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BIOMECHANICAL AND CLINICAL EVALUATION OF A NOVEL LESSER TUBEROSITY REPAIR TECHNIQUE IN TOTAL SHOULDER ARTHROPLASTY

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Introduction

As with arthroplasty of other large joints, shoulder replacement reliably improves a patient's quality of life[1-8]. However, although shoulder replacement is frequently successful, complications do occur[9-15]. Injury to the subscapularis can lead to weakness, decreased motion and stability, and diminished satisfaction following shoulder arthroplasty. Compromise or dysfunction of the subscapularis resulting from routine division and repair during the arthroplasty is a complication that is being recognized more frequently[16,17]. Subscapularis dysfunction may lead to a loss of active terminal internal rotation with an abnormal belly-press or lift-off test or the inability to perform a shirt-tuck test[18]. In a recent study, >65% of patients had subscapularis dysfunction following shoulder arthroplasty with a soft-tissue subscapularis repair[17].

While dysfunction is sometimes subtle, resulting in minor functional disabilities, rupture of the subscapularis is a devastating problem that can lead to gross anterior instability. Anterior instability following arthroplasty is typically secondary to rupture of the repaired subscapularis[13,19]. Reported rates of subscapularis rupture following primary arthroplasty have ranged from 3% to 11%[19-22]. Instability is the most frequent complication following shoulder arthroplasty and is the most common indication for revision surgery[9,11,19,23-25]. While the etiology of instability is often multifactorial, the greatest cause is soft-tissue imbalance[13,19,24,26,27].

In order to strengthen our subscapularis repairs and to prevent rupture, we have been performing a lesser tuberosity osteotomy to reflect the subscapularis and expose the joint in shoulder arthroplasties. The lesser tuberosity osteotomy does not violate the subscapularis tendon, and its repair provides a strong, secure closure that allows bone-healing. The strength of the repair is due to the combination of osseous fixation and the passage of nonabsorbable sutures behind the implanted prosthesis. Furthermore, the integrity of the repair can easily be assessed on standard axillary radiographs[28]. If the lesser tuberosity fragment is noted to be in the proper position, then disruption is unlikely.

We hypothesized that the lesser tuberosity osteotomy repair would (1) be stronger than other types of repairs used in shoulder arthroplasty and (2) decrease the risk of subscapularis rupture and dysfunction in patients treated with total shoulder arthroplasty.

In this paper, we will first describe the technique of the lesser tuberosity osteotomy and its repair. Second, we will present the results of biomechanical testing of three subscapularis repairs, including the one involving the lesser tuberosity osteotomy. Finally, we will report the clinical results in a consecutive series of patients who underwent total shoulder with a lesser tuberosity osteotomy and repair.

Materials and Methods

Technique of the Lesser Tuberosity Osteotomy Repair

A deltopectoral approach is used to provide routine exposure of the anterior aspect of the shoulder. Once the cephalic vein is mobilized, the biceps tendon is identified within its groove and the bicipital sheath is incised vertically. The biceps tendon is tenotomized and tagged at the level of the superior border of the pectoralis major tendon for tenodesis during final closure. With use of heavy scissors, the rotator interval is incised and the coracohumeral ligament is cut. Caution is taken to preserve the coracoacromial ligament. With the arm in external rotation, the anterior humeral circumflex vessels are identified and are cauterized below the inferior portion of the subscapularis. The lesser tuberosity is osteotomized with use of a 0.5-in (1.3-cm) curved osteotome placed in the bicipital groove. The goal is to remove a 2.5 cm^2, 4 to 5-mm-thick wafer of the lesser tuberosity (Figs. 1-A and 1-B). This size of tuberosity fragment mirrors the mean surface area of the subscapularis insertion onto the lesser tuberosity[29].

The lesser tuberosity wafer with the attached subscapularis is provisionally tagged with two sutures. The axillary nerve is identified, and the subscapularis is mobilized medially while the axillary nerve is protected with a finger or a metal retractor. If external rotation was lacking preoperatively, a 360° soft-tissue release at this stage helps to restore motion without increasing tension, compromising the strength of the tendon, or changing the native mechanical axis[6,30].

