J Shoulder Elbow Surg (2016) ■■, ■■–■■

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

ORIGINAL ARTICLE

Suture spanning augmentation of single-row rotator cuff repair: a biomechanical analysis

Nicholas A. Early, MD[a], John J. Elias, PhD[b,*], Steven B. Lippitt, MD[a], Danielle E. Filipkowski, MS[b], Robert A. Pedowitz, MD, PhD[c], William J. Ciccone II, MD[d]

[a]*Department of Orthopedic Surgery, Cleveland Clinic Akron General, Akron, OH, USA*
[b]*Department of Research, Cleveland Clinic Akron General, Akron, OH, USA*
[c]*University of California, Los Angeles, CA, USA*
[d]*Cornerstone Orthopedics, Wheat Ridge, CO, USA*

Background: This in vitro study evaluated the biomechanical benefit of adding spanning sutures to single-row rotator cuff repair.
Methods: Mechanical testing was performed to evaluate 9 pairs of cadaveric shoulders with complete rotator cuff repairs, with a single-row technique used on one side and the suture spanning technique on the other. The spanning technique included sutures from 2 lateral anchors securing tendon near the musculotendinous junction, spanning the same anchor placement from single-row repair. The supraspinatus muscle was loaded to 100 N at 0.25 Hz for 100 cycles, followed by a ramp to failure. Markers and a video tracking system measured anterior and posterior gap formation across the repair at 25-cycle intervals. The force at which the stiffness decreased by 50% and 75% was determined. Data were compared using paired *t*-tests.
Results: One single-row repair failed at <25 cycles. Both anterior and posterior gap distances tended to be 1 to 2 mm larger for the single-row repairs than for the suture spanning technique. The difference was statistically significant at all cycles for the posterior gap formation ($P \leq .02$). The trends were not significant for the anterior gap ($P \geq .13$). The loads at which the stiffness decreased by 50% and 75% did not differ significantly between the 2 types of repair ($P \geq .10$).
Conclusions: The suture spanning technique primarily improved posterior gap formation. Decreased posterior gap formation could reduce failure rates for rotator cuff repair.
Level of evidence: Basic Science Study; Biomechanics

Keywords: Rotator cuff; repair; biomechanical testing; gap formation; massive tear; in vitro

The primary goal of rotator cuff repair is to achieve sufficient initial fixation strength and resistance to gap formation to allow tendon-to-bone healing. Tendon-to-bone healing provides the best chance for good functional outcomes following repair.[14,31] Massive rotator cuff tears present additional challenges to achieving postoperative healing because of their large size, retraction, and tendon quality.[13] Rotator cuff tears >5 cm in length or involving 2 or more tendons are considered to be massive.[5,13]

Double-row rotator cuff repair was developed as an alternative to single-row repair to better approximate the anatomic rotator cuff footprint and to improve strength to facilitate healing. In vitro biomechanical studies have generally shown that gap formation and load to failure for double-row

*Reprint requests: John J. Elias, PhD, Department of Research, Cleveland Clinic Akron General, 1 Akron General Ave, Akron, OH 44307, USA.
E-mail address: john.elias@akrongeneral.org (J.J. Elias).

1058-2746/$ - see front matter © 2016 Journal of Shoulder and Elbow Surgery Board of Trustees. All rights reserved.
http://dx.doi.org/10.1016/j.jse.2016.07.012

repairs are superior to those for single-row repairs.[17,18,30] Double-row fixation techniques have also been shown to provide superior functional outcomes and decreased retear rates for treatment of massive cuff tears.[8,23] Difficulty in mobilizing a retracted tendon back to the bone footprint to allow 2 rows of anchors limits use of double-row techniques for massive tears, however. A recent study focused on massive cuff tears associated with pseudoparalysis indicated that double-row fixation could not be performed for 25% of the cases, even after extensive cuff release.[9]

Augmentation of single-row repairs could potentially improve fixation of massive rotator cuff tears that cannot be treated with double-row reconstruction. Spanning augmentation of a cuff repair was shown to significantly reduce gap formation for repaired tendons in vitro.[29] The previous study augmented single-row repair with an allograft secured within the tendon medially and to lateral anchors. Because of the expense of allograft tissue, spanning sutures are proposed as an alternative means to augment repair of massive rotator cuff tears.

This study was performed to evaluate spanning sutures as a means to augment single-row rotator cuff repair. Instead of suturing the tendon directly to the bone, as traditionally performed for double-row fixation techniques, the spanning sutures are secured adjacent to the musculotendinous junction. The sutures span a single row of anchors fixed directly to the tendon and are secured to anchors at the lateral margin of the anatomic supraspinatus tendon insertion. The hypothesis of the study is that augmentation with spanning sutures will improve postoperative yield strength and gap formation of a repaired tendon compared with single-row repair.

