Rotator cuff repair: The effect of double-row fixation on three-dimensional repair site

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There is a high rate of recurrent and residual tears after rotator cuff repair surgery. Recent cadaveric studies have provided surgeons with new knowledge about the anatomy of the supraspinatus tendon insertion. Traditional repair techniques fail to reproduce the area of the supraspinatus insertion, or footprint, on the greater tuberosity anatomically. Double-row suture anchor (DRSA) fixation is a new technique that has been developed to restore the supraspinatus footprint better. In this study, 3-dimensional mapping was used to determine the area of the footprint recreated with 3 different repair methods: a transosseous simple suture technique, fixation with a single row of suture anchors, and DRSA fixation. The DRSA fixation technique consistently reproduced 100% of the original supraspinatus footprint, whereas the single-row suture anchor fixation and transosseous simple suture techniques reproduced only 46% and 71% of the insertion site, respectively. Therefore, the footprint area of the DRSA fixation technique was significantly larger \( P < .05 \) than that of the other 2 techniques. Furthermore, double-row fixation may provide a tendon-bone interface better suited for biologic healing and restoring normal anatomy. (J Shoulder Elbow Surg 2006;15:691-696.)

Surgical repair is a common method for treating rotator cuff tears. Although this may be considered a fairly routine elective procedure, clinical success rates are reported to be, on average, lower than for other procedures commonly performed by orthopaedic surgeons.1,2,4,14,18,19,21

Although many different variables influence the final functional outcome of rotator cuff surgery, the most common complication is the structural failure of repair.10,12,13,15,16 Clinical studies using postoperative imaging have revealed an alarmingly high rate of recurrent tears.3,9,13,15,16 Consequently, there has been increasing interest in maximizing the repair site contact area during surgery, thereby increasing the tendon-bone contact area potentially to lead to more complete healing. Cadaveric studies by Tierney and Scheller22 have revealed that the native supraspinatus insertion, or footprint, is considerably expansive. Apreleva et al1 have shown that traditional repair techniques, using a single row of suture anchors (SRSA) or transosseous sutures (TOS), fail to restore the full contact area of the native supraspinatus footprint (NSF) on the greater tuberosity. This inability to reapproximate the supraspinatus insertion site anatomically may decrease the likelihood of complete healing. Recently, a technique of double-row suture anchor (DRSA) fixation has been developed in an attempt to restore the full tendon-bone interface better. The purpose of this study was to assess whether DRSA fixation provides superior repair contact area compared with the SRSA technique or TOS technique.

MATERIALS AND METHODS

Specimen preparation

A cadaveric study was performed using 7 fresh-frozen shoulders (age range, 61-75 years; 4 male and 2 female). Each specimen was thawed at room temperature for 24 hours before digitization. Specimens with a pre-existing rotator cuff tear or history of shoulder surgery were excluded. Soft tissues, including the skin and deltoid muscle, were dissected away. The glenohumeral joint was disarticulated, leaving the entire humeral attachment of the rotator cuff intact. This allowed complete access to the full outline of the insertion site, including the superior and inferior surfaces. The humeral shaft was stripped free of soft tissue and rigidly fixed in a custom frame.

Rotator cuff tear technique

Full-thickness supraspinatus tears were created uniformly by sharply dissecting the tendon from the bone. Tears measuring 2 cm from anterior to posterior were created, starting at the anterior border of the supraspinatus tendon, just posterior to the biceps tendon in the bicipital groove. The size of the tear did not exceed the anterior-to-posterior dimension of the supraspinatus footprint in any specimen. All 3 types of repairs were performed by the same orthopaedic surgeon on each specimen in the following order:
(1) TOS repair, (2) SRSA fixation, and (3) DRSA fixation (Figure 1, A-C).

