How should I fixate the subscapularis in total shoulder arthroplasty? A systematic review of pertinent subscapularis repair biomechanics

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Abstract

Background: The present study aimed to review the biomechanical outcomes of subscapularis repair techniques during total shoulder arthroplasty (TSA) to assist in clinical decision making.

Methods: A systematic review of multiple databases was performed by searching PubMed, Scopus, Cochrane Library, Google Scholar, and all databases within EBSCOhost to find biomechanical studies of subscapularis repair techniques in cadaveric models of TSA.

Results: Nine studies met the inclusion criteria. In the majority of studies, lesser tuberosity osteotomy (LTO) techniques had greater load to failure and less cyclic displacement compared to subscapularis tenotomy or peel methods. LTO repairs with sutures wrapped around the humeral stem demonstrated superior biomechanical outcomes compared to techniques using only a tension band. In terms of load to failure, the strongest repair of any study was a dual-row fleck LTO using four sutures wrapped around the stem.

Conclusions: Several cadaveric studies have shown superior biomechanical outcomes with LTO techniques compared to tenotomy. In the majority of studies, the strongest subscapularis repair technique in terms of biomechanical outcomes is a compression LTO. Using three or more sutures wrapped around the implant and the addition of a tension suture may increase the biomechanical strength of the LTO repair.

Keywords

lesser tuberosity osteotomy, subscapularis, tenotomy, total shoulder arthroplasty

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Introduction

Total shoulder arthroplasty (TSA) is a surgical procedure performed for shoulder arthritis with an incidence of 12.68/100,000 in 2010.¹ It is estimated that the incidence of TSA is increasing at a rate between 7% to 13% per year,^{1,2} and TSA has been proven to be an effective procedure for decreasing pain, increasing range of motion, and improving activities of daily living and quality of life.^{3,4} TSA produces good to excellent results 90% of the time.⁵ There are multiple reasons that a patient can have suboptimal results, including malposition and sizing of the components or failed subscapularis repair.^{6–12}

During a TSA, the subscapularis is often mobilized to obtain access to the glenohumeral joint, although subscapularis sparing techniques have been described recently with variable outcomes.^{13,14} Subscapularis

mobilization is traditionally performed by three main techniques, including subscapularis tenotomy, direct dissection of the subscapularis tendon from the bone (peel) or a lesser tuberosity osteotomy (LTO). Subscapularis repair failure rates have been reported between 13% and 47%, with greater than 60% of failures having subscapularis dysfunction.^{9,15,16} This dysfunction leads to reduced long-term stability of the

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Figure 1. (a) Completed subscapularis tenotomy repair.²¹ (b) Subscapularis peel repair with transosseous tunnels.²⁴ (c) Combined tendon-to-bone/tendon subscapularis repair.²⁴ (d) Single-row lesser tuberosity osteotomy.²² (e) Backpack technique.²² (f) Dual-row technique.²⁶

glenoid component as a result of anterior destabilization and the rocking horse effect.¹⁷

DeFranco et al.¹⁸ reviewed subscapularis management in open shoulder surgery and concluded that LTO may allow a biological advantage of stronger bone-to-bone healing. The purpose of this systematic review is to describe the techniques and fixation methods to repair the subscapularis tendon after TSA and to determine which technique and fixation methods have superior biomechanical stability. It was hypothesized that techniques utilizing LTO are biomechanically superior to tenotomy or peel.

Materials and Methods

A systematic review of multiple databases was performed to find articles published between 1990 and October 2015. PubMed, Scopus, Cochrane Library, Google Scholar and all databases within EBSCOhost were searched using various combinations of the keywords ‘subscapularis’, ‘shoulder arthroplasty’, ‘osteotomy’ and ‘tenotomy’. Inclusion criteria were cavaderic studies published in English describing biomechanical techniques to investigate the strength of a repaired subscapularis tendon after simulated TSA. Exclusion criteria included non-English publications. Because biomechanical testing protocols were not uniform across studies, a meta-analysis was not performed.

