Transosseous-equivalent repair with and without medial row suture tying: a cadaveric study of infraspinatus tendon strain measurement

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Background: How the use of the transosseous-equivalent (TOE) technique effects the stress concentration in repaired rotator cuff tendon is unknown. This study was conducted to determine the strain between the intact rotator cuff tendon and the tendon repaired using the TOE technique with and without medial row suture tying.

Materials and methods: Strain of the infraspinatus tendon from 10 fresh-frozen cadavers was measured at the (A) tendon insertion, (B) tendon footprint, (C) tendon of the medial suture level, and (D) musculotendinous junction of the tendon. The strain was measured during 2 cycles of internal and external rotations while applying 4 different loads to the infraspinatus. After the intact tendon was evaluated, an artificially created tear of the infraspinatus was repaired using the TOE technique. Medial row sutures were tied in 5 shoulders (T group) and untied in the rest (UT group). The strains at 4 sites were compared between the intact and the TOE-repaired tendon and between the T and UT groups.

Results: The strain was significantly reduced at site B in the repaired tendon in the T and UT groups compared with the intact tendon for all loads (P < .05). At site C, the strain increased for all loads in the T group compared with the intact tendon (P < .05).

Conclusion: The strain of the tendon over the footprint area was significantly smaller than the intact tendon when repaired with the TOE technique. The strain at the medial suture level was significantly greater when the medial sutures were tied compared with those untied.

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the intact rotator cuff tendon and the tendon repaired by the TOE technique. The comparison was additionally conducted between the repaired tendon with and without tying the medial row sutures. This study hypothesis was that the strain of the tendon at the pressurized area would decrease, that the strain of the tendon proximal to the medial row would not change after the TOE repair, and that the strain of the tendon would increase when medial row sutures were tied compared with the tendon without tied medial row sutures.

Materials and methods

Preparation of the specimens

Ten fresh-frozen cadaveric shoulders (7 right and 3 left) were harvested for this study after excluding specimens with macroscopic rotator cuff tear, severe joint contracture, or osteoarthritic change observed by computed tomography scan. The specimens were an average age of 86.6 years (range, 81-96 years). After the shoulders were thawed at room temperature for 24 hours, all of the soft tissues and acromion were dissected, except for the rotator cuff muscles.

The shoulder was set in a custom-made testing device along with an acrylic plate to fix the shoulder firmly to the device using Kirschner wires (Fig. 1), resembling the past report. This device allowed the humerus to rotate at a given angle of glenohumeral elevation and humeral rotation. Saline was sprayed on the specimen every 5 to 10 minutes during testing to keep it continuously moist.

Measurement of the tendon strain

A microstrain transducer (M-DVRT; MicroStrain, Burlington, VT, USA) was used for all of the testing to measure the strain on the tendon. At each evaluation site, 2 stainless barbs were inserted into the tendon 3 mm deep and 5 mm apart from each other (Fig. 2). This sensor provided a voltage that was linearly proportionated to the displacement of the magnetic cord to which the stainless barbs were attached. According to the company information, the resolution of this sensor is 1.5 μm and its repeatability is ±1 μm within the range of measurement of 6 mm. To record the displacement data, the transducers were connected to a 4-channel chart recorder (MB-STD, MicroStrain).

Four evaluation sites were defined using the infraspinatus tendon: (A) tendon insertion, (B) tendon footprint, (C) tendon of the medial suture level, and (D) musculotendinous junction of the tendon (Fig. 3). The infraspinatus tendon was chosen to prevent barbs from being obstructed by bony structures in the scapular spine or a coracoid process when the supraspinatus or subscapularis was chosen for testing. For site A, after the edge of the tendon was clarified, 2 barbs were placed over the edge. For site B, a lateral barb was placed 5 mm medial from the edge of the tendon. For site C, because the medial row sutures were planned to be passed through the tendon 10 mm from the edge, a lateral barb was placed 8 mm from the edge, depending upon the location of the medial row suture anchors. For site D, a lateral barb was placed 15 mm from the edge of the tendon.

