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Subscapularis tenotomy versus lesser tuberosity osteotomy during total shoulder arthroplasty for primary osteoarthritis: a prospective, randomized controlled trial

William N. Levine, MD[a,*], Julianne Munoz, MD[b], Stephanie Hsu, MD[c], Ian R. Byram, MD[d], Louis U. Bigliani, MD[a], Christopher S. Ahmad, MD[a], Pinkawas Kongmalai, MD[e], Jamal N. Shillingford, MD[a]

[a]*Center for Shoulder, Elbow, and Sports Medicine, Department of Orthopedic Surgery, Columbia University, New York, NY, USA*
[b]*Department of Orthopedic Surgery, University of Miami, Miami, FL, USA*
[c]*Department of Orthopedic Surgery, Northside Hospital Sports Medicine, Atlanta, GA, USA*
[d]*Department of Orthopaedic Surgery, Bone and Joint Institute of Tennessee, Franklin, TN, USA*
[e]*Department of Orthopaedics, Faculty of Medicine, Srinakarinwirot University, Nakhon Nayok, Thailand*

Background: There is no current consensus on subscapularis mobilization during total shoulder arthroplasty. The purpose of this prospective, randomized controlled trial was to compare functional and radiographic outcomes of the more traditional subscapularis tenotomy (ST) versus lesser tuberosity osteotomy (LTO).
Methods: This study enrolled 60 shoulders in 59 patients with primary osteoarthritis. Thirty shoulders were preoperatively randomized to each group. Preoperative and 6-week, 3-month, 6-month, and 1-year postoperative data were collected. Ultrasound was performed at 3 months to evaluate subscapularis healing in tenotomy subjects, whereas radiographs were used to evaluate osteotomy healing. Intraoperative data included operative time, tenotomy or osteotomy repair time, and osteotomy thickness.
Results: No significant differences in range of motion or clinical outcomes occurred at baseline or 1 year postoperatively between the 2 groups. The mean total case duration for ST was significantly less than that for LTO (129.3 minutes vs 152.7 minutes), along with a significantly shorter subscapularis repair time for ST (34.3 minutes vs 39.3 minutes, $P = .024$). At final follow-up, 27 of 29 LTO shoulders (93.1%) showed bone-to-bone healing on radiographs, whereas 26 of 30 ST shoulders (86.7%) had no full-thickness tear of the subscapularis on ultrasound at 3 months.
Conclusions: Both techniques produced successful objective and subjective clinical outcomes. LTO heals more reliably than ST. Mean total case and subscapularis repair times were significantly greater for LTO than for ST.

Institutional review board approval was obtained from the Columbia University Institutional Review Board (protocol No. IRB-AAAE1446).

*Reprint requests: William N. Levine, MD, Department of Orthopaedic Surgery, Shoulder Service, CSES, New York Presbyterian/Columbia University Medical Center, 622 W 168th St, PH-1130, New York, NY 10032, USA.
E-mail address: wnl1@columbia.edu (W.N. Levine).

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The deltopectoral approach is commonly used in total shoulder arthroplasty (TSA), which necessitates subscapularis tendon mobilization. TSA was initially described using a subscapularis tenotomy (ST) performed medial to the lesser tuberosity insertion and using end-to-end repair before closure.[17] Although excellent clinical results are achieved with TSA, high subscapularis dysfunction rates are reported, upward of 67%.[5,6,9,15,23,24] These failures are attributed to poor healing, aggressive therapy, poor tendon quality, a history of surgery, and component malposition.[1,16] Subscapularis dysfunction has been associated with poor functional outcomes, including loss of internal rotation (IR), and is the most common cause of painful shoulder instability after TSA.[8,15]

Lesser tuberosity osteotomy (LTO) was developed to combat concerns about poor tendon-to-tendon healing and histologic data suggesting disorganized scar rather than tendon formation.[9,22] Bone-to-bone healing was theorized to improve the repair strength and lessen subscapularis dysfunction. Initial biomechanical analyses showed improved fixation strength and higher load to failure with bone-to-bone repair.[14,19] A subsequent biomechanical study comparing 3 different subscapularis repair constructs (tendon to tendon, tendon to bone, and bone to bone) suggested that the bone-to-bone construct has the best repair strength and restoration of subscapularis length.[25] Qureshi et al[20] retrospectively compared the results of their previously used ST with the new LTO and showed a significant decrease in subjective patient complaints with difficulty in shirt tucking and improved belly-press outcomes. Scalise et al[21] showed that both techniques yielded good clinical outcomes, but patients who underwent LTO showed higher total Penn Shoulder Scores, fewer subscapularis abnormalities on ultrasound, and healed osteotomies in all cases.