The humeral head osteotomy is performed and the glenoid and the humeral canal are prepared in the standard fash-

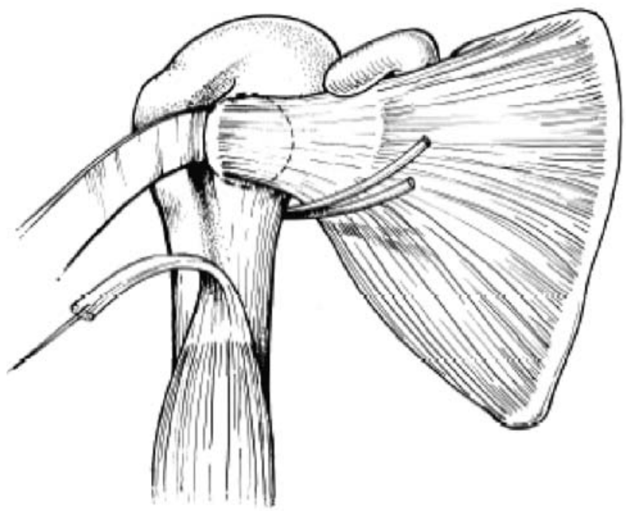

Fig. 1-A

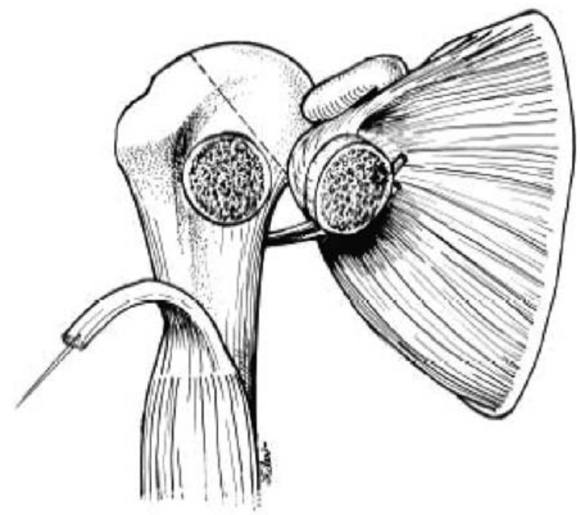

Fig. 1-B

Initiation (Fig. 1-A) and completion (Fig. 1-B) of the osteotomy of the lesser tuberosity with the attached subscapularis tendon. A 2.5-cm², 4 to 5-mm-thick osteotomy fragment is created.

ion. Before the humeral component is placed, a 2-mm drill-bit is used to create two parallel rows of three or four drill-holes each, with one row on each side of the osteotomy site (Fig. 2). Since the goal is a strong repair, a number-5 FiberWire suture (Arthrex, Naples, Florida) is passed transosseously into the lateral hole and out the medial hole of each set of drill-holes, with a bridge of suture lying within the humeral canal. A small clamp is placed on each pair of sutures to avoid tangling. The implant is then inserted in front of the suture bridges so that the sutures encircle the stem of the humeral implant (Figs. 3-A and 3-B). Just prior to terminal insertion of the stem, the four sets of sutures are pulled tight to remove excess slack and capture the prosthesis. The stem is then completely inserted. The sutures are tightened again to remove any residual redundancy. If cement is used, it is best to wait until it is hard before reattaching the osteotomy fragment. This technique ensures that each suture passes through bone twice and is looped around the stem within the medullary canal. Unless the suture breaks or breaks through the osteotomy site, it is virtually impossible for it to cut out.