Materials and methods

In vitro biomechanical testing was performed to determine if augmenting single-row rotator cuff repair with spanning sutures improves gap formation and fixation strength. Eleven pairs of cadaveric shoulders were tested, with an average age (± standard deviation) of 70 ± 10 years. All specimens were examined and determined to be free of existing rotator cuff disease in either shoulder. The rotator cuff muscle bellies were dissected from the scapula, and all soft tissues except the supraspinatus tendon were dissected from the humerus. The supraspinatus tendon was sharply elevated from the insertion on the tuberosity. For each pair of specimens, a standard single-row rotator cuff repair was performed on 1 shoulder and the suture spanning technique performed on the other, varying the side (right vs. left) repaired with each technique throughout the series of tests. The standard single-row technique was performed with 2 triple-loaded anchors (6.5-mm Healix; DePuy Synthes Mitek, Raynham, MA, USA) inserted at a 45° angle along the articular margin of the humerus (Fig. 1). The anchors were placed 15 mm apart. Sutures were passed 1 cm from the rotator cuff tendon edge in a simple configuration and tied with Samsung Medical Center (SMC) knots backed up by 5 alternating half-hitches with alternating posts. Passing the sutures 1 cm from the tendon edge aligned the tendon slightly medial of the footprint to represent tendon retraction. The suture spanning technique was performed by augmenting the single-row technique. Two

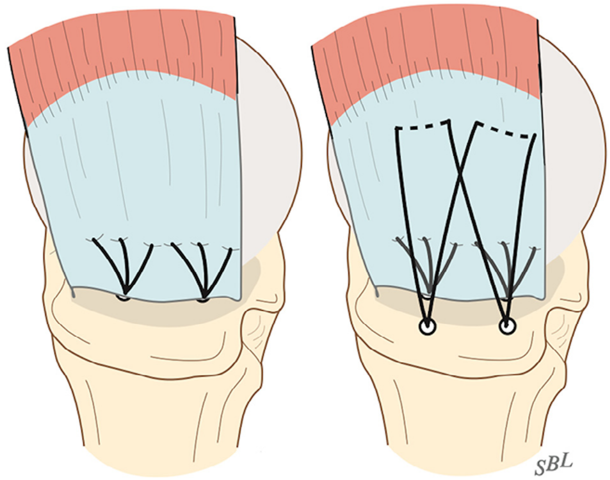

Figure 1 Schematic diagrams of the surgical techniques for single-row (*left*) and single-row augmented with spanning sutures (*right*) rotator cuff repair.

free sutures (Orthocord, DePuy Synthes Mitek) were passed through the tendon in a mattress configuration 3 to 4 mm lateral to the musculotendinous junction. Two 6.5-mm triple-loaded anchors were implanted as described for the single-row repair. The spanning sutures were not tied and were passed in a crisscross pattern laterally over the triple-loaded anchors and were fixed at the lateral edge of the footprint on the greater tuberosity with 2 knotless anchors (4.75-mm Healix). The spanning sutures were made taught under direct visualization, taking care to preserve the normal length of the tendon.

The distal end of each humerus was potted in a low-melting-point alloy and fixed at a 45° angle of abduction (Fig. 2). Two pairs of black 3-mm marking spheres were secured to the specimen to measure displacement. Two were placed at the lateral edge of the footprint and were secured to the greater tuberosity of the humerus. The other 2 markers were sutured into the anterior and posterior aspects of the tendon, at the approximate level of the sutures from the triple-loaded anchors. The supraspinatus muscle was secured within a tissue clamp frozen with dry ice. The clamp was secured to the actuator of a material testing machine (MTS, Eden Prairie, MN, USA), with a rotational degree of freedom in the plane of the tendon. The rotational degree of freedom allowed the clamp to adjust to differences in stiffness between the anterior and posterior aspects of the tendon and to maintain nearly constant tension along the width of the tendon. The repaired tendons were preloaded to 10 N for 1 minute, followed by cyclic loading to 100 N[1,4,20] for 50 cycles at 0.25 Hz. Two shoulders were overloaded at the first cycle of loading, so 2 pairs were not included in the analysis. Overloading was caused by poor feedback as the actuator approached the peak load, likely related to initial alignment or fixation of the specimen, causing the actuator to vibrate. Preliminary tests showed that the deformation reached a steady state by 50 cycles. Following cyclic loading, each tendon was loaded to failure at 1 mm/s. The maximum load during the test to failure was recorded (Fig. 3). The force levels at which the stiffness of the force vs. deformation curve recorded by the material testing machine decreased by 50% (initial yield load)[21] and 75% were also quantified.

A video-based motion analysis system (MaxTRAQ; Innovision Systems Inc, Columbiaville, MI, USA) was used to measure motion of the markers for the first loading cycle and cycles 25, 50, 75, and