However, more contemporary biomechanical and clinical data have not shown the same superior results with osteotomy. Whereas prior biomechanical studies evaluated cemented humeral fixation, Giuseffi et al[10] later studied uncemented arthroplasties. They found no difference in repair strength between tenotomy and osteotomy, and ST actually showed significantly less cyclic displacement.[10] In a recent randomized controlled trial comparing LTO with subscapularis peel, there was no difference in primary or secondary outcomes of function at 2-year follow-up.[3] That study differs from ours because the peel technique dissects the tendon directly off the humeral insertion, whereas ST, which we used, preserves 1 cm of lateral tendon.

Although LTO has gained recent popularity, ST remains widely used with good reported outcomes.[4] To our knowledge, this is the first randomized controlled trial comparing ST with LTO. Our purpose was to ascertain whether one technique afforded better clinical and/or radiologic outcomes. The hypothesis was that LTO would decrease subscapularis dysfunction and improve healing rates while maintaining comparable clinical outcomes and a comparable operative time compared with ST.

Materials and methods

This is a prospective, randomized controlled trial conducted at a tertiary referral center. From December 2009 to March 2012, patients undergoing TSA by 1 of 3 fellowship-trained shoulder surgeons (L.U.B., W.N.L., and C.S.A.) were randomly assigned to either ST or LTO. Patients were identified and enrolled in the study during the final office visit prior to surgery. The attending physician or research associate obtained informed consent. Randomization was performed by a random number list generated by SPSS software (IBM, Armonk, NY, USA) and assigned on the day of surgery.

The inclusion criteria were patients of any age and sex with advanced, primary glenohumeral osteoarthritis refractory to nonoperative management for a minimum of 1 year. Nonoperative management included lifestyle modification, nonsteroidal anti-inflammatory drug therapy, and physical therapy. The preoperative history, physical examination findings, and imaging were reviewed to confirm the diagnosis of primary osteoarthritis. The exclusion criteria included prior subscapularis injury, ipsilateral open or arthroscopic rotator cuff surgery, massive rotator cuff tear, previous lesser tuberosity fracture or deformity, inflammatory arthropathy, history of ipsilateral shoulder infection, and acute systemic infection.

The clinical preoperative examination was performed by an independent examiner. The data included active and passive range of motion (ROM) and strength testing in forward elevation (FE), abduction, external rotation (ER), and IR measured by an IsoForceControl dynamometer (version 1.1; Medical Device Solutions, Oberburg, Switzerland). IR integrity was assessed via the belly-press and lift-off tests.[26] Standard radiographs and computed tomography (CT) scans were obtained in all patients undergoing TSA per institutional protocol. The intact subscapularis tendon was confirmed based on physical examination. Magnetic resonance imaging was obtained only if there was any concern regarding subscapularis integrity on physical examination. Questionnaires for the Simple Shoulder Test (SST), Short Form 36 (SF-36), visual analog scale (VAS), and American Shoulder and Elbow Surgeons (ASES) index were completed preoperatively.

Surgical technique

All surgical procedures were performed by the deltopectoral approach by 1 of 3 fellowship-trained shoulder surgeons (L.U.B., W.N.L., and C.S.A.). The same prosthesis (Bigliani/Flatow; Zimmer, Warsaw, IN, USA) was used in all cases. The humeral component was cemented in 9 osteotomies and 7 tenotomies and was press fit

in 21 osteotomies and 23 tenotomies. Eccentric humeral heads were used in all cases.