The lesser tuberosity with the attached subscapularis is first reduced back to the humerus in its original anatomic position with a simple suture and then is secured by tying the three remaining sutures with use of a modified Mason-Allen technique (Fig. 4). The first suture is tied with the arm in neutral rotation to facilitate the reduction of the osteotomy fragment. The remaining sutures are then tied with the arm in 30° of external rotation to avoid overreduction of the osteotomy. If it is determined that external rotation continues to be substantially limited following the circumferential subscapularis releases, the lesser tuberosity osteotomy fragment may be placed medially in a prepared denuded cortical bed to allow increased external rotation. The rotator interval is closed with heavy nonabsorbable suture. The long head of the biceps tendon is then tenodesed to the inferior portion of the subscapularis or the superior edge of the pectoralis. The range of motion and the stability of the repair should then be assessed. The surgical closure is completed in a routine fashion.

There are several variations of the lesser tuberosity osteotomy that can be used while still adhering to the principles of an osteotomy wafer secured with sutures placed around the stem of the humeral prosthesis. Some of the challenge of passing sutures from within the humeral canal to the medial side of the osteotomy site can be lessened by using a single column of drill-holes just lateral to the osteotomy site. A secure closure

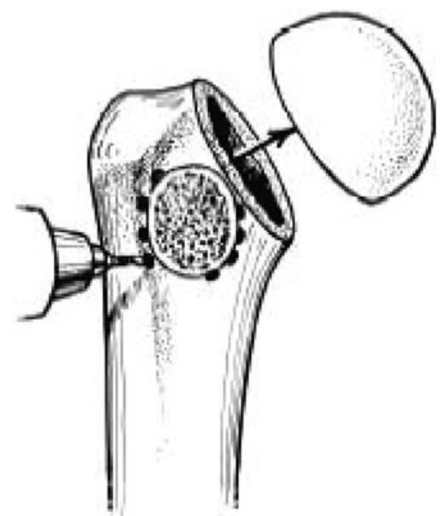

Fig. 2

Following removal of the humeral head and preparation of the humeral canal, two parallel rows of three or four suture drill-holes each are made, with one lateral and one medial to the osteotomy site. Note that the superiormost sutures may be passed through a single lateral drill-hole since the location for the medial drill-hole may have been removed by the humeral head osteotomy.

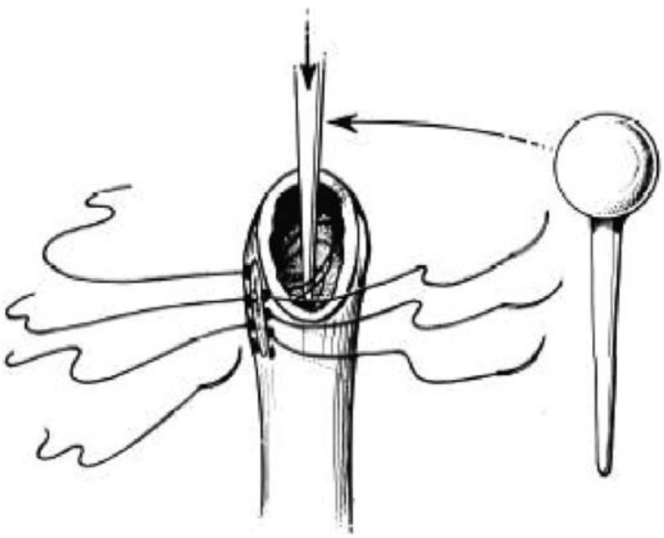

Fig. 3-A

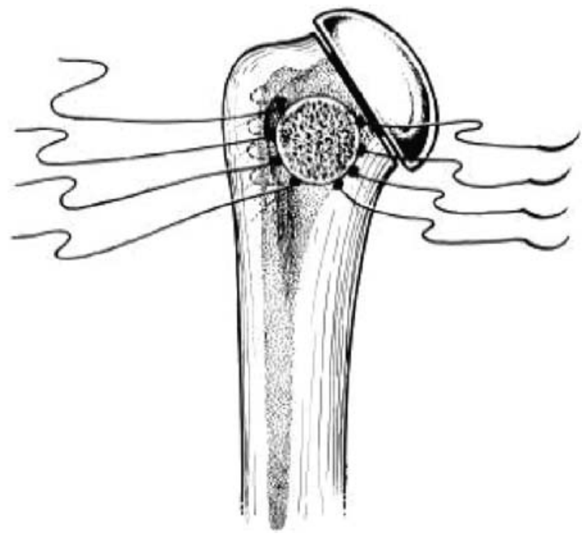

Fig. 3-B

Figs. 3-A and 3-B After the sutures have been placed, the humeral prosthesis is inserted with the sutures lying behind it. **Fig. 3-A** Lateral view. **Fig. 3-B** Anteroposterior view.

