JSES Open Access 1 (2017) 104–108

Contents lists available at ScienceDirect

JSES Open Access

journal homepage: www.elsevier.com/locate/jses

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

Hideaki Nagamoto, MD, PhD [a], Nobuyuki Yamamoto, MD, PhD [a], Yuki Shiota, MD [a], Jun Kawakami, MD [a], Takayuki Muraki, PT, PhD [b], Eiji Itoi, MD, PhD [a,*]

[a] Department of Orthopaedic Surgery, Tohoku University School of Medicine, Sendai, Japan
[b] Department of Physical Medicine and Rehabilitation, Tohoku University School of Medicine, Sendai, Japan

A R T I C L E I N F O

Keywords:
Rotator cuff tear
Transosseous-equivalent technique
Strain
Cadaver
Medial row
Suture tying

Level of evidence: Basic Science Study, Biomechanics

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.

Arthroscopic surgery for a rotator cuff tear, one of the most common shoulder disorders, has gained wide popularity as a result of significant improvement and evolvement of arthroscopic surgery techniques. Several different techniques have been reported to accomplish the repair.[5,14,15,17,19,22] Healing of the tendon to the bone can be influenced by various factors, including contact area, pressure, repair strength, cuff integrity, motion at the tendon-to-bone interface, and tissue quality.[1,4,11,16] The transosseous-equivalent (TOE) technique[17] has recently received significant attention for its cuff integrity after surgery,[10] advantages over the conventional double-row technique in reduction of surgical steps,[12] and avoidance of impingement or irritation that may be caused by the medial row knot.[21] Laboratory data have also shown that the TOE technique increases the contact area and contact pressure of the rotator cuff tendon compared with the conventional double-row technique and produces superior results compared with other arthroscopic repair options.[2,9,17,18]

Although the retear rate of the TOE technique has been reported to be lower or comparable to the conventional double-row technique, a characteristic retear pattern after the TOE technique, specifically a reruptured tendon at the medial row with a healed footprint, is becoming a major concern.[6,10,12,24] These reports describe medially retorn tendons with an intact footprint. They conclude that this type of unique failure may be caused by the strong pressure from the TOE construct, which may lead to tension overload along the medial suture-to-tendon interface or the possibility of relatively quick necrosis of the cuff tendon at the medial row.[6,24] These reports have suggested that the TOE technique may increase the strain difference between the normal tendon and the repaired tendon, resulting in stress concentration along the medial row.

Nevertheless, no studies investigating the stress or strain of tendons repaired with the TOE technique have been reported. Therefore, the purpose of this study was to compare the strain between

The Tohoku University Graduate School of Medicine Institutional Review Board approved this study (Study No.: 2012-1-521.)

* Corresponding author: Eiji Itoi, MD, PhD, Department of Orthopaedic Surgery, Tohoku University School of Medicine, 1-1 Seiryo-machi, Ao-baku, Sendai 980-8574, Japan.

E-mail address: itoi-eiji@med.tohoku.ac.jp (E. Itoi).

http://dx.doi.org/10.1016/j.jses.2017.05.001

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.[25] 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, MircoStrain).

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).[26] Torque was measurement 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,

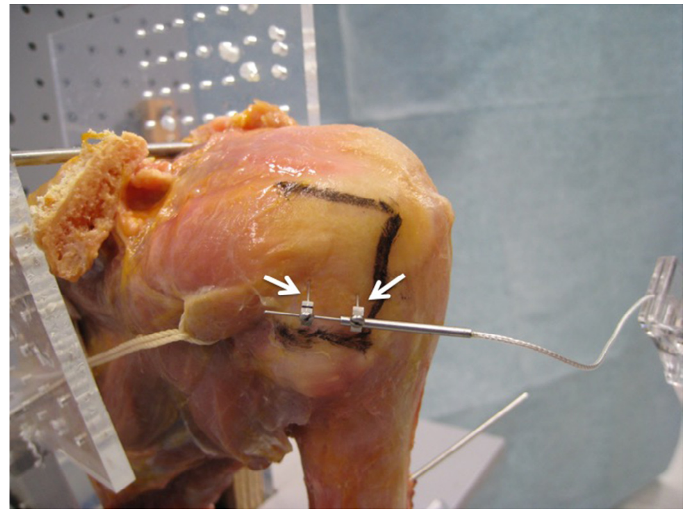

Figure 2 Stainless barbs of the microstrain transducer (*arrows*) were inserted in the tendon, and the distance between the barbs was set at 5 mm.

