of health that may contribute to outcomes, such as educational level, insurance type, socioeconomic status, are also not routinely collected by NSQIP but are inequities within society that have been shown to contribute significantly to varying levels of success after various procedures.[18,27,64] Fifth, although numerous relatively orthopedic-specific complications, such as joint space infections, deep incisional SSIs, and wound disruption or dehiscence, collectively referred to as deep wound complications, along with superficial SSI, were collected, further complications specific to this procedure, such as development of Popeye deformity, pain, cramping, and limited ROM, are not collected by NSQIP, thus precluding useful further analyses.[59] Similarly, the therapeutic indication for the procedure could not be queried as operative and clinic notes were not provided. Thus, data on relevant accompanying metrics, such as continuity of the rotator cuff at the time of intervention, could not be

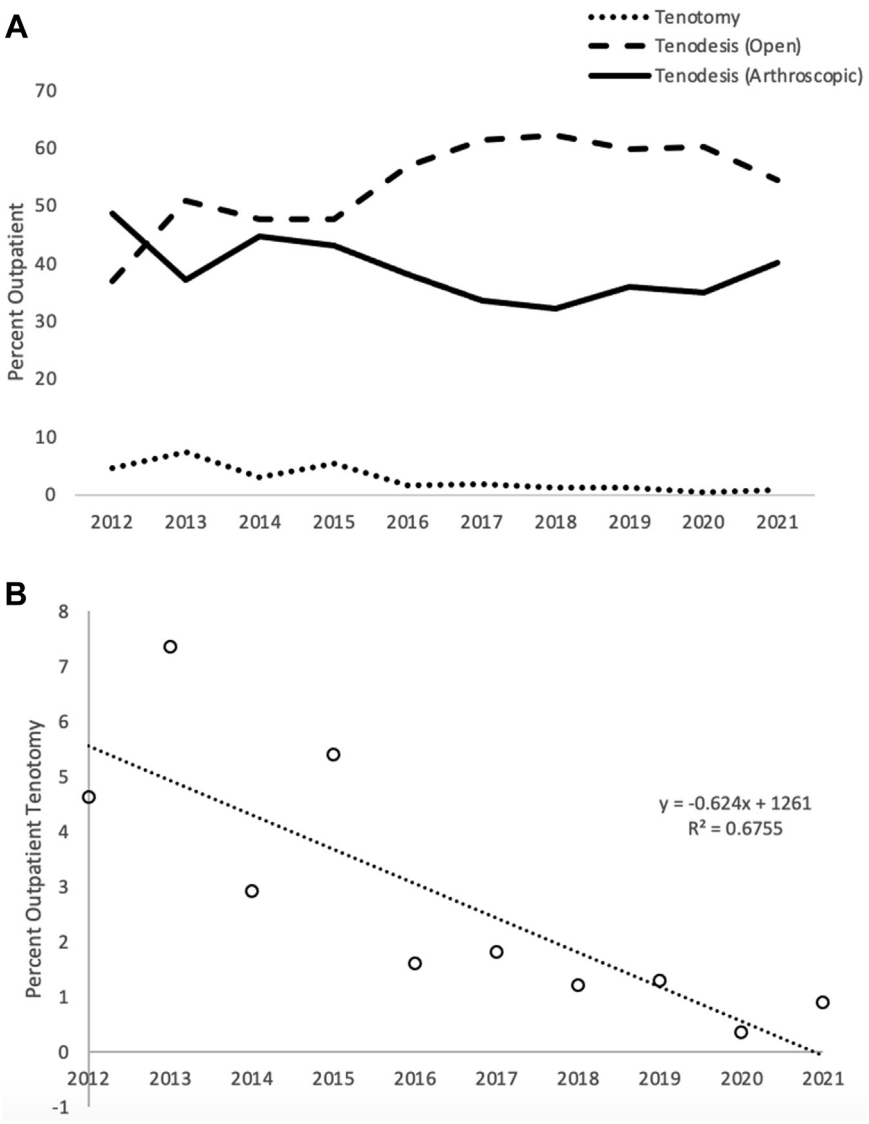

Figure 2 (**A**) Outpatient utilization trends for tenotomy, open tenodesis, and arthroscopic tenodesis from 2012 to 2021. (**B**) The percent of outpatient tenotomy has decreased significantly during the study period (equation: $y = -0.624x + 1261$; $R^2 = 0.6755$; $P = .004$).

collected. Sixth, while the cohorts in the present study were larger than those reported previously, the smaller sample size for tenotomy relative to open and arthroscopic tenodesis procedures (N = 264 vs. 6826 vs. 4437) makes it more susceptible to skewing effects. In particular, this could have affected the significant longer hospital stays seen in tenotomy in the present study, which may be best explained by preexisting comorbidities that predisposed a small number of patients to longer hospital stays, more so than the surgical approach itself. The smaller sample size of the tenotomy group makes it more susceptible to skewing effects due to the few outliers that experienced extended stays over 1 day. Thus, while this may be a true difference as a result of differing complication rates, it is possible that the observed difference is due to this skewing effect.[41] Similarly, while multivariable logistic regression was used to control for baseline differences and comorbidities, the nature of a retrospective review limits any conclusions to correlation and not causation; thus, we cannot definitely claim tenotomy as a procedure that causes, for instance, increased readmissions or serious adverse events. An additional limitation is that the CPT code used for tenotomy did not differentiate between open and arthroscopic approaches, unlike the two CPT codes used for the tenodesis approaches. Next, postoperative physical therapy protocols, intensity, and adherence were not assessed. These are factors that play a pivotal role in a patient's recovery and the potential development of various complication, such as the formation of emboli.[13] Next, as these procedures are minimally invasive, regardless of the approach, systemic complications are rare. The resulting paucity of various complication rates (namely, pulmonary, cardiac, renal, etc.) may limit the reliability of certain analyses; however, in cases of small sample sizes, appropriate statistical tests were used. However, the lack of significance of certain complication rates should be evaluated with the understanding that some analyses suffered from limited power. In an attempt to minimize these limitations, aggregated outcomes, catalogued as serious and minor adverse events, were provided, as is the typical practice when dealing with rare outcomes in general, but also in NSQIP database studies.[61] Finally, NSQIP relies on trained staff to report data; hospitals without these trained members do not contribute to the database. While the inclusion of over 700 hospitals throughout the United States aims to mitigate this limitation, and more hospitals are continuously being added to this number, it remains a limitation worth mentioning. The data could be further limited, as with any

dataset, by improper coding or reporting. Notably, however, the American College of Surgeons does subject itself to quality assurance practices aimed at reducing such errors.[59] Our study only included variables for which a maximum of 1.9% of patient records were missing data.

Conclusion

As there is much conflict regarding the best approach for managing LHBT pathology, the evaluation of national procedural trends, risk factors, and overall safety is paramount. The present study found that the tenotomy procedure has a shorter operative time but longer overall hospital stays, likely due to an overall higher complication rate. Accordingly, tenodesis procedures, whether open or arthroscopic, were associated with lower likelihoods of both readmission and serious adverse events. Additionally, utilization trends from 2012 to 2021 indicate that both the overall procedural volume, along with outpatient utilization, of tenotomies have significantly declined. The present study provides the highest-powered assessment of management of LHBT pathology treatment options through the lens of systemic perioperative complications. The data proffered here are essential for the assessment of patient risk as well as optimization of their outcomes. Overall, the overall low rates of complication rates seen in the present study support the safety of performing these procedures in the outpatient setting.

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