Tenotomy technique

The subscapularis tendon was sharply incised 1 cm medial to its lesser tuberosity insertion, leaving a small cuff of tendon for repair. The subscapularis was released with electrocautery from superior to inferior along with the capsule. An anteroinferior capsulectomy of the middle and inferior glenohumeral ligaments was carefully performed to gain mobilization of the subscapularis along with release of all subcoracoid adhesions and the coracohumeral ligament. After humeral reaming, 4 drill holes were placed along the bicipital groove and lesser tuberosity. A heavy nonabsorbable suture was placed through each pair of horizontal holes by a free needle. These sutures were then passed medially along the tendon, bringing the subscapularis laterally to its insertion site, and tied over the bone bridge after the humeral component was placed. Tendon-to-tendon sutures were placed to approximate the free edge of the subscapularis to the remaining cuff on the lesser tuberosity. All repairs achieved at least 30° of ER without tension.

Osteotomy technique

The lesser tuberosity was identified after the biceps was tenotomized. LTO was initiated from lateral to medial with an oscillating saw and completed with an osteotome, aiming parallel to the subscapularis for a 10-mm-thick osteotomy. The remaining inferior subscapularis was released off the humerus. Capsular release was completed around the inferior neck of the humerus in both techniques. The tuberosity that had undergone osteotomy was then measured with sterile calipers. Remaining capsular or subcoracoid adhesions were released to mobilize the subscapularis. Prior to humeral implantation, 4 drill holes were made lateral and medial to the osteotomy site. A heavy nonabsorbable suture was passed in an outside-in manner laterally and in an inside-out manner medially through each pair of holes, looping around the humeral stem as it was inserted. Sutures were augmented by one or two 20-gauge cerclage wires per surgeon preference, each consistently using his preferred method. As the humeral stem was seated, sutures and wires were pulled taut. The medial sutures and wires were passed medial to the osteotomy fragment, tensioned, and tied over the thickest area of bone to achieve secure compression of the osteotomy fragment to the bed. All repairs achieved at least 30° of ER without tension.

Intraoperative data

Intraoperative data included total operative time, tenotomy or osteotomy repair time, and osteotomy thickness. Operative times were logged during surgery from incision to skin closure. Subscapularis repair time represented the duration between the glenoid implantation and final tendon repair time points to include time spent drilling holes and passing suture and/or wire prior to humeral implantation.

Postoperative protocol

Patients in both groups followed the same postoperative rehabilitation protocol. A 30° abduction sling was used for 6 weeks postoperatively. On postoperative day 1, the patients were advised to perform passive FE exercises in the supine position and take the sling off to perform elbow, wrist, and finger exercises. Passive gentle ER in the scapular plane was allowed to 30°. After full passive ROM was achieved, active FE, IR, and ER were gradually restored after 4 weeks. Supine active FE strengthening without weights was started after 6 weeks. Other advanced strengthening exercises were deferred before 12 weeks to allow for appropriate soft-tissue healing.

Postoperative outcomes

Postoperative outcome measures included active and passive ROM and strength testing in FE, abduction, ER, and IR at 6 weeks, 3 months, 6 months, and 1 year postoperatively. SST, VAS, SF-36, and ASES scores were collected at these time points, as were Grashey anteroposterior and axillary radiographs, in all patients. Postoperative radiographs were analyzed for anatomic sizing, prosthetic loosening, or evidence of instability in any direction. At 3 months postoperatively, radiographic analysis of lesser tuberosity healing was conducted, which was confirmed by cortical contact and continuity of the lesser tuberosity to the humeral shaft. For tenotomy patients, ultrasound of the subscapularis was performed at 3 months postoperatively by a single trained physician, as it has been previously validated as a tool to assess rotator cuff function after TSA.[1,12,13,18] The tendon was classified as having a full-thickness tear or no full-thickness tear. If the ultrasound was unable to be scheduled at the time for any reason, radiographs were obtained per institutional protocol to assess anterior subluxation of the humeral prosthesis serving as a surrogate for subscapularis failure.