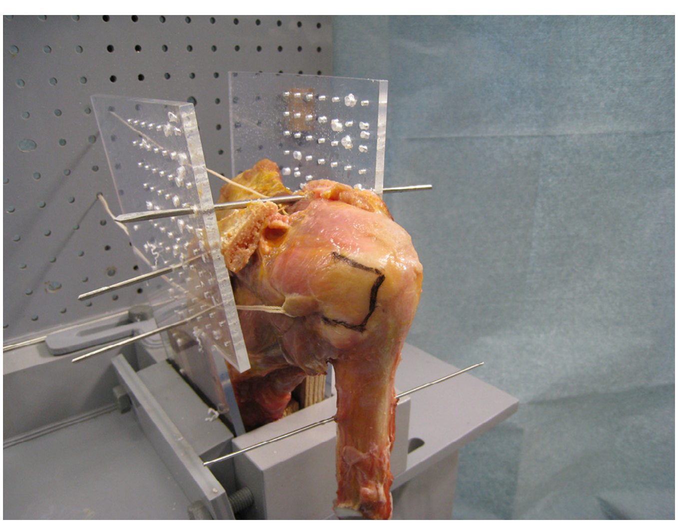

Figure 1 Image of the custom-made testing device and experimental setup.

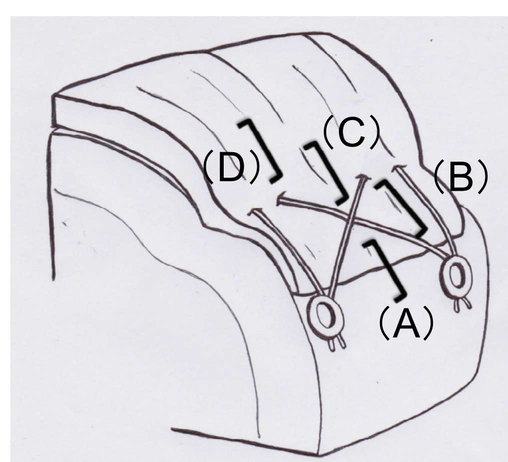

Figure 3 Evaluation sites of the infraspinatus tendon: insertion of the tendon (**A**), footprint of the tendon (**B**), tendon where the medial sutures were passed (**C**), and musculotendinous junction of the tendon (**D**).

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.[25] 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.[20] 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.[7,21] Medial sutures were separated approximately 4 mm apart.[3,19]

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, 84.0 ± 8.3 and 82.8 ± 8.3 mg/cm^3 for the infraspinatus footprint, 84.4 ± 9.0 and 75.6 ± 9.0 mg/cm^3 for the medial-anchor-inserted area, and 82.0 ± 9.4 and 88.8 ± 9.4 mg/cm^3 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.[6]

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.

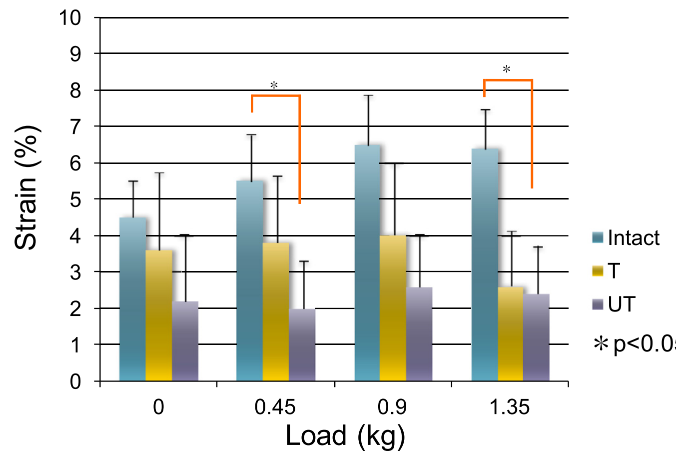

Figure 4 Strain at site A (insertion of the tendon). The *range bars* show the standard deviation. *T*, tied group; *UT*, untied group.

Results

Comparison of strain between the intact and the TOE-repaired tendon

At site A, comparison of the strain of the intact tendon and the T group was not statistically significant. When the strain was compared between the intact tendon and the UT group, statistical significance was reached for 0.45 kg (P = .04) and 1.35 kg (P = .02; Fig. 4).

At site B, the T group showed significantly smaller strain than the intact group for 0 kg (P = .04), 0.45 kg (P = .01), 0.9 kg (P = .01), and 1.35 kg (P = .02). The UT group also showed significantly smaller strain than the intact group for 0 kg (P = .03), 0.45 kg (P = .01), 0.9 kg, (P = .01), and 1.35 kg (P = .02; Fig. 5).

