Imaging characteristics of lesser tuberosity osteotomy after total shoulder replacement: a study of 220 patients

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**Background:** The lesser tuberosity osteotomy (LTO) has been gaining popularity as a method of exposing the glenohumeral joint during total shoulder replacement, whereby a small fragment of bone is removed from the lesser tuberosity, thus preserving the subscapularis tendon. To date, no large, randomized studies have reported evaluations of LTO healing and healing rates.

**Methods:** We reviewed the radiographs and available computed tomography images of 362 patients who underwent a total shoulder arthroplasty by the same surgeon between 2006 and 2012. The integrity of the LTO site was graded as not seen, bony union, nondisplaced nonunion, and displaced nonunion. The smoking status of patients was also assessed.

**Results:** Of 362 patients investigated, 220 had a minimum of 6 months of radiographic follow-up. The LTO site was not seen in 37 patients; of the remaining 183, 159 patients (86.89%) demonstrated bony union, 8.80% of whom were smokers; 16 patients (8.74%) demonstrated nondisplaced nonunion, 6.3% of whom were smokers; and 8 patients (4.3%) demonstrated displaced nonunion, 25.0% of whom were smokers. Overall, 19 of the 24 nonunions were in male patients (79.1%) and 5 were in female patients (20.8%).

**Conclusions:** This is the first large-scale study to report the healing rate of LTOs. LTO healing is best assessed on radiographs; if nondisplaced or displaced nonunions are suspected, computed tomography can be a helpful additional examination. The number of radiographs where there is a lack of adequate visualization of the LTO site raises important questions about definitive radiographic evaluation using current techniques.

**Level of evidence:** Level IV, Case Series, Treatment Study.

**Keywords:** Total shoulder arthroplasty; lesser tuberosity osteotomy healing; joint replacement

Surgical management of the subscapularis tendon during total shoulder replacement remains a topic of debate. When the deltopectoral approach is used, the traditional subscapularis tenotomy provides direct access to the glenohumeral joint and relies on primary tendon-to-tendon healing to restore subscapularis integrity. With concerns about consistent tendon-to-tendon healing and the histologic data that the tendon-to-tendon healing does not heal with
new tendon, but rather disorganized scar, lesser tuberosity osteotomy (LTO) has recently gained popularity. Several clinical series have documented improved subscapularis function compared with the standard transtendinous approach in postoperative patients. By removing a small fragment of bone from the lesser tuberosity with the subscapularis tendon still attached, exposure to the glenohumeral joint is similarly possible. The osteotomy may be reattached with transosseous sutures once the joint replacement is complete. This technique evolved from the theory that the healing potential of 2 bone surfaces is greater than that of tendon-to-tendon repairs traditionally done. Jandhyala et al recorded superior subscapularis function with LTO over tenotomy in a single-surgeon series with both techniques. As reported by Gerber et al, the healing of the LTO may be defined as cortical continuity between the fragment of the lesser tuberosity and the cortex of the proximal humerus onto which it has been repositioned. Most published series using the LTO technique have reported osteotomy unions on radiographs to be 100%. A series published by Lapner et al reported a 95% healing rate of LTO when evaluated by computed tomography (CT) examination. To date, 1 published series of 4 patients has described lesser tuberosity detachment during the early postoperative period.

The principal objective of this study was to retrospectively assess LTO healing from routine postoperative radiographs, and CT scans when available, at a minimum of 6 months of follow-up. We assess healing at the osteotomy site and describe the radiographic and CT appearance, including a characteristic but not previously described “half-moon” sign, as seen in displaced nonunion cases. Healing trends for LTOs were then related to individual smoking status. In reviewing all postoperative radiographs of a single surgeon, we also obtained the percentage of postoperative cases where the radiographic technique was not adequate to answer our specific clinical question of LTO healing.