Statistical analysis

Power analysis determined that a total of 56 shoulders, 28 in each group, would give a 95% power to detect a 5-point difference in the ASES score. Independent-sample *t* tests were performed for all continuous variables (ROM; strength; and SST, SF-36, VAS, and ASES scores) to assess differences between ST and LTO at baseline and at each follow-up time point. A *t* test was also performed for each group to evaluate improvement from baseline to each follow-up time point. A regression analysis was performed to evaluate the effects of independent variables on postoperative dependent variables. All statistical analysis was performed with SPSS software.

Results

There were 75 patients assessed for eligibility. We excluded 15 patients because they did not meet the inclusion criteria (8 patients) or for other reasons (7 patients). Therefore, a total of 30 patients were randomly assigned to either ST or LTO (Fig. 1).

The ST group had slightly lower FE strength at baseline (37 ± 5 N) compared with the LTO group (55 ± 7 N, $P = .03$); however, we found no other statistically significant differences in any other preoperative measures or demographic characteristics including age, sex, or hand dominance. Between the ST and LTO groups, no significant differences occurred at baseline or at 1 year postoperatively in clinical outcomes (VAS, SST, ASES, and SF-36 scores) or ROM in FE, ER,

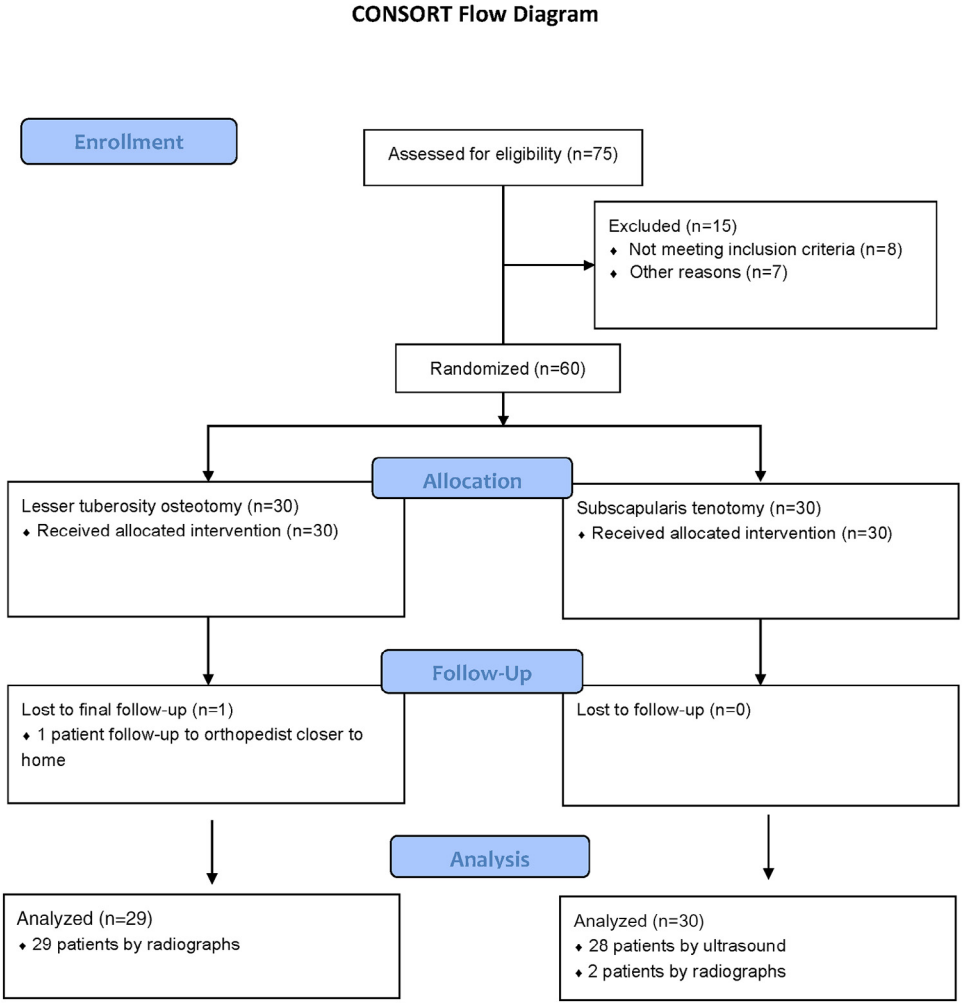

Figure 1 Consolidated Standards of Reporting Trials (*CONSORT*) flow diagram of patient randomization to lesser tuberosity osteotomy and subscapularis tenotomy groups.