is then obtained by wrapping the sutures around the neck of the humeral prosthesis before capturing the subscapularis and osteotomy fragment (Fig. 5). Another variation, originally described by Gerber (personal communication, 1999), is to place a button-plate over the osteotomy wafer during the repair to reduce the likelihood of the suture cutting through the bone and the bone-tendon junction and to make it easier to identify the lesser tuberosity osteotomy repair on an axillary radiograph. Yet another variation, used in smaller shoulders, is to employ three drill-holes and sutures rather than four. This still allows a rigid repair and lessens the potential for confusion, which sometimes occurs with four sets of sutures.

Biomechanical Testing

The lesser tuberosity osteotomy repair as well as two other, commonly used subscapularis repairs were tested biomechanically. The first repair, following release of the subscapularis tendon from the lesser tuberosity, was done with transosseous sutures[31]. The second repair was a soft-tissue repair following subscapularis release 1 cm medial to its insertion onto the lesser tuberosity[31]. The third repair was the lesser tuberosity osteotomy repair described above, with the sutures passed around the implant and over the osteotomy site. The humeral prosthesis of the Anatomical Shoulder System (Zimmer, Warsaw, Indiana), inserted with cement, was used for the testing. Each repair was secured with four number-5 FiberWire sutures with use of Mason-Allen stitches. Twenty-seven specimens without a subscapularis defect—nine for each repair technique—were tested.

To test the repairs, the humerus was cut approximately 10 cm distal to the inferior articular surface, potted in standard epoxy, and installed in a custom vise mounted to the base of a servohydraulic materials testing system (MTS Systems, Eden Prairie, Minnesota). The position of the shoulder during testing simulated 45° of abduction in neutral rotation with the line of pull at 135° to the axis of the humerus, allowing the subscapularis repair to be stressed in line with its muscle-tendon axis[32,33]. Once the humerus was positioned, the free subscapularis muscle was secured tightly in a pneumatic clamp attached to the actuator of the materials testing system.

The testing parameters for this study were derived from supraspinatus testing, as we are unaware of any previously reported parameters for subscapularis testing. Each specimen was loaded cyclically to 100 N at a rate of 1 Hz for 3000 cycles. The force of 100 N was based on the expected passive internal rotation contraction force of the supraspinatus during the early postoperative period after a shoulder arthroplasty[34]. This value is approximately one-third of the expected maximum contraction force as estimated by Burkhart et al.[35] on the basis of the maximum contraction of the supraspinatus determined on the basis of cross-sectional area. The number of cycles was based on seventy repetitions a day for six weeks, a reasonable estimate of physical therapy during the early postoperative period.

Cyclic displacement was measured with use of a 9-mm differential variable reluctance transducer (DVRT; MicroStrain, Burlington, Vermont). Following the 3000 cycles, the specimens were tested to determine their maximum load to failure. The loading rate of 33 mm/sec was based on a previous study demonstrating this to be the rate "that occurs in normal daily activities."[36] The mechanism of failure was recorded for each specimen that was tested.

The values obtained for cyclic displacement and maximum load to failure for each repair were analyzed with a Tukey post hoc test and analysis of variance with use of JMP software (version 4.0, SAS Institute, Cary, North Carolina) to determine significance. The significance level was set at $p < 0.05$ for all tests.