The Concept Rotator Cuff Repair System (Linvatec, Largo, FL) was used to create 2 transosseous tunnels for the TOS repair in each specimen. The medial entry holes for TOS repair were placed in the humeral head at the line formed by the articular cartilage, and the lateral entry holes for the TOS technique were placed 15 mm distal to the lateral ridge of the greater tuberosity. Mitek Fastin RC suture anchors (DePuy Mitek, Norwood, MA), loaded with No. 2 Ethibond (Ethicon, Somerville, NJ), were used for SRSA and DRSA fixation. Two anchors were used for the SRSA repair, and four were used for the DRSA repair. The suture anchors for the SRSA repair and the lateral row of the DRSA repair were placed along the lateral ridge of the greater tuberosity. The medial row of suture anchors for DRSA fixation was placed in the humeral head at the line formed by the articular cartilage. Both transosseous tunnels and suture anchors were spaced 10 mm apart from anterior to posterior. Simple vertical sutures were placed, with only one

Figure 1 Surgical and digitization technique. Each specimen was repaired by all 3 techniques (A-C). The area of contact was digitized (D-G) and overlaid on the NSF (H-K). Anatomic illustrations show that whereas the SRSA and TOS methods fail to cover the native footprint, the DRSA fixation technique covers 100% of the NSF (L-O).
suture limb being passed through the tissue, for the SRSA fixation technique and for the lateral row of suture anchors in the DRSA fixation technique. For the medial row of the DRSA repair, horizontal mattress sutures were used, with both limbs being passed through the tissue. Corresponding suture limbs were spaced 10 mm apart (Figure 1, D-G).

**Digitization technique**

The area of the original tendon insertion site within the tear (NSF) was determined first for baseline comparison by 3-dimensional (3D) digitization, by use of a MicroScribe G2X digitizer (Immersion, San Jose, CA) (Figure 1, H). The medial and lateral borders of the tendon insertion were carefully marked with an ink pen before the fibers were dissected sharply from the greater tuberosity. The anterior extent of the footprint ended at the bicipital groove. The posterior extent of the insertion site extended 2 cm posterior to the bicipital groove. For each measurement, a fine-tipped stylus was used to plot 60 to 120 points, evenly spaced along the surface of the NSF. From this, the area of the NSF was calculated, by use of the computer software. After the NSF was determined for each specimen, the repairs were performed in the following order: TOS technique, DRSA fixation, and SRSA fixation. The outline of the tendon-bone contact area, produced by the repair, was then determined for each technique by use of the 3D digitization protocol originally described by Apreleva et al. The fine-tipped stylus was used to plot multiple points around the tendon-bone contact area of each repair. Only the areas of firm tendon-to-bone approximation were included in the footprint outline. If the tendon could be lifted up at any portion, this part was not counted as a contact area. Points were plotted laterally first, and then medially, by lifting up the tendon to allow access underneath. Each outline was then digitized 3 successive times (Table I), and the same investigator (J.D.M.) performed the mapping of all specimens to minimize inconsistency. The data were processed by use of Rhinoceros NURBS modeling software (McNeel and Associates, Seattle, WA), and the repair site areas were compared for the different repair techniques (Figure 1, I-K).

**Statistical analysis**

Appropriate power analysis was performed on the preliminary data to ensure an adequate sample size with 90% power ($\alpha = .05$ and $\beta = .1$). The effect of each repair technique was evaluated by use of a 1-way repeated-measures analysis of variance and Bonferroni multiple-contrast post hoc tests, as required. Statistical significance was set at $P < .05$. SigmaStat 3.0 software (SPSS, Chicago, IL) was used to perform all of these analyses.

**RESULTS**

We found that the lateral extent of the intact supraspinatus tendon insertion was located consistently along the lateral ridge of the tuberosity and that the medial aspect of the tendon inserted within 1 mm or less of the articular cartilage. The mean area ($\pm$ SD) of the NSF was 268.02 $\pm$ 35.75 mm$^2$, with a mean medial-lateral dimension of 14.1 mm (range, 11.5-17.0 mm) (Figure 1, I). The TOS technique produced
a footprint area of 189.28 ± 34.72 mm², restoring a mean of 71% of the NSF. The TOS footprint area was significantly smaller than the NSF. The SRSA fixation technique created a mean footprint area of 123.56 ± 41.47 mm² and represented a reapproximation of 46% of the NSF. This also proved to be a significantly smaller footprint area than the original NSF. However, the repair footprint area of the DRSA fixation technique was found to be 281.76 ± 26.78 mm², consistently reproducing over 100% of the original NSF and providing a significantly greater footprint area than either of the other 2 repair techniques evaluated (Figure 1, M-O). These data are summarized in Table II and Figure 2.