and IR. At 1 year, FE was 150° ± 6° in the ST group versus 153° ± 7° in the LTO group whereas ER was 50° ± 2° in the ST group versus 52° ± 3° in the LTO group (Fig. 2). IR was T11 in both groups. No significant differences in strength were found at any follow-up time point (Fig. 3). The VAS score at 1 year was 1.9 in the ST group and 1.8 in the LTO group; the SF-36 score was 64.9 and 71.1, respectively; and the ASES score was 74.6 and 75.6, respectively (Fig. 4). At 3 months postoperatively, the SST score in the ST group was significantly lower than that in the LTO group, 5.5 versus 7.6 ($P = .01$), but not at final follow-up, 7.6 versus 9.1. Significant gains ($P = .007$) occurred in FE, ER, IR, and VAS, SST, and ASES scores from baseline to 1 year postoperatively within each group (Fig. 4).

The mean total case duration for ST was significantly less than that for LTO (129.3 minutes vs 152.7 minutes), along with a significantly shorter subscapularis repair time (34.3 minutes vs 39.3 minutes, $P = .024$). LTO thickness averaged 8 mm (range, 3-12 mm).

Of 29 LTO shoulders, 27 (93.1%) showed bone-to-bone healing on axillary radiographs at final follow-up. One of the patients in whom failure occurred returned at 34 months with pseudoparalysis, anterior subluxation on radiographs, and CT showing an intact cerclage wire but no bone beneath, with inferomedial lesser tuberosity displacement. Another LTO failure was found at 1 year with lesser tuberosity nonunion and superior migration of the humeral component. One patient was lost to follow-up to an orthopedic surgeon closer to home,

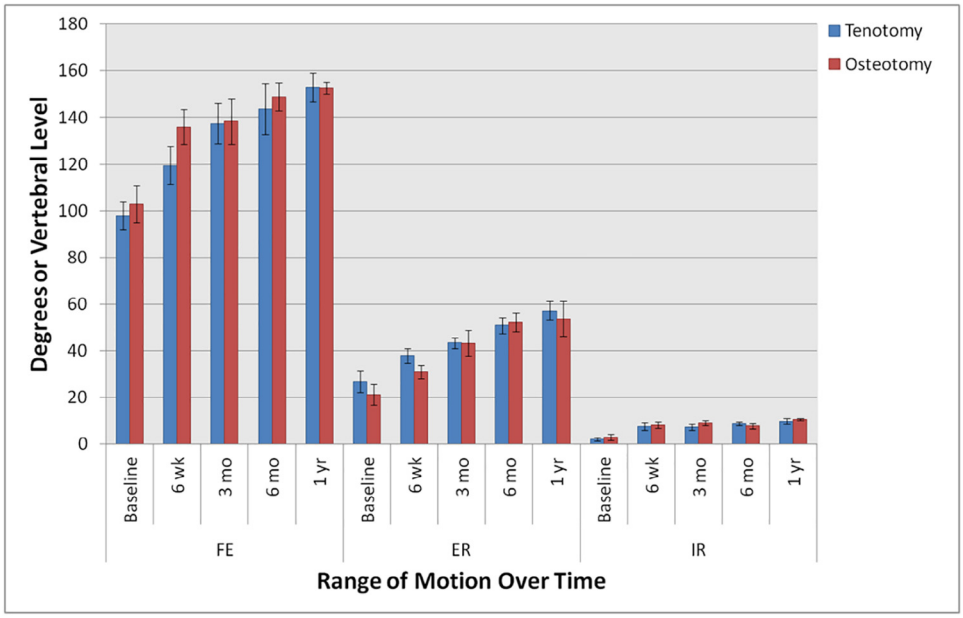

Figure 2 Range of motion at 6 weeks, 3 months, 6 months, and 1 year showed no significant difference between the 2 groups. *FE*, forward elevation; *ER*, external rotation; *IR*, internal rotation.

