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Pullout strength of cement-augmented and wide-suture transosseous fixation in the greater tuberosity

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ABSTRACT

Background: Obtaining strong fixation in low-density bone is increasingly critical in surgical repair of rotator cuff tears because of the aging population. To evaluate two new methods of improving pullout strength of transosseous rotator cuff repair in low-density bone, we analyzed the effects of 1) using 2-mm suture tape instead of no. 2 suture and 2) augmenting the lateral tunnel with cement.

Methods: Eleven pairs of osteopenic or osteoporotic cadaveric humeri were identified by dual-energy x-ray absorptiometry. One bone tunnel and one suture were placed in the heads of 22 specimens. Five randomly selected pairs were repaired with no. 2 suture; the other six pairs were repaired with 2-mm suture tape. One side of each pair received lateral tunnel cement augmentation. Specimens were tested to suture pullout. Data were fitted to multivariate models that accounted for bone mineral density and other specimen characteristics.

Findings: Two specimens were excluded because of knot-slipping during testing. Use of suture tape versus no. 2 suture conferred a 75-N increase (95% CI: 37, 113) in pullout strength ($P < 0.001$). Cement augmentation conferred a 42-N improvement (95% CI: 10, 75; $P = 0.011$). Other significant predictors of pullout strength were age, sex, and bone mineral density.

Interpretation: We show two methods of improving the fixation strength of transosseous rotator cuff repairs in low-density bone: using 2-mm suture tape instead of no. 2 suture and augmenting the lateral tunnel with cement. These methods may improve the feasibility of transosseous repairs in an aging patient population.

1. Introduction

Rotator cuff tears and their surgical repairs are increasing in prevalence, likely because of the aging population (Colvin et al., 2012; Harryman et al., 2003). Compared with younger patients, older patients are at higher risk of full-thickness rotator cuff tears (Sher et al., 1995; Tashjian, 2012) and experience a higher retear rate because of poor soft-tissue healing and lower bone mineral density (Abtahi et al., 2015; Gerber et al., 2007; Tashjian, 2012; Tingart et al., 2004). Obtaining strong fixation in the osteopenic or osteoporotic bone seen in this population is increasingly critical in the surgical repair of rotator cuff tears.

The original standard of open transosseous repair has been superseded gradually by arthroscopic suture-anchor repair. Although suture anchors offer a higher mean failure load than anchorless transosseous sutures, advantages of using the transosseous approach remain (Salata et al., 2013). Transosseous surgery preserves bone stock, leaves less foreign material behind, and is associated with a more favorable failure mechanism compared with anchored repairs (Kilcoyne et al., 2017; Kuroda et al., 2013). Recent studies have suggested that transosseous repairs yield equivalent outcomes to anchored constructs at a lower cost (Kuroda et al., 2013; Srikumaran et al., 2016). However, transosseous approaches rely on the inherent integrity of the bone, potentially limiting the feasibility of this technique in patients with low bone density. To overcome the weakness of osteopenic or osteoporotic bone, we propose replacing no. 2 suture with 2-mm suture tape, which has been shown to strengthen the suture-tendon interface (Burkhart et al., 2014). To assess the suture-bone interface, Leger St-Jean et al. (2015) compared maximum pull-out strength when using 2-mm suture tape versus no. 2 suture and found that suture tape conferred a significant advantage. However, further research is needed to assess whether suture tape is similarly effective in the target population of patients with low BMD. Recent studies have also suggested that cement augmentation may strengthen repairs in low-density bone (Braunstein et al., 2015; Klos et al., 2010). Braunstein et al. (2015) used osteoporotic cadaveric humeri to demonstrate that cement-augmented suture anchors achieved

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higher pull-out strength than conventional suture anchors. However, to our knowledge, no studies have assessed the effect of cement augmentation in transosseous rotator cuff repair.

The goal of our study was to evaluate the effectiveness of suture tape and cement augmentation, either alone or in combination, in strengthening transosseous rotator cuff repairs in osteopenic or osteoporotic cadaveric bone. We hypothesized that each method would improve biomechanical performance as measured by ultimate failure load, and that the use of both methods would yield the best biomechanical performance.

2. Methods

2.1. Sample preparation

We randomly assigned 22 cadaveric human shoulders, including lower arms, from 11 matched pairs to one of four experimental groups. Each upper extremity was screened using dual-energy x-ray absorptiometry (Discovery QDR system, Hologic Inc., Bedford, MA, USA). Specimens with a T-score of less than − 1.0 at the distal radius were included. Other inclusion criteria were intact humeral head and lack of evidence of fracture or previous surgical procedures.