At site C, the T group showed significantly greater strain than the intact group for 0 kg (P = .04), 0.45 kg (P = .01), 0.9 kg (P = .002), and 1.35 kg (P = .005). However, the differences between the intact group and the UT group and between the T group and the UT group were not significant (Fig. 6).

At site D, there were no significant differences among the intact, T, and UT groups (Fig. 7).

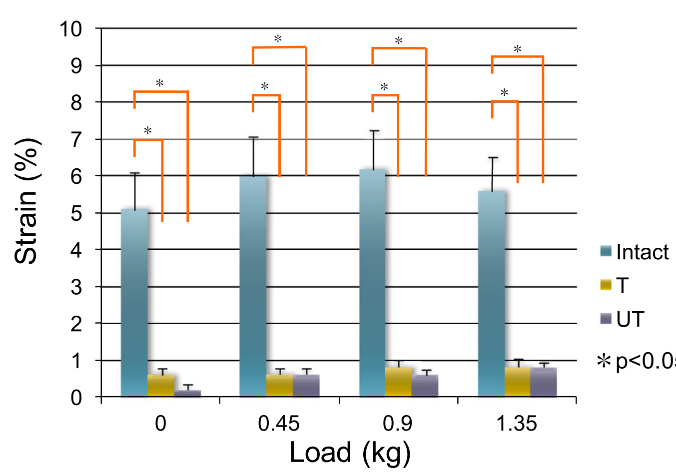

Figure 5 Strain at site B (footprint of the tendon). The *range bars* show the standard deviation. *T*, tied group; *UT*, untied group.

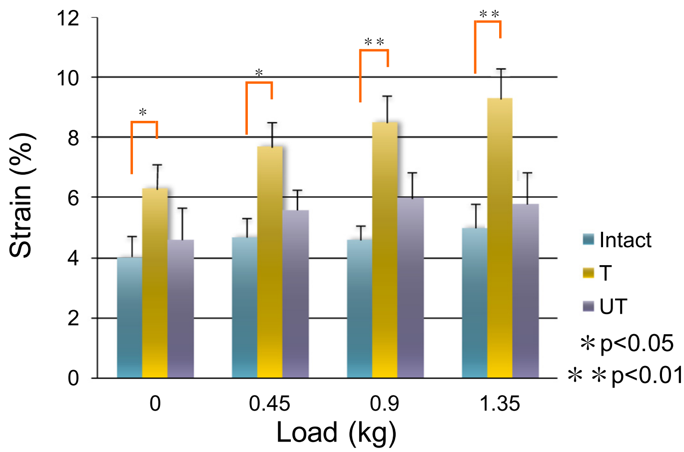

Figure 6 Strain at site C (tendon where the medial sutures were passed). The *range bars* show the standard deviation. *T*, tied group; *UT*, untied group.

Difference in strain between the intact tendon and TOE-repaired tendon

The strain differences between site A and B were not significant for both the T and UT groups. Between site A and C, the strain differences were significantly greater at site C for the T group at 0 kg ($P = .001$), 0.45 kg ($P = .01$), 0.9 kg ($P = .02$), and 1.35 kg ($P = .04$) and for the UT group at 0 kg ($P = .01$), 0.45 kg ($P = .001$), 0.9 kg ($P = .02$), and 1.35 kg ($P = .01$). Between sites A and D, the strain differences were significantly greater at site D for all of the UT groups at 0 kg ($P = .03$), 0.45 kg ($P = .001$), 0.9 kg ($P = .001$), and 1.35 kg ($P = .001$). For the T groups, the strain differences were significantly greater at site D only when the loads were 0.45 kg ($P = .01$) and 0.9 kg ($P = .001$). Between sites B and C, the strain differences were significantly greater at site C for T at 0 kg ($P = .001$) 0.45 kg ($P = .02$), 0.9 kg ($P = .02$), and 1.35 kg ($P = .04$) and for UT at 0 kg ($P = .03$), 0.45 kg ($P = .001$), 0.9 kg ($P = .03$), and 1.35 kg ($P = .01$). Between sites B and D, the strain differences were significantly greater at site D for all of the UT groups except for 0 kg ($P = .001$ for 0.45 kg, $P = .002$ for 0.9 kg, and $P = .007$ for 1.35 kg). For the T groups, the strain differences were significantly greater at site D only when the loads were 0.45 kg ($P = .01$) and 0.9 kg ($P = .001$). The strain difference between sites C and D were not significant for both T and UT groups.