Clinical Evaluation

Following approval by our institutional review board, we reviewed the clinical results of a consecutive series of total shoulder arthroplasties, performed by the senior authors (J.J.P.W. and P.J.M.), in which the lesser tuberosity osteotomy repair was used. Exclusion criteria included a prior shoulder arthroplasty, known subscapularis injury, rheumatoid arthritis, or an immediate postoperative infection. Patients' records were reviewed for evidence of subscapularis rupture and dysfunction. Dysfunction was defined as an inability to achieve terminal internal rotation with an abnormal belly-press or lift-off test or an inability to perform a shirt-tuck test. Patients who did not have documented evaluation of subscapularis function with a belly-press or lift-off test were contacted by telephone and asked whether they had difficulty tucking their shirt into the back of their pants, as this test has been shown to be highly specific for subscapularis dysfunction[17]. Rupture was defined as nonunion of the lesser tuberosity or dislocation of the prosthesis as seen on an axillary radiograph. All radiographs were assessed by an independent reviewer.

Results

Biomechanical Testing

Following the transosseous repairs, there was an average (and standard deviation) of 2.11 ± 1.41 mm (range, 0.53 to 4.89 mm) of displacement with cyclic loading and the maximum load to failure averaged 506 ± 175 N (range, 209 to 784 N). The mechanism of failure was the suture cutting through

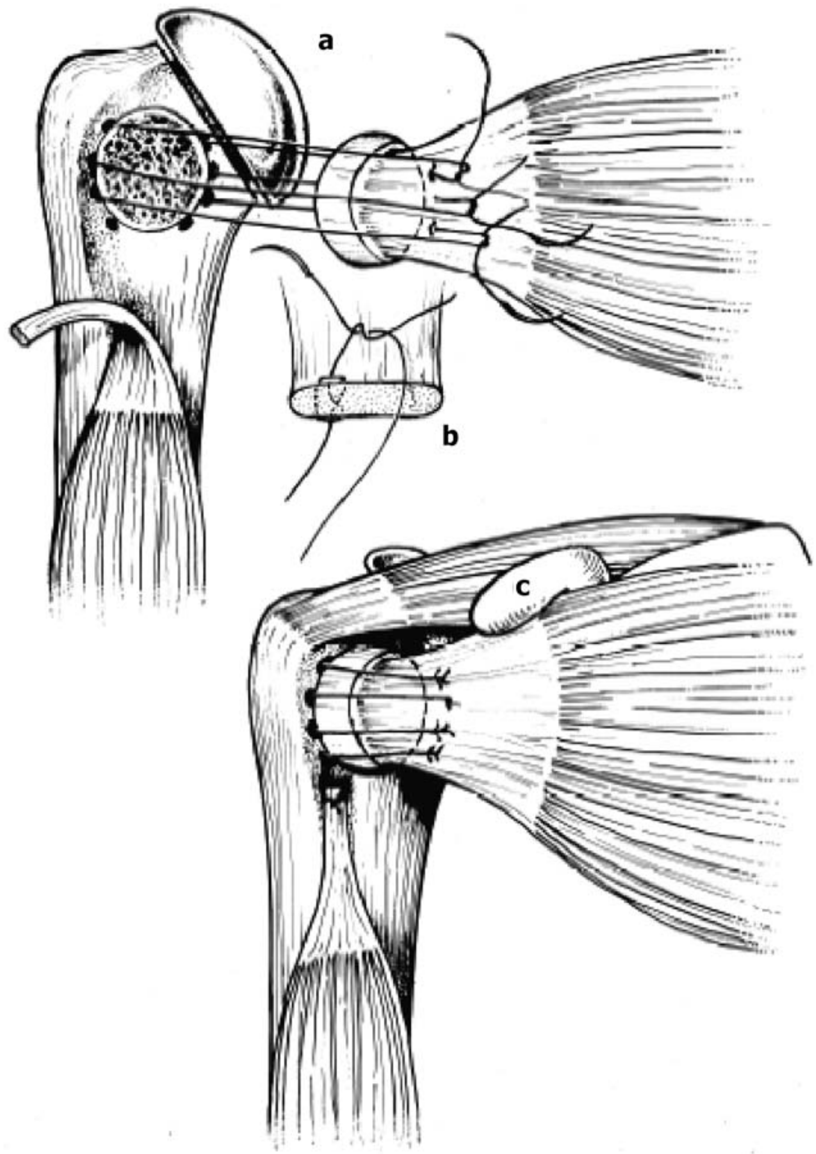

Fig. 4

Securing of the lesser tuberosity osteotomy fragment with a single simple suture is followed by placement of modified Mason-Allen sutures medial to the osteotomy wafer. a = Anteroposterior view of placement of the sutures. b = Mason-Allen suture. c = Finished repair.