Materials and methods

Between January 2006 and June 2012, 362 patients were treated with a primary total shoulder arthroplasty using the LTO technique at a single tertiary referral center, performed by the senior author (L.D.H.). The study excluded 142 patients secondary to a lack of postoperative imaging at a minimum of 6 months; thus, 220 patients were included in this study. Of those 220, 183 had LTOs that could be visualized on radiograph, and in 26 patients, follow-up CT examinations were reviewed in conjunction with radiographs. Postoperative radiographs consisted of Grashey (true glenohumeral anteroposterior [AP] with 30°–40° posterior oblique), axillary (patient supine with arm abducted 90° and raised 60°–70° anteriorly), and transscapular (60° anterior) views. No fluoroscopic control was used when obtaining radiographs. When there was clinical concern about underlying subscapularis function, a CT arthrogram was performed to further evaluate healing status of the LTO while simultaneously assessing the integrity of the subscapularis tendon. If the patient reported intravenous contrast allergy, CT air arthrogram or routine CT was performed.

CT examinations (arthrogram and nonarthrogram) were obtained at 2-mm slice thickness with coronal and sagittal reformations on a 128-slice Siemens AS+ scanner (Siemens Healthcare, Erlangen, Germany). A retrospective review of postoperative radiographs and CTs was performed by consensus between both the operating surgeon and an experienced fellowship-trained musculoskeletal radiologist.

The integrity of the lesser tuberosity osteotomy site was graded as not seen, bony union, nondisplaced nonunion, and displaced nonunion:

- The osteotomy site was defined as “not seen” when the readers could not confidently see the osteotomy site to grade its integrity.
- “Bony union” was defined when cortical continuity and bridging trabeculae were seen between the LTO fragment and the proximal humerus.
- “Nondisplaced nonunion” was defined when the lesser tuberosity was located in its expected anatomic position but there was a lack of detectable cortical continuity or bridging trabeculae between the lesser tuberosity fragment and the proximal humerus. The term “fibrous union” was not used, because the presence of fibrous tissue at the interface between the LTO and the donor site had not been seen clinically under direct visualization. In addition, CT arthrography routinely showed intra-articular contrast undermining the LTO site.
- “Displaced nonunion” was defined when the lesser tuberosity fragment was not identified at its expected anatomic position. In these cases, the lesser tuberosity fragment was detached from its osteotomy site and subsequently displaced.

The records of patients who were categorized as bony union, nondisplaced nonunion, and displaced nonunion were reviewed to evaluate smoking status.

Surgical technique

A standard deltopectoral approach was performed with the patient in a modified beach chair position with a pneumatic arm holder (Smith & Nephew, Andover, MA, USA). The subscapularis was exposed and the proximal biceps removed to expose the intertubercular groove. The rotator interval was widely opened to expose the proximal subscapularis, and an osteotomy of approximately 5 mm of the lesser tuberosity was performed so that it exited lateral to the articular surface. The osteotomy varies by individual because the size of the lesser tuberosity varies by individual. Ideally, the osteotomy is 3- to 4-mm thick and approximately 15-mm wide (the mean size of the lesser tuberosity lateral to the articular surface). In essence, the entire lesser tuberosity in thickness was not harvested, just a thin segment robust enough to reattach. The subscapularis was taken down in a subperiosteal fashion below the osteotomy and reflected medially. No attempt to ligate the anterior humeral circumflex artery was made during exposure. A standard total shoulder arthroplasty was then performed.

The lesser tuberosity was repaired with alternating #5 and #2 FiberWire sutures (Arthrex, Naples, FL, USA) passed through transosseous tunnels and cerclaging the prosthetic stem (Fig. 1).
Alternating simple and Mason Allen sutures were then placed at the subscapularis tendon and lesser tuberosity junction. The deltopectoral interval was closed in routine fashion.

The patient engaged in a traditional postoperative therapy protocol with passive range of motion for 4 weeks. Active assistive range of motion began at 4 weeks and strengthening at 12 weeks. If a nonunion was visualized, the physical therapy was modified to avoid excessive external rotation and resisted internal rotation.