**DISCUSSION**

Recent investigations have revealed that the supraspinatus insertion, or footprint, on the greater tuberosity is much larger than previously appreciated. Tierney and Scheller observed that “the insertional footprint is quite broad, almost twice the thickness of the actual tendon” and that the mean medial-to-lateral width of the insertion site ranged from 12 to 24 mm. Dugas et al also quantified the area of the supraspinatus footprint and found that its medial-to-lateral distance averaged a substantial 14.7 mm. The dimensions of the footprint and the relationships with associated structures are fairly consistent and predictable. In our study, we found that the lateral extent of the tendon insertion was located consistently along the lateral ridge of the tuberosity and, as in the findings of Dugas et al, that the medial aspect of the tendon normally inserts very close—within 1 mm—to the articular margin along the anterior 2 cm of the greater tuberosity. Knowing these landmarks can serve as a helpful guide to restoring anatomy during rotator cuff repair surgery.

Individual rotator cuff tears vary widely in their character and inherent prognoses when repair surgery is performed, but the current success rate of rotator cuff repair certainly leaves room for improvement. Clinical outcomes are reported to average only 85% for good to excellent results. This is lower than the success rates for other elective procedures that orthopaedic surgeons perform. Structural failure of repair is considered to be the most common complication. Recent clinical studies using postoperative imaging have shown an alarmingly high incidence of recurrent or residual tears after rotator cuff repair, ranging from 20% to 82% of cases. Certainly, there are many factors involved in determining the ultimate outcome of rotator cuff repair, such as quality of repair, preoperative tear size, amount of rotator cuff muscle atrophy and fatty degeneration, and postoperative restoration of shoulder flexibility and strength, among others. Some variables are beyond the surgeon’s control, but one important factor that surgeons do have direct influence over is repair technique. Increasing emphasis is being placed on improving fixation and maximizing the repair site contact area, in an effort to enlarge the tendon-bone interface surface area and potentially enhance more complete

### Table II

<table>
<thead>
<tr>
<th>Specimen</th>
<th>NSF (mm²)</th>
<th>TOS (mm²)</th>
<th>SRSA (mm²)</th>
<th>DRSA (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>204.26</td>
<td>163.46</td>
<td>88.06</td>
<td>238.24</td>
</tr>
<tr>
<td>B</td>
<td>259.07</td>
<td>162.24</td>
<td>90.73</td>
<td>289.24</td>
</tr>
<tr>
<td>C</td>
<td>258.06</td>
<td>154.94</td>
<td>79.84</td>
<td>258.10</td>
</tr>
<tr>
<td>D</td>
<td>297.79</td>
<td>242.39</td>
<td>192.50</td>
<td>314.26</td>
</tr>
<tr>
<td>E</td>
<td>261.20</td>
<td>174.47</td>
<td>144.23</td>
<td>282.35</td>
</tr>
<tr>
<td>F</td>
<td>316.67</td>
<td>228.24</td>
<td>152.64</td>
<td>308.88</td>
</tr>
<tr>
<td>G</td>
<td>279.12</td>
<td>199.24</td>
<td>116.94</td>
<td>281.27</td>
</tr>
<tr>
<td>Mean (± SD)</td>
<td>268.02 ± 35.75</td>
<td>189.28 ± 34.72</td>
<td>123.56 ± 41.47</td>
<td>281.76 ± 26.78</td>
</tr>
</tbody>
</table>

Percent of NSF: 71% for TOS, 46% for SRSA, and 106% for DRSA.

**Figure 2** Graphic results of measured 3D footprint area for NSF and each repair technique.
healing. Apreleva et al\textsuperscript{1} recently performed a study using 3D digitization to measure the size of the repair footprint produced with various rotator cuff repair techniques. The study demonstrated that although none of the techniques fully restored the NSF, a TOS technique with a simple vertical stitch provided a significantly larger footprint than the SRSA technique, implying that the TOS technique may be superior to a repair using suture anchors.

The results of our study differ somewhat compared with the findings of Apreleva et al,\textsuperscript{1} who found the footprints created by the TOS and SRSA techniques to be 85% and 67% of the original footprint area, respectively. This is in contrast to our study’s results of 71% and 46%, respectively. This is most likely a result of a difference in methods. Apreleva et al\textsuperscript{1} compared the area of the repair footprint (within the 2-cm tear) with the entire supraspinatus insertion site, including the intact fibers not involved in the manufactured tear. Alternatively, our study compared the repair contact area with only that portion of the supraspinatus footprint that was detached by the 2-cm tear (NSF). Because there is a natural variation among specimens with regard to the area of the individual supraspinatus insertion site, the method chosen for this study eliminated the influence of this confounding variable and is believed to be more reflective of the actual percentage of the insertion that is restored by the repair technique.