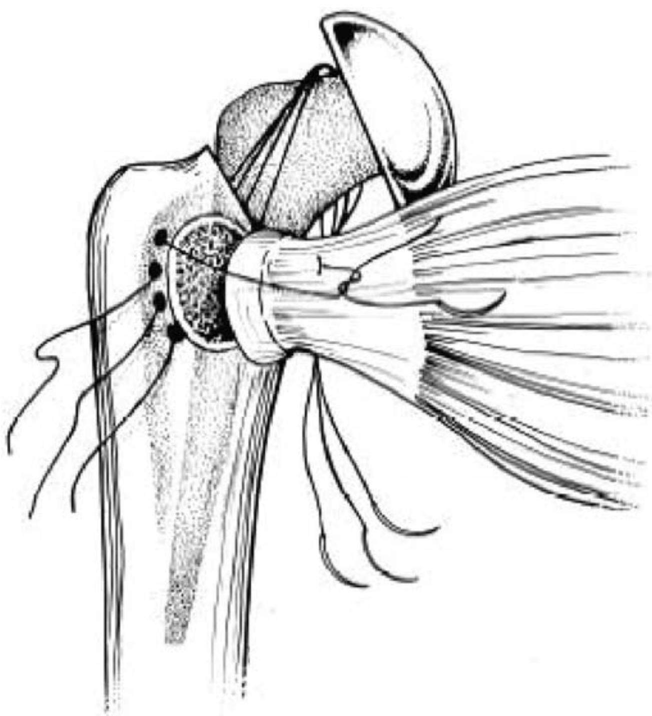

Fig. 5
An alternative method for the lesser tuberosity osteotomy repair. A single lateral row of drill-holes is used, with passage of the sutures around the neck of the prosthesis and capturing of the osteotomy fragment with Mason-Allen sutures.

the tendon in all but one case, in which the suture cut through the bone.

Testing of the soft-tissue repairs demonstrated an average of 2.72 ± 1.24 mm (range, 0.96 to 5.4 mm) of displacement with cyclic loading and an average maximum load to failure of 334 ± 88 N (range, 204 to 491 N). The mechanism of failure was always the suture cutting through the tendon.

After the lesser tuberosity osteotomy repairs, there was an average of 0.88 ± 0.54 mm (range, 0.08 to 1.8 mm) of displacement with cyclic loading and the maximum load to failure averaged 738 ± 261 N (range, 330 to 1125 N). The mechanism of failure was the suture breaking through the osteotomy wafer in all but two cases, in which the suture cut through at the bone-tendon junction and resulted in avulsion of the tendon. Those two cases had the lowest maximum loads to failure (330 and 356 N) in the group, in which the next lowest maximum load to failure was >700 N.

The displacement under cyclic loading after the lesser tuberosity osteotomy repair differed significantly from that after both the transosseous repair (p = 0.02) and the soft-tissue repair (p = 0.0009). The maximum load to failure after the lesser tuberosity osteotomy repair also differed significantly from that after both the transosseous repair (p = 0.04) and the soft-tissue repair (p = 0.0004). There was no association between sex, age, or bone mineral density of the specimen and cyclic displacement or load to failure. The results of the biomechanical testing are summarized in Table I.

Clinical Evaluation

Between June 2000 and July 2003, seventy-six consecutive patients who met the inclusion criteria were treated with a total shoulder arthroplasty by the two senior surgeons (J.J.P.W. and P.J.M.). There were forty-eight men and twenty-eight women with a mean age of 61.7 years. The average duration of follow-up was fifteen months. The preoperative diagnoses included osteoarthritis (sixty patients), posttraumatic arthritis (six), capsulorrhaphy arthropathy (seven), osteonecrosis (two), and synovial osteochondromatosis (one).