Statistical analysis

Variables of interest included the patient’s age at surgery, sex, surgical side, and smoking status. A binary variable was created for the outcome of interest, which was bony union of the LTO compared with nonunion of the LTO (displaced and non-displaced). A binary variable was also created for the patient’s smoking status: current smokers vs all other (never smokers and former smokers). In bivariate and multivariable regression, age was assessed using 10-year increments.

Analysis of radiograph visualization of the LTO according to patient positioning included all 220 patients. All advanced data analysis was done excluding those eligible individuals whose LTO could not be visualized on the radiograph, resulting in 183 individuals included in further analysis. Univariate descriptive statistics were calculated for all variables of interest, with mean, standard deviation (SD), and range calculated for continuous variables, and number (%) calculated for categoric variables. Bivariate statistics were calculated for a comparison of explanatory variables of interest to the binary union variable. The subsequent analysis was performed using logistic regression. Bivariate statistics were calculated for patient sex compared with the other explanatory variables of interest (age, current smoking status, and surgical side) also using logistic regression.

Five adjusted multivariable logistic regression models were created (Table I). Multivariable models were compared with unadjusted models as well as with each other by difference in the \( \chi^2 \) likelihood ratio to assess for best fit model, with a threshold \( \chi^2 \) value determined using a distribution table. Statistical significance was attained with \( P < .05 \). Statistical analysis was performed using SAS 9.3 software (SAS Institute Inc, Cary, NC, USA).

Results

Of 362 consecutive patients with total shoulder replacement performed between January 2006 and June 2012, 220 met our follow-up imaging criteria of a minimum of 6 months (range, 3 months-6.5 years). Our criterion of a 6-month minimum follow-up was instituted with consideration of the accepted definition of a “nonunion” as a lack of bony consolidation or bridging trabeculae across a fracture or surgical site after 6 to 9 months.16

Evaluation of radiographic and CT findings

Evaluation of LTO

Of the 220 patients with 6 or more months of follow-up, the LTO site was “not seen” in 37 patients (16.8%), leaving 183 patients who had a visualized LTO. This was most often secondary to suboptimal positioning and nonorthogonal radiographic views. Although portions of the LTO could be seen on these radiographs, the actual osteotomy site was not visualized in its entirety to confidently assess for the presence of cortical continuity or bridging trabeculae, or both.

Overall, patients whose LTO was visualized were an average age of 62.46 years (SD, 11.44; range, 27.26-85.10 years), 54.1% were male, 59.9% had surgery on their right side, and 9.8% were current smokers at the time of surgical consent (Table II).

The LTO site demonstrated “bony union” (Fig. 2) in 159 patients (86.9%), of whom 80 (50.3%) were male and 79 (49.7%) were female. The median age of these patients was 62.76 years (SD, 11.55; range, 27.26-85.10 years), and
14 of the 159 patients (8.8%) who had a documented smoking status and a bony union were documented as current smokers (Table III). The axillary and transscapular Y views were the best radiographic views to visualize bony union at the LTO.

“Nondisplaced nonunion” of the LTO was noted in 16 of the 183 patients (8.7%) whose LTO was visualized. In this category, 13 of the 16 patients (81.3%) were male and 3 (18.8%) were female. These patients were a median age of 61.98 years (SD, 11.22; range, 42.06-82.58 years). One of the 16 patients (6.3%) with nondisplaced nonunion was documented as a current smoker.

In 13 of the 16 patients, the nondisplaced nonunion was best demonstrated on axillary views (Fig. 3). This finding in many of these patients was confirmed on the transscapular views. In 3 of the 16 patients, the transscapular view was the best diagnostic view in the radiographic series to identify the nondisplaced nonunion (Fig. 4, A). In these cases, it was important to note that the nondisplaced nonunion was not well seen on the additional radiographic projections (Fig. 4, B). These results emphasize the importance in obtaining true orthogonal views to make an accurate diagnosis on radiographs. On CT arthrogram imaging, nondisplaced nonunion demonstrated interposition.