Various methods have been advocated to increase the repair site contact area. It has been suggested that a more lateral placement of a single row of anchors on the greater tuberosity may increase the repair site area. However, this maneuver simply shifts the footprint laterally without actually increasing its size. The reason that a TOS technique with a simple stitch creates a larger tendon-bone contact area is that 2 fixation points are created in the coronal plane (1 medial and 1 lateral), whereas there is only 1 fixation point in the coronal plane with an SRSA repair technique. The TOS technique only has this footprint-enhancing effect when a simple stitch is used. If a horizontal mattress stitch is used with TOS repair, for instance, this creates only 1 point of fixation in the coronal plane, like SRSA fixation, and does not enhance the size of the repair footprint. No matter what fixation method is used, a basic principle applies: the amount of tissue that a single suture loop approximates to the bone is a direct function of the distance between corresponding suture limbs at the surface of the bone. For example, for a single suture anchor, this distance is about the diameter of the hole that the anchor is inserted into, because this is the maximum separation that the suture limbs can achieve at the surface of the bone. A simple TOS stitch provides a larger purchase of tissue with a single suture loop because the limbs are separated by a greater distance at the level of the bone. Therefore, spreading the medial and lateral fixation points apart will increase the contact area. This is the premise behind the DRSA fixation technique, which uses suture anchors to create 2 separate fixation points in the coronal plane to maximize the footprint area.

There are a number of benefits to using suture anchors for rotator cuff repair fixation versus TOS repair. For instance, suture anchors allow surgeons to perform all-arthroscopic repairs, which are gaining in popularity, whereas the TOS repair requires a traditional open or miniopen surgical approach. Furthermore, studies have suggested that suture anchor repairs impart stronger fixation than transosseous sutures, as there is less of a tendency for bony failure when subjected to cyclic loading.\textsuperscript{5,6,17,20}

In an effort to increase the repair footprint of suture anchor repairs, some surgeons have begun using a double-row fixation technique clinically.\textsuperscript{8} In our study, it was shown that a DRSA fixation technique performed significantly better in maximizing the supraspinatus repair footprint and was the only technique tested that was able to recreate the original insertion anatomy of the rotator cuff consistently. It was interesting to note that the DRSA technique actually produced a repair footprint slightly larger than the NSF, because the medial suture anchors tended to pull a portion of the tendon down onto the articular cartilage adjacent to the articular margin. The concept of double-row fixation is consistent with the current trend in orthopaedics to perform anatomic repairs, in keeping with the ideal that reapproximating normal anatomy is fundamental for restoring optimal function.

In addition to providing better restoration of the broad supraspinatus tendon insertion, it is likely that double-row fixation may also have other advantages. It has been shown that double-row fixation creates a substantially stronger initial repair with its higher number of fixation points and perhaps reduces torsional forces across the repair interface with the tandem arrangement of fixation points.\textsuperscript{17} Whether DRSA fixation actually leads to a better functional outcome, however, is not revealed by this study, and further investigation will be essential. Technical studies will need to be completed to investigate the feasibility of performing double-row fixation on challenging tears, such as chronic, retracted tears, where excess tension on the repair must be avoided. Clinical studies will also be necessary to justify the added expense and additional operative time needed for the use of more implants in rotator cuff repair by determining whether a greater repair contact area actually leads to a broader area of biologic healing, a more durable union of tendon and bone, and improved patient outcomes.

In conclusion, the supraspinatus tendon repair foot-
print of the DRSA fixation technique is significantly larger than that of the SRSA fixation technique or TOS technique. Furthermore, the DRSA fixation technique consistently reproduces 100% of the original supraspinatus footprint area, whereas both the SRSA and TOS techniques fail to do so, recreating only 46% and 71%, respectively. Double-row fixation may be a superior rotator cuff repair technique by providing a tendon-bone interface better suited for biologic healing and restoring normal anatomy, but this needs to be investigated further in future studies.

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REFERENCES