Of 28 ST shoulders that underwent ultrasound postoperatively, 24 had an intact subscapularis whereas 2 showed partial attenuation. Two patients were found to have full-thickness tears (Fig. 5). One patient with subscapularis attenuation had negative lift-off and belly-press tests at most recent follow-up, whereas the other showed positive lift-off and belly-press signs at 1 year. Surprisingly, 1 patient with a torn subscapularis on ultrasound showed negative belly-press and lift-off tests at most recent follow-up. In 2 additional ST patients who were unable to schedule ultrasound, radiographs showed anterior subluxation (Fig. 6). We included them as subscapularis repair failures. One such patient showed signs of superior subscapularis insufficiency on examination with a deficit in FE, whereas the other patient had positive

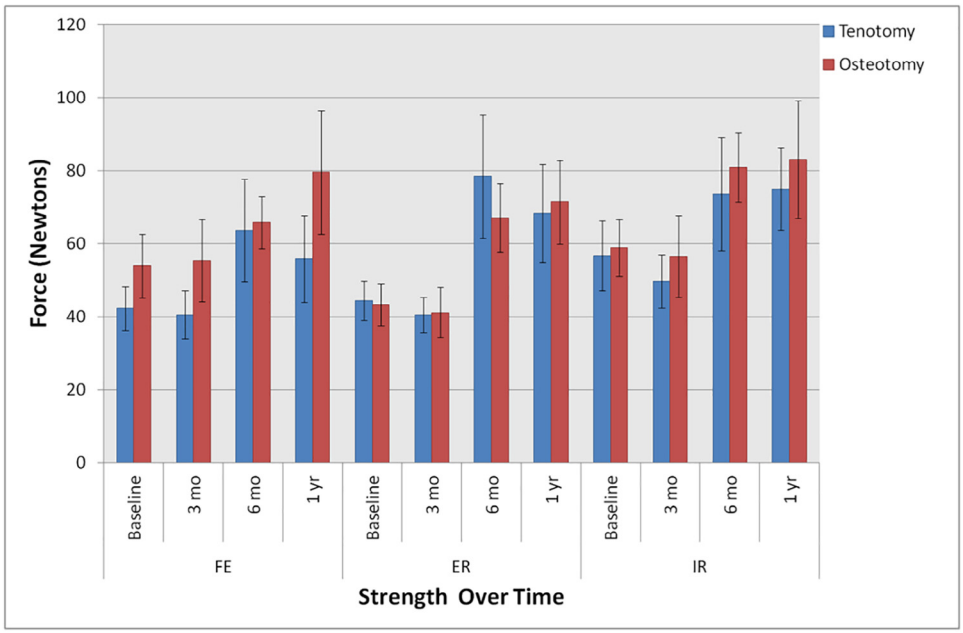

Figure 3 No significant difference in strength of forward elevation (*FE*), external rotation (*ER*), and internal rotation (*IR*) was found in any period.