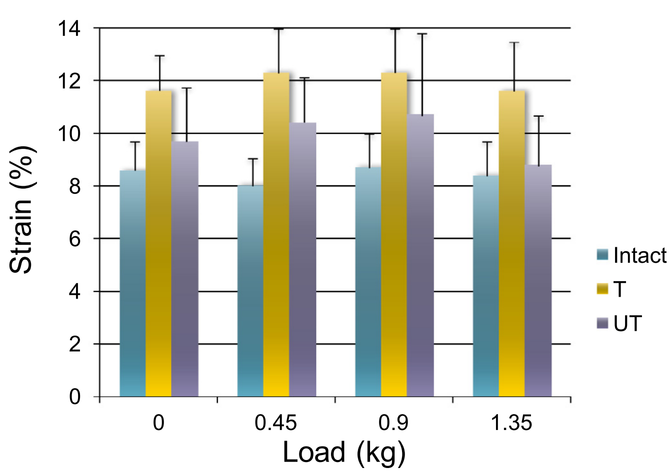

Figure 7 Strain at site D (musculotendinous junction of the tendon). The *range bars* show the standard deviation. *T*, tied group; *UT*, untied group.

Comparison of strain between the loads

The strain comparison between loads for both the T and UT groups did not show any significance for all the conditions. There were high positive correlations between the strain and the load at site A (0.92-0.93), site C in the intact group (0.92-0.97), and site C in the UT group (0.91-0.95).

Discussion

Several studies report medial cuff failure after cuff repair.[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.[23,24]

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,[8] 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.[6]

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.

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 and musculotendinous junction. Maguire et al[15] reported that the knotted TOE construct, which is equivalent to the T group in the present study, showed superior results in the contact area compared with an untied suture bridge construct, also equivalent to the UT group in the present study. The knotted double-suture bridge construct appeared to be an especially more stable construct with less tendon movement or gap formation during loading. This can be interpreted that tying the medial sutures may increase the contact pressure of the tendon, which may in turn decrease the blood flow to the tendon.

Kim et al[13] 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 knot-tying 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