Tendon-to-tendon

Subscapularis tenotomy is a common method for accessing the glenohumeral joint during total shoulder arthroplasty, although recently it has been shown to be associated with abnormal biokinetics and postoperative subscapularis rupture.¹⁹ Subscapularis tenotomy is

usually performed 1 cm medial to its insertion on the lesser tuberosity perpendicular to the muscle fibres (Fig. 1a).^{19–23} Five studies^{19–23} were identified that tested the biomechanics of tenotomy repair. These studies used a variety of techniques to repair the tenotomy, including four sutures tied in a modified Mason-Allen configuration,^{19,20,22} eight sutures in a figure-of-eight fashion,²¹ or four sutures in a horizontal mattress configuration.²³

Tendon-to-bone

In the tendon-to-bone technique, the subscapularis is released periosteally or subperiosteally off the lesser tuberosity – referred to as a ‘subscapularis peel’ (Fig. 1b). Three studies^{22,24,25} were identified that tested the biomechanics of the tendon-to-bone repair. To perform the repair, four drill holes are placed approximately 5 mm to 8 mm from the edge of the humeral cut, with the most lateral hole adjacent to the bicipital groove in the subscapularis footprint. Suture is placed through the drill holes, and after the prosthesis is inserted, the tendon is repaired with a modified Mason-Allen technique.

Tendon-to-bone/tendon combination

The subscapularis tenotomy procedure can be augmented with a combined tendon-to-bone/tendon approach (Fig. 1c).^{24,25} The standard tenotomy is performed and drill holes are placed laterally to the subscapularis soft tissue stump. To repair the tendon, sutures are passed through drill holes, through the tendon, and tied in a Mason-Allen configuration. Separate sutures are then placed side-to-side on the stump and the subscapularis muscle side of the tendon.

Lesser tuberosity osteotomy

Lesser tuberosity osteotomy has been popular as a result of bone healing rather than soft tissue healing (Fig. 1d). In the LTO technique, a fragment of the lesser tuberosity (with the subscapularis attached) is removed from the humerus to allow for visualization and access of the joint. Eight studies^{19–23,25–27} were identified that tested the repair biomechanics of LTO.

Osteotomy size

The size of the osteotomy in LTO repairs may play a role in the biomechanical strength of subscapularis repair. Two studies^{20,27} were found that studied the thickness of the LTO and its biomechanical implications. Thick osteotomies were defined as fragments comprising 100% of the lesser tuberosity height and thin osteotomies comprising 50% of this height.^{20,27} In a study by Schmidt et al.,²⁷ a significantly greater number of thin repair sites remained intact during load-to-failure testing. The thin repairs also had less initial displacement during testing. There were no significant differences in load to failure testing in a study by Fishman et al.²⁰ The difference in results between the two studies can possibly be attributed to different fixation methods used (see Discussion).

Compression

A compression suture, in which the suture completely encircles the lesser tuberosity bone piece, can be used to re-attach the lesser tuberosity. Five studies^{19–22,27} were found that investigated the strength of this method. Two studies^{21,22} used the same method, in which they drilled two parallel rows of holes, one each on the medial and lateral sides of the osteotomy site. A suture was then passed in the lateral side, around the implant, and out the medial side before being passed through the tendon and tied. Krishnan et al.¹⁹ used the same general principle but passed the suture through the tendon first before passing it transosseously through the osteotomy site, and then out the lateral aspect of the bicipital groove before being tied. Fishman et al.²⁰ tested two compression techniques. In the first technique, five drill holes were drilled lateral to the bicipital groove before passing suture through the lateral hole, around the implant stem, out the medial aspect of the osteotomy, and then through the tendon before being tied. In the middle hole, a titanium cable was used instead of a suture. The second technique of Fishman et al.²⁰ was similar, although only two sutures were used to secure the lesser tuberosity. The compression technique of Schmidt et al.²⁷ was performed by drilling two holes lateral to the bicipital groove and two holes medial to the osteotomy.

A suture was then placed through the lateral holes, around the implant, out the medial holes, and through the tendon before tying the sutures.

Tension

Another method to re-attach the lesser tuberosity is a tension technique, which uses a suture through the humerus and out the greater tuberosity where it is fixed (Fig. 1e). Four studies^{23,25,26,28} were found that investigated the tension technique. Three studies^{23,25,26} used the technique described by Gerber et al.,²⁸ in which four 2-mm holes are drilled 1 cm apart on the medial aspect of the bicipital groove and out the greater tuberosity and then the LTO is performed. After the implant is placed, a suture is placed transosseously through one hole, then a horizontal mattress suture is placed superficial-to-deep through the tendon at the bone–tendon junction. The suture is then passed through the bone tunnel adjacent to the starting drill hole and is tied around a base plate. Another suture is placed through the remaining two holes. This technique creates a tension effect that keeps the lesser tuberosity fragment apposed against the pull of the subscapularis.