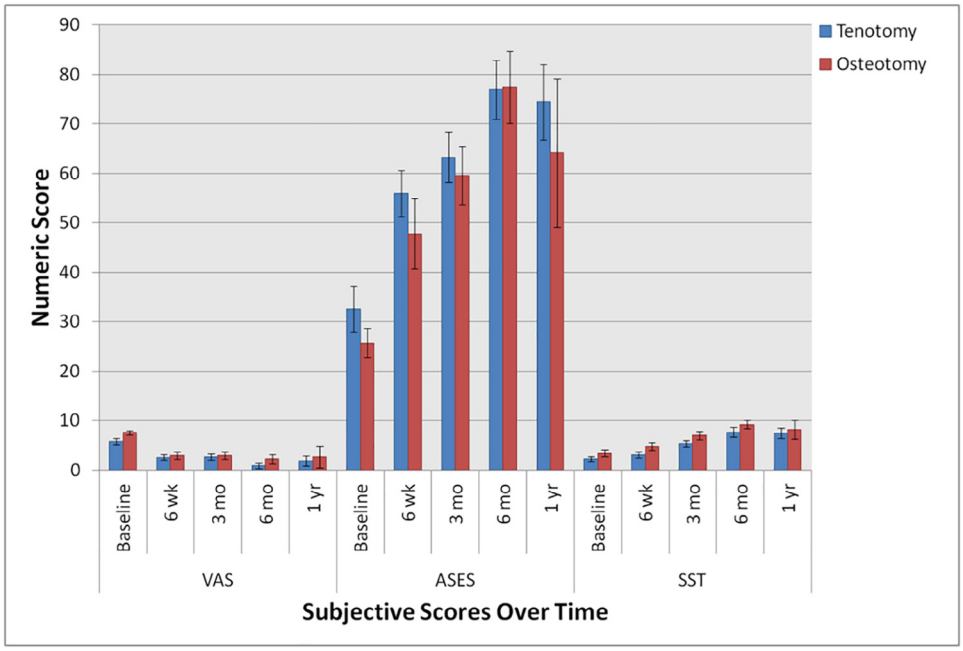

Figure 4 Visual analog scale (*VAS*), American Shoulder and Elbow Surgeons (*ASES*), and Simple Shoulder Test (*SST*) scores at baseline and at 6 weeks, 3 months, 6 months, and 1 year postoperatively showed no significant difference between the 2 groups.

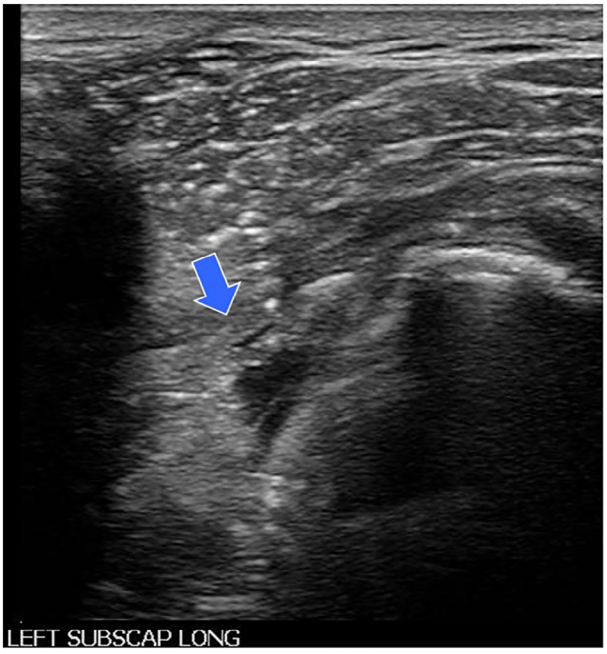

Figure 5 Ultrasound of a failed subscapularis (*SUBSCAP*), with the *arrow* pointing to the lesion.

belly-press and lift-off signs at 1 year. Therefore, 26 of 30 ST shoulders (86.7%) showed no full-thickness tear of the subscapularis.

No evidence of component loosening or instability was found in either group. Other postoperative complications in the ST group included 1 patient with a partial-thickness, bursal-sided tear of the supraspinatus managed nonoperatively, as

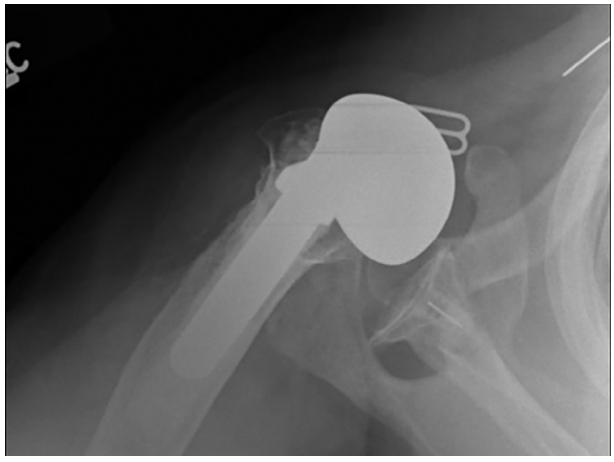

Figure 6 Axillary film of the right shoulder in a patient with subscapularis failure from the subscapularis tenotomy group. Significant anterior subluxation of the humeral component was found.

well as subacromial impingement requiring arthroscopic bursectomy and anterior acromioplasty. In 1 LTO patient, pain developed at 3 months postoperatively owing to a loose cerclage wire, requiring hardware removal and lysis of adhesions. Other LTO complications included 1 case of transient postoperative radial nerve palsy, subacromial bursitis in 2 patients, and trapezius spasms in 1 patient. No other postoperative complications, infections, or revisions occurred in either group.