The humerus was rotated from the neutral rotation to the maximum internal rotation with the arm in 0° of abduction and then externally rotated back to the neutral rotation manually. The maximum range of motion of the cadaveric shoulders was measured under a constant torque with pulleys and weights (800 N-mm for abduction and flexion and 250 N-mm for internal and external rotations). Torque was measured by a force transducer (Digital Force Gauge; Imada Co., Ltd., Toyohashi, Japan). The average maximum range of motion of the shoulders was 80 ± 10° for flexion,
78 ± 11° for abduction, 28 ± 12° for internal rotation at the side, and 48 ± 12° for external rotation at the side. Internal and external rotations were repeated twice and the mean values were used for analysis.

The humeral head was kept centered in the glenoid while the humerus was rotated by loading each tendon in the direction of the glenoid by pulling the attached cables with weights: 10 N for the subscapularis and 3.5 N for the supraspinatus. For the infraspinatus, 4 varied loads were used to investigate the relationship between the load and the tendon strain: 0 kg, 0.45 kg, 0.9 kg, and 1.35 kg. These loads were calculated following the previous report’s methodology, with the mean electromyographic activation of the infraspinatus’ external rotation at 0° of abduction while standing. Loads of 0 kg, 0.45 kg, 0.9 kg, and 1.35 kg were consistent with 0%, 17%, 33%, and 50% of the maximum loads of the infraspinatus, respectively.

Once the evaluation of the intact tendon was finished, the infraspinatus tear was artificially created with a scalpel at the footprint, with a width of 2 cm and length of 1 cm. Two medial anchors (TWINFIX 5.0 Ti Suture Anchor; Smith & Nephew, Andover, MA, USA) were inserted, and the single suture was passed through the tendon in a mattress fashion. The sutures were passed through 10 mm medially from the edge of the tendon. Medial sutures were separated approximately 4 mm apart.

The shoulders were randomly assigned to 2 groups: the medial row sutures were tied in 5 shoulders (T group) and untied in the remaining 5 shoulders (UT group). Because we were unable to use the paired specimens owing to the limited number of specimens and budget, we measured the bone densities of the anchor inserted area to rule out that difference between the 2 groups. The bone densities of the T and UT group were, respectively, 9.4 ± 9.4 mg/cm³ for the infraspinatus footprint, 8.4 ± 9.0 and 75.6 ± 9.0 mg/cm³ for the medial-anchor-inserted area, and 82.0 ± 9.4 and 88.8 ± 9.4 mg/cm³ for the lateral-anchor-inserted area, none of which were statistically significant. Lateral fixation sites were placed 1 cm lateral to the edge of the greater tuberosity.

The TOE repair was completed by fixing the sutures in cross fashion using lateral anchors (Footprint PK 4.5, Smith & Nephew). The anchors were placed and all sutures were tied by the same surgeon (H.N.) to minimize the variability of the repair technique. The creation of the rotator cuff tear and the repair of the tendon were also done by the same surgeon (H.N.).

Measurements of the strain after the TOE repair were done at the same measurement sites with the intact rotator cuff tendon. The strain during the internal and external rotations were digitally recorded in Excel 2013 software (Microsoft Corp., Redmond, WA, USA). Strain was calculated by subtracting the original length of the barbs in the starting position at the neutral rotation position from the most extended length during internal rotation and then dividing by the original length. The average strains of all the evaluation sites for the intact tendon and the TOE-repaired tendon were calculated.

Data analysis

All statistical analyses were performed using JMP Pro 11 software (SAS Institute Inc., Cary, NC, USA). Comparison of strain between the intact and the TOE-repaired tendon, the T and UT groups, and the difference in strain between the intact and T or UT groups were analyzed using an analysis of variance technique. The strain between the loads in each condition was also analyzed using analysis of variance, then the groups were compared individually by using a post hoc Tukey-Kramer honest significant difference test. The result was considered statistically significant if the P value was <.05.
Discussion

Several studies report medial cuff failure after cuff repair.\textsuperscript{6,10,12,24} They describe tension overload of the suture-to-tendon interface at the medial row, potential overtensioning of the medial row, a relatively large hole in the cuff created by retrograde suture-passing instruments, and increased abrasion through the cuff by braided suture materials that may have played a role as the cause.\textsuperscript{6,24}