Schmidt et al.²⁷ tested a combination of both the tension and compression techniques. This technique was comprised of the standard compression technique with one tension suture.²⁷

Dual-row

Three studies^{19,20,26} were found that examined the dual-row or Corn-Row repair technique (Fig. 1f). A medial and lateral row of sutures are used. The lateral row is similar to the single-row compression technique mentioned above. This lateral row is created by passing a suture through the subscapularis tendon at the bone–tendon junction, then passed transosseously through the osteotomy bed from the medial to lateral side, exiting the bone just medial to the bicipital groove. The suture does not encircle the humeral component. The suture is then tied to secure the lesser tuberosity. To create the medial row, four sutures are passed transosseously parallel to the humeral head cut. These sutures enter the cortex of the humerus and exit through the cut surface of the humeral head. They are then passed through the capsulotendinous subscapularis unit in a horizontal mattress fashion at the point where it is in contact with the humeral head cut.

Biomechanical testing protocols

Two studies^{20,24} followed the same testing protocol. The shoulder specimen was preloaded to a 5-N tare load for 1 minute, and subsequently subjected to a

series of increasing cyclic loads for 40 cycles at 0.25 Hz. The amplitude of the loading was increased in 25-N increments until a maximum load of 250 N or until failure occurred. If the specimen had not failed at 330 N, the specimen was held at 5 N for 1 minute, and then a constant ramp displacement of 1 mm/s was applied until gross failure.

One study²⁶ preloaded specimens to 10 N and then subjected them to cyclic loading of 180 N at a rate of 1 Hz for 500 cycles. Following cyclic testing, each specimen was held at 10 N for 10 s and then loaded to complete failure at a rate of 1 mm/s.

Three studies^{21,22,27} loaded specimens cyclically to 100 N at a rate of 1 Hz for 3000 cycles. The specimens that remained intact after cyclic loading were subjected to maximum load to failure testing, loading specimens at a rate of 33 mm/s.

One study²³ preloaded specimens to 10 N. Each specimen was initially tested at 150 N for 500 cycles, and then at 300 N for 1500 cycles. If specimens did not fail by 3000 cycles, loading of the specimen was stopped and it was concluded that failure would be unlikely. One study²⁵ preloaded shoulder specimens to 10 N for 1 minute, loaded for 150 cycles from 10 N to 100 N at 0.5 Hz, and finally pulled to failure at 1 mm/s.

Results

Tenotomy

Van den Berghe et al.²³ compared the tendon-to-tendon (TT) and tendon-to-bone (TB) tenotomy techniques

with an LTO tension repair (Table 1). They found TB to have a higher rate of failure compared to LTO tension when testing cycles to fatigue ($p=0.02$). They reported no difference when comparing TT with TB ($p=0.24$) or LTO ($p=0.46$) tension repairs. In addition to cycles to fatigue, they measured the length change during repair. The TT had a mean shortening of 5.3 mm and the TB had a mean lengthening of 2.6 mm ($p=0.02$). The LTO repair had no length change.

Ponce et al.²² compared the TT, TB and LTO-compression repairs. The TB repairs had a mean (SD) displacement of 2.11 (1.41) mm and maximum load to failure of 506 (175) N, whereas the TT repairs had a mean (SD) displacement of 2.72 (1.24) mm and maximum load to failure of 334 (88) N (Fig. 2). The LTO-compression repairs had a mean (SD) displacement of 0.88 (0.54) mm, which was significantly less compared to both TT ($p<0.001$) and TB repairs ($p=0.02$). The mean (SD) load to failure of LTO-compression repairs was 738 (261) N, which was significantly greater compared to both TT ($p<0.001$) and TB repairs ($p=0.04$).

Giuseffi et al.²¹ compared TT and LTO-compression repairs. There was no difference in maximum load to failure [439 (96) N and 447 (89) N, respectively]; however, the TT repair showed significantly less cyclic displacement [0.8 (0.2) mm] compared to the LTO-compression repair [1.8 (0.6) mm, $p=0.002$].