All seventy-six patients had preoperative subscapularis function, with normal results of the belly-press or lift-off test. Postoperative subscapularis function, as evaluated with a belly-press, lift-off, or shirt-tuck test, was normal in sixty-two patients, abnormal in five, and not documented in nine. Of the seven patients with a diagnosis of capsulorrhaphy arthropathy, six had normal subscapularis function and one did not have subscapularis function documented postoperatively. Radiographic evaluation demonstrated union of the osteotomy site in all seventy-six patients. However, the time to union could not be established accurately because of the wide variation in the timing of the postoperative radiographs and also because many patients had an anatomic reduction of the osteotomy site, which gave the appearance of union long before one should have occurred. The one patient who had clinical failure had had poor-quality soft tissues at the time of the index surgery. She did well initially and then had a deterioration in function. It remains unclear whether the osteotomy failed or the subscapularis ruptured secondarily. The clinical results are summarized in Table II.

TABLE I Results of Biomechanical Testing

Repair	Cyclic Displacement* *(mm)*	Difference Compared with Lesser Tuberosity Osteotomy Repair†	Maximum Load to Failure* *(N)*	Difference Compared with Lesser Tuberosity Osteotomy Repair†
Lesser tuberosity osteotomy	0.88 ± 0.54		738 ± 261	
Transosseous	2.11 ± 1.41	p = 0.02	506 ± 175	p = 0.04
Soft-tissue	2.72 ± 1.24	p = 0.0009	334 ± 88	p = 0.0004

*The values are given as the mean and standard deviation. †Both p values are significant.

TABLE II Clinical Results

Subscapularis Function	All Patients		Subset with Capsulorrhaphy Arthropathy	
	Preop.	Postop.	Preop.	Postop.
Normal	76	62	7	6
Abnormal	0	5	0	0
Dysfunction		5		
Rupture		1		
Not tested	0	9	0	1

Discussion

The subscapularis is the largest of the rotator cuff muscles, and it is critical for stability following shoulder arthroplasty. The contractile force of the subscapularis is equal to that of the other three rotator cuff muscles combined[37]. Routine surgical division and repair of the subscapularis is not a benign process and may result in dysfunction or rupture. Soft-tissue balance in shoulder arthroplasty is critical for stability and, therefore, success. Postoperatively, a balance should be achieved between stability of the subscapularis repair and early motion[38]. Limiting early motion because of concerns about the strength of the repair may lead to excessive scarring, stiffness, and dysfunction. However, an emphasis on early motion may compromise the subscapularis repair and lead to rupture and gross instability. To improve the quality of the subscapularis repair, one of the senior authors (J.J.P.W.) began routinely using the lesser tuberosity osteotomy repair in total shoulder arthroplasties in 1999, after introduction to the technique by Gerber et al.[13]. In 2002, the lesser tuberosity osteotomy repair was modified by one of us (P.J.M.), who placed the sutures around the stem. The goal of the lesser tuberosity osteotomy is to maximize the strength of the subscapularis repair without violating the subscapularis tendon.

In our study, the lesser tuberosity osteotomy repair proved to be more secure and stronger than both the transosseous and the soft-tissue repair, and the mechanism of failure revealed the weakness of each repair. The weakness of the transosseous repair was at the bone-tendon junction, where all but one of the specimens failed. The weak link in the soft-tissue repair was the tendon, as the mechanism of failure was always cutout of the suture through the repaired tendon even though Mason-Allen stitches had been used. All but two of the lesser tuberosity osteotomy repairs failed by the suture sawing through the lesser tuberosity osteotomy fragment. The progression from tendon to tendon-bone-interface to osseous failure for the three repairs is reflected in the increasing strengths of the repairs.

Subscapularis dysfunction resulting in loss of active end internal rotation is being recognized more frequently, with most cases being seen following a routine soft-tissue repair of the subscapularis[17]. In our series, 93% (sixty-two) of the sixty-seven patients treated with the lesser tuberosity osteotomy repair had subscapularis function at the time of short-term follow-up.