### Table II
Univariate descriptive statistics of categoric variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>No. (%) [SD] (Mean or Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>62.5 [11.4] (27.3-85.1)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>99 (54.1)</td>
</tr>
<tr>
<td>Female</td>
<td>84 (45.9)</td>
</tr>
<tr>
<td>Union type*</td>
<td></td>
</tr>
<tr>
<td>Bony</td>
<td>159 (86.9)</td>
</tr>
<tr>
<td>Nondisplaced nonunion</td>
<td>16 (8.7)</td>
</tr>
<tr>
<td>Displaced nonunion</td>
<td>8 (4.4)</td>
</tr>
<tr>
<td>Side</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>69 (40.1)</td>
</tr>
<tr>
<td>Right</td>
<td>103 (59.9)</td>
</tr>
<tr>
<td>Smoking status</td>
<td></td>
</tr>
<tr>
<td>Never smoker</td>
<td>88 (50.9)</td>
</tr>
<tr>
<td>Former smoker</td>
<td>68 (39.3)</td>
</tr>
<tr>
<td>Current smoker</td>
<td>17 (9.8)</td>
</tr>
</tbody>
</table>

SD, standard deviation.
* Excluding not seen.

### Table III
Predictor variables of interest by odds of nonunion (displaced and non-displaced) compared with bony union

<table>
<thead>
<tr>
<th>Variable</th>
<th>Nonunion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age increase 10 years</td>
<td>Unadjusted OR (95% CI)</td>
</tr>
<tr>
<td>Male</td>
<td>19 (19.2)</td>
</tr>
<tr>
<td>Female</td>
<td>5 (6.0)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Surgical side</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>5 (7.3)</td>
</tr>
<tr>
<td>Right</td>
<td>18 (17.5)</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>3 (17.7)</td>
</tr>
<tr>
<td>Never + former</td>
<td>20 (12.8)</td>
</tr>
</tbody>
</table>

CI, confidence interval; OR, odds ratio.
* Number (%) of patients in that category who had any type of nonunion.
† Logistic regression.
‡ Statistically significant.

**Figure 2** Bony union at the lesser tuberosity osteotomy site. Axillary radiograph demonstrates cortical continuity and bridging trabeculae across the osteotomy site.

**Figure 3** Nondisplaced nonunion healing of the lesser tuberosity osteotomy. An axillary radiograph demonstrates the lesser tuberosity osteotomy fragment in the correct anatomic position. No cortical continuity or bridging trabeculae is seen between the osteotomy fragment and the underlying humerus.
of arthrographic contrast between the osteotomy fragment and the humerus (Fig. 5). This finding confirms the lack of intervening tissue between the osteotomy fragment and the underlying humerus.

Of the 183 patients whose LTO was visualized, “displaced nonunion” at the LTO site (Fig. 6) was noted in 8 patients (4.3%), of whom 6 (75%) were male and 2 (25%) were female. These patients were a median age of 57.55 years (SD, 9.57; range, 46.91-73.97 years). Of the 8 patients with displaced nonunions, 2 (25.0%) were documented as current smokers. In contrast to the other entities, the AP view proved to be an important source of information, allowing visualization of the displaced lesser tuberosity fragment (Fig. 7). A CT examination in 5 of the 8 patients confirmed the displaced nonunion.

In patients with displaced nonunion at the LTO site, the displaced lesser tuberosity fragment has a characteristic appearance of a “half-moon”: one border demonstrates the outer curved border of the lesser tuberosity and the opposing border exhibits a surgically formed straight margin (Fig. 8). The images of all of our patients with displaced nonunion demonstrated the “half-moon”
Discussion

Subscapularis dysfunction after total shoulder arthroplasty has been widely reported and may yield significant pain and debilitation for patients. Furthermore, with enhanced physical diagnosis of subtle subscapularis dysfunction, several publications have documented such deficiencies in up to 67% of patients. Alternative operative techniques, such as the subscapularis peel and LTO, have evolved as an attempt to optimize clinical function of the subscapularis after total shoulder arthroplasty. Although Lapner et al. reported no significant difference between LTO and subscapularis peel techniques in subscapularis strength, several biomechanical studies have demonstrated biomechanical and clinical improvement using the lesser tuberosity technique. To improve the quality of subscapularis repair, the senior author began routinely using the LTO technique in total shoulder arthroplasties starting in the year 2000.