The paired samples were separated at the elbow for ease of subsequent mechanical testing, and lower arms were discarded. The paired humeri were dissected free of soft tissue, stored at − 20 °C, and thawed at room temperature for 24 h before repair and testing. The 11 pairs were randomly assigned to one of two suture types; five pairs used standard no. 2 suture (No. 2 Ultrabraid, Smith & Nephew, Andover, MA, USA), and six pairs used 2-mm suture tape (Ultratape, Smith & Nephew). Within each suture type group, one side of each pair was randomly selected to undergo standard transosseous suture placement, and the contralateral side received transosseous sutures augmented with cement. After instruction by a fellowship-trained shoulder specialist (the senior author), the first author placed sutures and performed the augmentation in a consistent fashion for each specimen.

2.2. Group 1

Group 1 underwent standard transosseous suture placement with no. 2 suture. A bone awl was used to create a medial tunnel 5 mm lateral to the articular margin and 1 cm posterior to the bicipital groove. The hook of the tunneling device (ArthroTunneler, Tornier Inc., Bloomington, MN, USA) was inserted into the medial tunnel, and the lateral tunnel was created using a drill placed through the tunneling device. The suture inserter was loaded with no. 2 suture and inserted through the device, creating a tunnel 1 cm inferior to the tip of the greater tuberosity. After the device captured the suture, the suture inserter was retracted and the hook withdrawn, leaving a single transosseous suture (Fig. 1).

2.3. Group 2

Group 2 underwent cement-augmented transosseous suture placement with no. 2 suture. The technique was identical to that described above. For cement augmentation, a custom-designed cannula was used. The tip was pinched off, and a 2-mm-wide slot was milled onto its lateral edge (Fig. 2). After suture placement, the cannula tip was inserted 1.5 cm into the lateral drill hole and used to deliver 1 mL of bone cement (Simplex P Bone Cement, Stryker Corporation, Mahwah, NJ, USA). The cannula was rotated 180° above the suture to ensure even augmentation of the superior surface of the lateral tunnel. Fluoroscopic images were used to confirm augmentation (Fig. 3). The sutures slid within the tunnel without difficulty after the cement cured completely.

2.4. Group 3

Group 3 underwent standard transosseous suture placement with 2-mm suture tape. The same technique was used as in group 1, with the suture inserter loaded with suture tape instead of no. 2 suture.

2.5. Group 4

Group 4 underwent cement-augmented transosseous suture placement with 2-mm suture tape using the same technique as in group 2.

2.6. Testing protocol

A machinist vice was clamped into an adjustable-angle mount positioned at 20° to the horizontal (Fig. 4), consistent with typical clinical placement of anchors. In contrast to the testing set-up described by Leger St-Jean et al. (2015), which applied tension away from the axis of the humeral neck, we applied tension along the physiologic pull of the supraspinatus tendon, approximately parallel to the central axis of the humeral neck. Instead of distributing stress evenly across the bone tunnel, this direction of pull places more stress on the outside edge of the lateral tunnel, consistent with research findings that transosseous repairs place the highest stress concentration at the cortex of the greater tuberosity (Sano et al., 2007). Each humerus was mounted in the vice with cortical screws. The custom mount was then clamped to the base of a MTS Bionix 858 Tabletop Test System (MTS Systems Corporation, Eden Prairie, MN, USA). The sutures were tied around a rod attached to the actuator of the test system. The actuator pulled the sutures at a rate of 1 mm/s until failure occured. Load at failure and failure modes were recorded.

2.7. Statistical analysis

Statistical analysis was performed with Stata, version 12, software (StataCorp LP, College Station, TX, USA). The Shapiro-Wilk test and frequency histograms were used to assess continuous variables for normal distribution. All continuous variables—age, failure load, and bone mineral density (BMD)—followed a normal distribution. Comparisons of BMD and age between pairs were performed with Student *t*-tests. Sex distribution was compared using the Pearson chi-squared test. An unadjusted comparison of failure load between groups was performed with analysis of variance. Adjusted analysis with failure load as the dependent variable and augmentation, suture type, age, sex, BMD, and side (right/left) as covariates was performed with a generalized linear latent and mixed model with a random-effects term to account for sample pairing. Results are reported as means with 95% confidence intervals. Statistical significance was determined at $P < 0.05$.

3. Results

In two specimens, the sutures attached to the test system actuator slipped before the end of load-to-failure testing. Hence, the left humerus of one specimen and the right humerus of another specimen were excluded from analysis, leaving 20 specimens for analysis (Table 1). Sample force-displacement curves generated during testing are included in Supplementary Data (Fig. 5).

There were no significant differences in age or BMD between groups. Mean (± standard deviation) BMD in shoulders receiving normal suture (groups 1 and 2) was 0.59 ± 0.12 g/cm^2 versus 0.57 ± 0.08 g/cm^2 in shoulders receiving suture tape (groups 3 and 4) ($P = 0.597$). Mean age of cadavers was 76 years (range, 68–82) in groups 1 and 2 versus 79 years (range, 62–91) in groups 3 and 4 ($P = 0.493$). Seven of 11 cadavers were female; sex distribution was similar between groups ($P = 0.135$). In all specimens, failure occurred when suture cut through bone (Fig. 6, Supplementary Data). In cement-