Fishman et al.²⁰ compared TT, dual-row LTO, LTO-compression with #5 Fiberwire (Arthrex, Naples, FL, USA) and LTO compression with a titanium cable. All four techniques had no significant

Table 1. Biomechanical testing of different subscapularis mobilization and repair techniques after total shoulder arthroplasty in cadaveric studies

Study	Techniques compared	Outcomes measured
Ahmad et al. ²⁴	TB, TT + bone tunnel	Load to failure, cyclic displacement
Fishman et al. ²⁰	TT, LTO-dual row, LTO-compression, LTO compression + titanium cable	Load to failure, cyclic displacement
Giuseffi et al. ²¹	TT, LTO-compression	Load to failure, cyclic displacement
Heckman et al. ²⁶	LTO-dual row, LTO-tension	Load to failure, cyclic displacement
Krishnan et al. ¹⁹	TT, LTO-single row, LTO-dual row	Load to failure
Ponce et al. ²²	TT, TB, LTO-compression	Load to failure, cyclic displacement
Schmidt et al. ²⁷	LTO-thin, LTO-thick, LTO compression, LTO compression + tension	Load to failure, cyclic displacement
Van den Berghe et al. ²³	TT, TB, LTO-tension	Cyclic displacement
Van Thiel et al. ²⁵	TB, TT + bone tunnel, LTO-tension	Load to failure, cyclic displacement

TB, tendon-to-bone; TT, tendon-to-tendon; LTO, lesser tuberosity osteotomy.

Figure 2. Load to failure after various subscapularis repair techniques. TB, tendon-to-bone; TT, tendon-to-tendon; LTO, lesser tuberosity osteotomy. *Statistical significance within the study. In the study by Krishnan et al.,¹⁹ both the LTO-single- and dual-row repairs were statistically stronger in terms of load to failure compared to TT, with no difference between the LTO repairs. In the study by Ponce et al.,²² the LTO-compression repair was statistically stronger than both the TT and TB repairs. One study²⁶ did not report SDs.

difference in load to failure, although the LTO-compression group had the greatest ultimate failure load [405 (118) N]. The TT repair displayed significantly greater gapping than the LTO repairs.

Krishnan et al.¹⁹ tested TT, LTO-single row and LTO-dual row by load to failure. Both the single-row (430 N) and dual-row LTO (466 N) techniques were significantly stronger than the TT technique (252 N) (both $p=0.04$). No difference was found between the dual-row or single-row LTO techniques.

Lesser tuberosity osteotomy

Van Thiel et al.²⁵ compared TB, a combination TT with bone tunnel, and LTO-tension repairs. The LTO-tension repair had less cyclic displacement, greater load to failure and greater stiffness compared to the other two techniques, although this was not statistically significant.

Schmidt et al.²⁷ tested both thick and thin LTO techniques, as well as compression and compression/tension repairs. The mean (SD) initial displacement was less in the thin LTO-compression group [5.1 (2.7) mm] compared to the thick LTO [9.9 (4.9) mm], although, when the tension band was added, this difference was negated. Combination tension band/compression repairs had less total cyclic displacement (mean 3.5 mm) compared to compression-only repairs (mean 7.5 mm) ($p=0.024$). There were no significant differences when comparing load to failure for the four constructs. When comparing thick with thin, the thin LTO had more sites remaining intact during load to failure testing. It was concluded the ideal repair is a thin LTO with a compression/tension repair.

Heckman et al.²⁶ tested LTO-tension repair and LTO-dual-row repair. The tension repair had significantly greater initial displacement as well as a lower ultimate tensile strength (6.9 mm and 511 N) compared to the dual-row repair (4.6 mm and 632 N) ($p=0.007$ and 0.01, respectively).

Among the various LTO techniques, repairs with sutures wrapped around the humeral stem^{19–22,27} demonstrated superior biomechanical outcomes than techniques using only a tension band.^{23,25,26} Studies did not directly compare the number of sutures, although techniques with three or four sutures^{19–22,26}, on average, had a greater load to failure by 39% than techniques using two sutures.^{20,25,27} Techniques using #5 suture^{19,20,22,25} had a greater mean load to failure by 28% compared to techniques using #2 suture.^{20,21,26,27} Cyclic displacement was significantly lower with a thin bony osteotomy (50% of lesser tuberosity height; 4.3-mm displacement) compared to a thick osteotomy (100% of lesser tuberosity height; 6.7-mm displacement) ($p=0.011$).²⁷ In terms of ultimate load to failure, the strongest repair of any study was a dual-row fleck LTO using four sutures wrapped around the stem [738 (261) N].²²