Another touted advantage of this technique is the ability to monitor its healing on radiographic follow-up. Most published studies have reported 100% healing rates as determined by radiographs. To date, only one published series of 4 patients has described lesser tuberosity detachment during the early postoperative period. Radiographs may also be diagnostic of an osteotomy displacement postoperatively if a patient experiences a trauma to the operative shoulder, because it is the likely point of failure in the early postoperative course.

Our study describes the variable imaging (radiographic and CT) findings of postoperative LTOs when critically reviewed; our associated rates are 37 of the 220 patients were not seen; of the remaining 183, 159 patients presented with bony union, 16 with nondisplaced nonunion, and 8 with displaced nonunion. In our retrospective study of postoperative radiographs, we found that the efficacy of postoperative radiographs is highly dependent on patient positioning and projection of the radiographs. Although in theory radiographic technique should be able to identify healing at the osteotomy site, a nonorthogonal view is often nondiagnostic. Small variations in patient positioning or in the alignment of the x-ray beam greatly affect accurate assessment of a single small osteotomy site. Our results show that the optimal orthogonal views to evaluate the LTO site are the axillary and the transscapular views.

Complete detachment of the LTO is the functional equivalent of complete subscapularis rupture and is associated with a displaced LTO. This complication, although infrequent, is devastating after total shoulder arthroplasty and will lead to poor clinical outcome with anterior instability. Moeckel et al. reviewed 236 shoulder arthroplasties and reported 7 complete subscapularis ruptures (3%) that required revision surgery. Several authors have detailed factors other than the rotator cuff which play a role in glenohumeral stability. Not only do component position and version have an effect upon stability, but native glenoid version and version correction also have significant effects on the ultimate relationship between the humeral head and the glenoid.

In optimized radiographic views, displaced nonunion LTOs can often be seen on all projections. The axillary and

Figure 6 Displaced nonunion of the lesser tuberosity osteotomy. An axillary radiograph demonstrates a displaced lesser tuberosity fragment.
transscapular views are the best views to see the osteotomy site, but AP views can be used to identify the displaced lesser osteotomy fragment. Our study also describes the characteristic but not previously described “half-moon” sign. Our findings demonstrate that this novel sign is diagnostic of a displaced nonunion at the LTO site. This finding was seen on radiographs and CT examinations in our patients with nonunion.

The correlation between smoking and poor fracture healing is well detailed in previous reports. These articles report delayed, incomplete, and nonunion of fractures in clinical outcomes studies and experimental animal models. There was no significant association in our data between current smoking at the time of surgery and having an outcome of nonunion, but smoking did appear to indirectly influence the relationship between a patient’s sex and their union outcome. In a systematic review of 11 studies containing 1194 patients, Thomsen et al evaluated preoperative smoking cessation programs and concluded that patients who began a program 4 to 8 weeks ahead of surgery were most likely to minimize the risk of postoperative complications. In fact, tobacco avoidance for fewer than 4 weeks before surgery claimed no benefits. Yen et al found that in an experimental animal model, abstinence from smoking effectively combated the adverse effects of smoking when this equaled the overall smoking time. The senior author of this study routinely counsels his patients to cease smoking a minimum of 4 weeks before their replacement surgery, a practice that should be strictly enforced to maximize LTO healing potential.

The group whose LTO did not heal is overwhelmingly populated by younger patients (median age, 57.5 years;

Figure 7  A displaced nonunion lesser tuberosity osteotomy fragment is seen on (A) anteroposterior, (B) axillary, and (C) transscapular radiographs.