Discussion

We sought to determine the optimal technique for subscapularis management in TSA because many reported complications

are associated with postoperative subscapularis dysfunction, including pain, instability, and decreased strength.[7,11,16] Past studies reported variable results after ST during TSA, and newer retrospective reviews of LTO have heightened the discussion.[4,6,8,16] Our initial hypothesis was that LTO would yield improved IR strength, better healing, comparable outcome scores, and a comparable total operative time. Several aspects of this hypothesis were supported, namely lower rates of subscapularis failure and similar outcome scores for LTO. However, we found longer subscapularis repair and total operative times for LTO but no difference in postoperative IR strength.

Our results indicate that LTO (93.1%) heals more reliably than ST (86.7%). This difference may result from increased compression of the bone-to-bone healing over tendon-to-tendon healing. In addition, age has been shown to have a direct inverse correlation with tendon healing in rotator cuff studies of the supraspinatus tendon.[2] Given the average age of our patient population, tendon quality may play a role in poor healing capacity. We are unable to comment on the postoperative condition of the subscapularis muscle belly technically, as we did not perform postoperative CT scans, as Gerber et al[8] did previously. Rather, we used ultrasound, radiography, clinical strength, and examinations to determine the muscle integrity. No significant difference in subscapularis function was found by examination or by IR dynamometer strength testing.

Miller et al[15] reported subscapularis dysfunction rates as high as 67% postoperatively by the belly-press, lift-off, or shirt-tuck test. In a follow-up to this historical cohort, Qureshi et al[20] reviewed patients undergoing LTO instead of ST and found overall improved postoperative results for the belly-press test (60% negative) and shirt-tuck test (83% able). We did not find any significant difference in postoperative IR strength as we had hypothesized; both groups recovered IR strength without significant deficit.

Of interest, 1 ST patient showed a full subscapularis tear by ultrasound but showed negative belly-press and lift-off tests. Moreover, the 2 patients with attenuated tendons on ultrasound differed in subscapularis functional tests. Armstrong et al[1] showed low sensitivity, low specificity, and a low positive predictive value for the belly-press test postoperatively, instead regarding ultrasound as the gold standard to evaluate subscapularis healing. Variable reliability of these clinical tests and contributions by other muscles to IR may explain the difference we found in radiographic and clinical examinations.

We did not hypothesize that the thickness of the LTO would affect healing potential or functional results, which our results confirm. Concerns regarding how LTO thickness might affect repair stability and the ability to withstand suture or wire cut-through were unfounded in our series because all osteotomies were stable on repair, with 93.1% showing evidence of healing at 3 months.

We found longer subscapularis repair and total operative times for LTO than for ST. Because each of the 3 surgeons predominantly performed ST prior to the study, some difference should be attributed to the learning curve. However, technical aspects associated with LTO may also account for time differences. There was a slight trend for each surgeon to shorten his LTO repair time, but owing to the technical steps of the procedure, we believe LTO may continue to take slightly longer to perform.

These early-term results show that LTO may provide more reliable subscapularis healing in TSA, but despite this, there were no significant differences in clinical outcomes. Strengths of the study include the prospective, randomized study design; consistent preoperative and postoperative measurements; standardized intraoperative measurements; use of the same TSA system; and standard postoperative ultrasounds and radiographs to evaluate ST or LTO healing. Limitations of our study include the small variation in technique of multiple surgeons. Given that our primary outcome targets included healing rates and intraoperative findings, we thought that the assessment could be satisfactorily performed in a 1-year follow-up period. Although an inherent limitation of our study, the difference in technique between the 3 surgeons may enhance the clinical applicability of this study.

Conclusion

This prospective, randomized controlled trial showed that LTO and ST produce comparable successful subjective and objective clinical outcomes. LTO heals more reliably than ST. Mean total case and subscapularis repair times were significantly greater with LTO than with ST.

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Disclaimer

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