Tendon-to-bone

Ahmad et al.²⁴ compared TB and a combination TT with bone tunnel. The combined repair technique required a significantly greater number of cycles to reach a 1-mm gap (56 versus 16 cycles, $p<0.001$), 3-mm gap (119 versus 47 cycles, $p<0.01$) and 5-mm gap (206 versus 47 cycles, $p<0.01$) compared to the TB technique. There was no significant difference in

load to failure between groups, although the combination group had a lower load to failure, on average, compared to the TB group [280 (168) N and 448 (191) N, respectively].

Discussion

In most of the studies reviewed, the strongest, most durable subscapularis mobilization and repair technique was the lesser tuberosity osteotomy. Bone-to-bone fixation improves factors such as suture pull-out strength and gapping. A previous meta-analysis comparing the biomechanical properties of subscapularis tenotomy with single- or dual-row LTO in cadavers determined that LTO techniques result in a significantly higher ultimate load to failure at a 'time zero' analysis.²⁹ Within the LTO technique, there have been many surgical adaptations and innovations in an attempt to improve the procedure. Subscapularis tendon repair must be able to withstand the maximal force of contraction of the subscapularis muscle, which is approximately 250 N and equal to the three other rotator cuff muscles combined.¹⁸ In the study by Fishman et al.,²⁰ the tenotomy, fleck LTO, cable LTO and two-suture LTO were compared. Tenotomy repair had the lowest load to failure of the four repairs, although it was still 300 N and well above the maximal force of contraction of the subscapularis muscle. However, subscapularis failure is typically associated with chronic, repetitive movements of smaller loads (cyclic loading) as opposed to a single large force event.²⁹ Because each repair can sustain loads greater than the maximal force of contraction of the subscapularis muscle, the more clinically applicable biomechanical test may be cyclic displacement.

The 'ideal' amount of bone fleck is not clearly defined. Several studies employing the LTO approach have used a small bony fragment similar to the anatomic footprint of the subscapularis. Displacement of the bone fleck could interfere with healing and result in a decreased strength or motion if it alters the length-tension relationship. Budge et al.³⁰ hypothesized that a larger LTO fragment would have better biomechanical properties as a result of more reliable bone-to-bone healing because of a decreased possibility of bony resorption, rigid internal fixation of the fragment and enhanced glenoid exposure. The ideal thickness of the osteotomy wafer is also controversial. Gerber et al.²⁸ recommended a thickness of 5 mm to 10 mm. Ponce et al.²² noted that one subscapularis repair failure in their study was a result of too thin a wafer. One study²⁷ investigated LTO size and found inferior outcomes with a thick LTO. Furthermore, a thick osteotomy also presents the risk of disrupting the integrity of the humeral cortex and metaphysis, especially in the

setting of a press-fit humeral implant. This could result in an unstable implant or a fracture of the proximal humerus.

Postoperative protocols and the recovery timeline for TSA are partly determinant on soft tissue healing of subscapularis tenotomy or bone healing following LTO and typically include early passive motion and range of motion exercises with gradual progression to resistance exercises.^{5,9,13} Biomechanical failure of subscapularis tenotomy and LTO is mostly through soft tissue and bone failure, respectively, and not through suture failure.²⁹ Utilizing the biomechanically strongest subscapularis mobilization and repair technique may reduce unnecessary complications associated with weaker constructs during this period of healing.

There are limitations to the present study. A meta-analysis of load to failure and cyclic displacement data for similar subscapularis repair techniques was not possible because of the heterogeneity in biomechanical testing protocols. In addition, no studies directly compared repair strength by number or type of sutures or suture configuration. Given the variations in testing protocols, future biomechanical studies should attempt to standardize testing.

Based on the available data reported in this systematic review, biomechanical outcomes are superior following total shoulder arthroplasty with a lesser tuberosity osteotomy in the majority of studies. Using a thin bony wafer and combination of compression and tension repair with three or more sutures wrapped around the humeral implant may improve the biomechanical strength of an LTO repair. Future research is necessary to determine whether differences in clinical outcomes and failure rates are affected by the utilization of these various subscapularis repair techniques in the clinical setting.

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Ethical Review and Patient Consent

No ethical approval was necessary for this review.

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