Figure 8  The characteristic “half-moon” sign of the displaced, nonunion lesser tuberosity osteotomy fragment is demonstrated on (A) a computed tomography scan axial image and (B) a computed tomography arthrogram sagittal reformation, showing the straight surgical border (arrow) and outer curved border.
Table IV  Variables of interest by patient sex

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male sex</th>
<th>Unadjusted OR (95% CI)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age increase 10 years</td>
<td>0.737 (0.563-0.964)</td>
<td>.0258</td>
<td></td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current</td>
<td>1.289 (0.467-3.560)</td>
<td>.6240</td>
<td></td>
</tr>
<tr>
<td>Never+Former</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgical side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>0.562 (0.303-1.040)</td>
<td>.0666</td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CI, confidence interval; OR, odds ratio.
* Logistic regression.
† Statistically significant.

Table V  Multivariable regression of bony union compared with nonunion (displaced and nondisplaced)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Male sex</th>
<th>Likelihood ratio†</th>
<th>P†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unadjusted</td>
<td>3.752 (1.335-10.539)</td>
<td>7.6829</td>
<td>1</td>
</tr>
<tr>
<td>Model 1‡</td>
<td>3.334 (1.165-9.535)</td>
<td>9.8266</td>
<td>2</td>
</tr>
<tr>
<td>Model 2‡</td>
<td>4.980 (1.616-15.346)</td>
<td>10.2250</td>
<td>3</td>
</tr>
<tr>
<td>Model 3‡</td>
<td>3.622 (1.279-10.256)</td>
<td>7.7282</td>
<td>2</td>
</tr>
<tr>
<td>Model 4‡</td>
<td>4.446 (1.418-13.935)</td>
<td>11.9804</td>
<td>3</td>
</tr>
<tr>
<td>Model 5‡</td>
<td>4.312 (1.365-13.624)</td>
<td>12.1539</td>
<td>4</td>
</tr>
</tbody>
</table>

CI, confidence interval; OR, odds ratio.
* Odds of nonunion for men compared with women. OR values in boldface are statistically significant.
† Compared with a model with no covariates.
‡ All P values are statistically significant.

Our study has several limitations, including the retrospective nature of the study. In addition, when reviewing the radiographs, we were not blind to the study objectives, possibly increasing our sensitivity in the evaluation of the LTO site. An additional limitation was that consensus was achieved by the reviewing orthopedic surgeon and musculoskeletal radiologist at a single interpretive session rather than at separate independent sessions. Finally, all of the patients were derived from one surgeon’s practice, and although they were selected consecutively for this study, only those patients with appropriate postoperative imaging were included, possibly introducing some bias between those patients who were and were not included in the study.

Although 183 of 220 of radiographs did provide adequate LTO visualization, the potential information from the other 37 cases would have enhanced the power of our study. Secondary to radiographic technique, nearly one-fifth of the obtained radiographs failed to help answer our clinical question. In cases where there is a concern for LTO healing and initial radiographs do not adequately show the LTO site, clinicians may consider CT for further evaluation of healing and possible displacement.

Conclusions

Our study is the first retrospective study to evaluate and describe LTO healing from routine postoperative radiographs on a large number of total shoulder arthroplasty patients. In the postoperative evaluation of LTOs, obtaining appropriately positioned and high-quality radiographs to accurately assess the osteotomy site is of paramount importance. We believe that if initial radiographs are unrevealing and there is persistent suspicion of a nonhealed osteotomy, repeat radiographs or CT examination can be considered. If a patient cannot adequately tolerate the axillary position for plain radiographs, a CT examination might be the next best test. Our novel “half-moon” sign should add to confidence in the diagnosis of nonunion.

Finally, smoking cessation is a practice that should be discussed preoperatively with patients and strictly enforced to maximize LTO healing potential. In addition, younger and fitter patients, especially men, should be strongly advised to follow the rehabilitation protocols according to schedule and not return to active range of motion ahead of schedule.

Further clinical studies regarding the significance of a nondisplaced nonunion and a displaced nonunion are needed in the future to define the outcomes associated with these radiographic findings.

Disclaimer

The authors, their immediate families and any research foundation, with which they are affiliated,
References


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