Rupture of the subscapularis repair is an infrequent and devastating complication following total shoulder arthroplasty. It has been attributed to poor surgical technique, poor tissue quality, use of an oversized component, lack of retroversion of the humeral head, and overly aggressive mobilization during rehabilitation[9-13]. In a review of the results of 236 shoulder arthroplasties, Moeckel et al. reported that seven (3%) were followed by anterior instability, always in association with postoperative rupture of the subscapularis repair, and required revision surgery[19].

There was a single rupture of the lesser tuberosity osteotomy repair in our clinical series, for a rupture rate of 1% (one of seventy-six). A review of the case of the patient with the rupture identified a thin fragmented osteotomy wafer, which probably compromised the strength of the repair. As a result, we recommend that, when the osteotomy fragment is thin or fragmented or severely osteopenic bone is encountered, a button-plate be used to augment the repair and prevent the sutures from cutting out.

It is yet to be proven whether our low rates of subscapularis dysfunction and rupture were directly due to the strength of the repair. Our results do support the trend noted by Miller et al.[17], who reported that improved subscapularis function was associated with a stronger repair, and we believe it reasonable to assume that a stronger subscapularis repair is responsible for superior subscapularis function.

We also believe that the low dysfunction and rupture rates in our series were related to the fact that we did not violate the subscapularis tendon and thus allowed early motion more safely. According to Gerber et al., an ideal tendon repair should satisfy three important criteria: (1) it should have a high initial fixation strength, (2) it should allow minimal gap formation at the interface, and (3) it should maintain mechanical stability until healing of the tendon to bone is complete[39]. The lesser tuberosity osteotomy repair appears to meet these criteria.

The frequency of subscapularis rupture in primary shoulder arthroplasty is even higher in patients with a history of anterior stabilization surgery, with rates ranging from 3% (one of thirty-one) to 11% (three of twenty-seven)[20-22]. Seven patients in the current series had had a previous subscapularis-splitting stabilization procedure. None of them had a rupture, and all six who were evaluated demonstrated subscapularis function. Therefore, we concluded that the lesser tuberosity osteotomy repair technique is safe, even in patients with prior subscapularis-splitting surgery.

This study had several weaknesses. First, the clinical evaluation comparing the three repair techniques was performed in a consecutive case series instead of a randomized trial. The need for a large number of patients in each group to identify a significant clinical difference was prohibitive. Second, the parameters for testing the subscapularis were derived from supraspinatus testing, as the ideal parameters for testing of the subscapularis are unknown. These parameters did, however, provide a consistent method with which all of the repairs were tested. Unfortunately, we did not record the thicknesses of our osteotomy wafers so that we could determine whether there is a critical thickness necessary to prevent the suture from cutting out and to achieve the highest maximum load to failure. The third weakness of the study was that only 88% (sixty-seven) of the seventy-six patients in the clinical study had documentation of postoperative subscapularis function. As was the case for the time to union of the osteotomy site, we could not accurately determine the time to the return of subscapularis function. These times are important for determining when to remove restrictions on external rotation and permit strengthening exercises to begin. We also did not evaluate preoperative and postoperative imaging studies to see if lesser tuberosity osteotomy repair of the subscapularis had an effect on fatty infiltration changes. Lastly, while the overall subscapularis function was excellent and there were no noticed trends for loss of external rotation, we did not critically measure preoperative and postoperative external rotation to identify any subtle changes.

The factors determining stability of a shoulder after arthroplasty are not fundamentally different from the factors involved in stabilizing a normal shoulder. If a balance between mobility and stability is reached, total shoulder arthroplasty will often result in nearly normal shoulder function[40]. Achieving articular conformity and proper version of the prosthesis in combination with the active stabilizing influence of the rotator cuff are critical steps. While the superior strength of the lesser tuberosity osteotomy repair and the excellent functional results in our study are encouraging, it is essential to understand that this particular subscapularis repair technique is only one important step in achieving a successful outcome of a total shoulder arthroplasty. ■

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