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Ahmad CS, Stewart AM, Izquierdo R, Bigliani LU. Tendon-bone interface motion in transosseous suture and suture anchor rotator cuff repair techniques. Am J Sports Med 2005;33:1667-71. http://dx.doi.org/10.1177/0363546505278252
2. Andres BM, Lam PH, Murrell GAC. Tension, abduction, and surgical technique affect footprint compression after rotator cuff repair in an ovine model. J Shoulder Elbow Surg 2010;19:1018-27. http://dx.doi.org/10.1016/j.jse.2010.04.005
3. Bales C, Anderson K. Arthroscopic double-row repair of full-thickness rotator cuff tears using a suture bridge technique. Oper Tech Sports Med 2007;15:144-9. http://dx.doi.org/10.1053/j.otsm.2007.05.005
4. Bishop J, Klepps S, Lo IK, Bird J, Gladstone JN, Flatow EL. Cuff integrity after arthroscopic versus open rotator cuff repair: a prospective study. J Shoulder Elbow Surg 2006;15:290-9. http://dx.doi.org/10.1016/j.jse.2005.09.017
5. Burks RT, Crim J, Brown N, Fink B, Greis PE. A prospective randomized clinical trial comparing arthroscopic single- and double-row rotator cuff repair. magnetic resonance imaging and early clinical evaluation. Am J Sports Med 2009;37:674-82. http://dx.doi.org/10.1177/0363546508328115
6. Cho NS, Lee BG, Rhee YG. Arthroscopic rotator cuff repair using a suture bridge technique—is the repair integrity actually maintained? Am J Sports Med 2011;39:2106-16. http://dx.doi.org/10.1177/0363546510397171
7. Cho NS, Yi JW, Lee BG, Rhee YG. Retear patterns after arthroscopic rotator cuff repair. single-row versus suture-bridge technique. Am J Sports Med 2010;38:664-71. http://dx.doi.org/10.1177/0363546509350081
8. Christoforetti JJ, Krupp RJ, Singleton SB, Kissenberth MJ, Cook C, Hawkins RJ. Arthroscopic suture bridge transosseous equivalent fixation of rotator cuff tendon preserves intratendinous blood flow at the time of initial fixation. J Shoulder Elbow Surg 2012;21:523-30. http://dx.doi.org/10.1016/j.jse.2011.02.012
9. Cole BJ, ElAttrache NS, Anbari A. Arthroscopic rotator cuff repairs: an anatomic and biomechanical rationale for different suture-anchor repair configurations. Arthroscopy 2007;23:662-9. http://dx.doi.org/10.1016/j.arthro.2007.02.018
10. Frank JB, ElAttrache NS, Dines JS, Blackburn A, Crues J, Tibone JE. Repair site integrity after transosseous-equivalent suture-bridge rotator cuff repair. Am J Sports Med 2008;36:1496-503. http://dx.doi.org/10.1177/0363546507313574
11. Kim DH, ElAttrache NS, Tibone JE, Jun BJ, DeLaMora SN, Kvine RS, et al. Biomechanical comparison of a single-row versus double-row suture anchor technique for rotator cuff repair. Am J Sports Med 2006;34:407-14. http://dx.doi.org/10.1177/0363546505281238
12. Kim KC, Shin HD, Lee WY. Repair integrity and functional outcomes after arthroscopic suture-bridge rotator cuff repair. J Bone Joint Surg 2012;94:e48. http://dx.doi.org/10.2106/JBJS.K.00158
13. Kim SJ, Kim SH, Moon HS, Chun YM. Footprint contact area and interface pressure comparison between the knotless and knot-tying transosseous-equivalent technique for rotator cuff repair. J Shoulder Elbow Surg 2016;32:7-12. http://dx.doi.org/10.1016/j.arthro.2015.07.004
14. Ma CB, Comerford L, Wilson J, Puttlitz CM. Biomechanical evaluation of arthroscopic rotator cuff repairs: double-row with single-row fixation. J Bone Joint Surg Am 2006;88:403-10. http://dx.doi.org/10.2106/JBJS.D.02887
15. Maguire M, Goldberg J, Bokor D, Bertollo N, Pelletier MH, Harper W, et al. Biomechanical evaluation of four different transosseous-equivalent/suture bridge rotator cuff repair. Knee Surg Sports Traumatol 2011;19:1582-7. http://dx.doi.org/10.1007/s00167-011-1436-x
16. Park MC, Cadet ER, Levine WN, Bigliani LU, Ahmad CS. Tendon-to-bone pressure distributions at a repaired rotator cuff footprint using transosseous suture and suture anchor fixation techniques. Am J Sports Med 2005;33:1154-9. http://dx.doi.org/10.1177/0363546504273053
17. Park MC, ElAttrache NS, Ahmad CS, Tibone JE. "Transosseous-equivalent" rotator cuff repair technique. Arthroscopy 2006;22:1360, e1-1360.e5. http://dx.doi.org/10.1016/j.arthro.2006.07.017
18. Park MC, ElAttrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ. Part 1: footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. J Shoulder Elbow Surg 2007;16:461-8. http://dx.doi.org/10.1016/j.jse.2006.09.010
19. Pauly S, Kieser B, Schill A, Gerhardt C, Sheibel M. Biomechanical comparison of 4 double-row suture-bridging rotator cuff repair techniques using different medial-row configurations. Arthroscopy 2010;26:1281-8. http://dx.doi.org/10.1016/j.arthro.2010.02.013
20. Reinold MM, Wilk KE, Fleisig GS, Zheng N, Barrentine SW, Chmielewski T, et al. Electromyographic analysis of the rotator cuff and deltoid musculature during common shoulder external rotation exercises. J Orthop Phys Ther 2004;34:385-94. http://dx.doi.org/10.2519/jospt.2004.34.7.385
21. Rhee YG, Cho NS, Park CS. Arthroscopic rotator cuff repair using modified Mason-Allen medial row stitch—knotless versus knot-tying suture bridge technique. Am J Sports Med 2012;40:2440-7. http://dx.doi.org/10.1177/0363546512459170
22. Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. Arthroscopy 2005;21:1307-16. http://dx.doi.org/10.1016/j.arthro.2005.08.011
23. Trantalis JN, Boorman RS, Pletsch K, Lo IK. Medial rotator cuff failure after arthroscopic double-row rotator cuff repair. Arthroscopy 2008;24:727-31. http://dx.doi.org/10.1016/j.arthro.2008.03.009
24. Voigt C, Bosse C, Vosshenrich R, Schulz AP, Lill H. Arthroscopic supraspinatus tendon repair with suture-bridging technique. functional outcome and magnetic resonance imaging. Am J Sports Med 2010;38:983-91. http://dx.doi.org/10.1177/0363546509359063
25. Yamamoto N, Itoi E, Tuoheti Y, Seki N, Abe H, Minagawa H, et al. Glenohumeral joint motion after medial shift of the attachment site of the supraspinatus tendon: a cadaveric study. J Shoulder Elbow Surg 2007;16:373-8. http://dx.doi.org/10.1016/j.jse.2006.06.016
26. Yamamoto N, Muraki T, Sperling JW, Steinmann SP, Itoi E, Cofield RH, et al. Impingement mechanisms of the Neer and Hawkins signs. J Shoulder Elbow Surg 2009;18:942-7. http://dx.doi.org/10.1016/j.jse.2009.02.012