Blood supply has been reported to be an important factor for tendon healing after the repair of the rotator cuff tendon. The TOE construct reportedly reduces the blood supply,\textsuperscript{4} which, with the addition of the possible strangulation by undue tension at the medial row, may weaken the tendon and eventually lead to relatively quick necrosis of the cuff at the medial row.\textsuperscript{4}

Previous reports suggest stress concentration along the medial sutures may have occurred, which might be responsible for the characteristic retear pattern after using the TOE technique. However, stress concentration or strain of the tendon before and after using the TOE repair or between the medial row has yet to be confirmed. To our knowledge, this is the first study to determine the strain of the tendon before and after using the TOE repair.

The present study revealed that the strain significantly decreased for the tendon over the footprint and significantly increased over the medial row sutures. This study also showed that there was a significant increase in strain between the footprint and the medial row when the TOE technique was used. A significant increase in tendon strain over the medial row can be interpreted from these results. This strain increase may cause a stress concentration at the medial row, which may be one of the contributing factors for the medial rerupture clinically observed after use of the TOE technique. However, although the comparison of the strain did not reach a significant level, there was a trend of increased strain in the T group compared with the UT group at the tendon of the medial suture level but also over the footprint and the medial suture level.

Previous reports suggest that tying the medial row sutures may increase the contact pressure of the tendon, which may in turn decrease the blood flow to the tendon.\textsuperscript{4}

Kim et al.\textsuperscript{15} demonstrated in a study of cadaveric shoulders that the mean pressurized contact area and interface pressure around the medial row was significantly greater when the medial knotting TOE repair was used compared with the medial knotless TOE repair using a modified Mason-Allen technique. Their results coincide with our study that the strain at the medial suture level was significantly greater when the sutures were tied compared with those untied. The difference between their study and ours was that our study surveyed the strain of the tendon, not just along the medial suture level but also over the footprint and the medial suture level and revealed the strain decrease for the tendon over the footprint and increase over the medial row sutures.

From these past reports, tying the medial row can be one of the factors to increase the strain along the medial row, which may eventually lead to a retear. Future analysis of a clinical study, analyzing
the medial retear rate of those with and without tied medial row sutures, may provide clinical support to our biomechanical data. Strain comparisons between loads did not show any significant differences under all conditions. In some conditions, however, the correlation coefficient was high (0.92-0.93 at site A, 0.92-0.97 at site C with intact tendons, and 0.91-0.95 at site C in the UT group), showing a tendency of strain increase along with the load increase. The small differences in the load weights probably prevented the observation of any significant differences between load rates. Another possibility is that the number of shoulders was too small to detect a difference. This study has several limitations. First, because this study was conducted using cadaveric shoulders at time 0, the tendon elasticity might be different from actual conditions because the strain of the tendon may change postoperatively over time. Clinically, there are no specific techniques to measure the tendon strain in live shoulders, preoperatively or postoperatively. To clarify the tendon strain, using cadaveric shoulders was unavoidable at the present time. Second, although we showed the difference in strain at various sites of the repaired tendon, the relevance between the strain difference and retear remain unclear. Further studies to clarify this relationship are needed.

Third, tendon thickness was not measured. The difference in tendon thickness may affect the strain characteristics. However, when measuring the thickness of the tendon using a digital caliper, creating a rotator cuff tear was unavoidable before testing, and the precise thickness could not have been measured after testing because the tendon would be repaired by the TOE after tests due to repair procedures.

Fourth, specimens were not tested in paired shoulders. As stated in the exclusion criteria, specimens with macroscopic rotator cuff tear, severe joint contracture, or osteoarthritic change observed by computed tomography scan were excluded. Unfortunately, in some pairs, 1 shoulder showed no tear whereas the other had a rotator cuff tear or other conditions included in the exclusion criteria. Therefore, testing in pairs was impossible because the number of available specimens and our budget was limited. However, we assume that the influence on the results was minimal because the calculation of the bone density between the T and UT groups showed no statistically significant difference.

Conclusion

The strain of the tendon over the footprint area was significantly smaller when repaired using the TOE technique compared with the intact tendon. The strain at the medial suture level was significantly greater when the medial sutures were tied compared with those untied.

Disclaimer

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