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Biomechanical comparison of suture anchor versus margin convergence plus suture anchor for rotator cuff repair

Shi-yi Chen MD, PhD^{1,2}, Hilary L Malcarney MD², George A C Murrell MD, PhD²

¹Department of Sports Medicine and Arthroscopy Surgery, Fudan University Sports Medicine Center, Huashan Hospital, Shanghai, China; and ²The Sports Medicine and Shoulder Service, Orthopaedic Research Institute, St. George Hospital Level 2, Sydney, New South Wales, Australia

Objective: To evaluate results of margin convergence versus suture anchors in rotator cuff repair, and to determine which method is mechanically superior.

Methods: Eighteen kangaroo shoulders were randomly divided into three groups ($n = 6$). A full thickness tendon defect $1.0 \text{ cm} \times 1.5 \text{ cm}$ in size was created in the supraspinatus tendon at humeral insertion, simulating a massive rotator cuff tear. Three different techniques were employed for rotator cuff repair: (i) Mitek GII suture anchor alone (Group 1); (ii) margin convergence alone (Group 2); and (iii) margin convergence plus Mitek GII suture anchor (Group 3). Combined loads were applied to each specimen. After completion of cyclic loading, the construct was loaded to failure. ANOVA and LSD (Least Significant Difference) multiple comparisons of the means were applied to results.

Results: Cyclic load testing showed progressive gap formation in each repaired specimen with increasing cycles. Group 1 reached 50% failure at an average of 34 cycles, Group 2 at 75 cycles and Group 3 at 73 cycles. There were significant difference between Groups 1 and 2, and Groups 1 and 3 ($P \leq 0.001$). After 100 loading cycles, the average gap size was 6.8 mm, 6.1 mm and 4.7 mm in Groups 1, 2 and 3, respectively. There was a significant difference between Groups 1 and 3 ($P \leq 0.015$). All specimens eventually reached failure.

Conclusion: Rotator cuff repairs with margin convergence +/- suture anchor were far stronger than suture anchor alone, both in gap formation and ultimate failure load. However, progressive gap formation with cyclic loading seems inevitable after cuff repair, which may facilitate clinical understanding of the phenomena of re-tear or residual defect.

Key words: Biomechanics; Rotator cuff; Shoulder

Introduction

Rotator cuff tears are a common cause of shoulder pain and dysfunction. Modern techniques of rotator cuff repair, including mini-open and arthroscopic repairs, have achieved satisfactory results of between 80% and 95%^{1–4}. However, some high rates, between 25% and 50% or even much higher, of residual defects or re-tear after rotator cuff repair have been described^{3–6}. One of the proposed reasons for this high re-tear rate is the high tension present at the sutured site. According to Burkhart⁷, rotator cuff tears can

be broadly classified into two patterns: Crescent-shaped or U-shaped tears. Crescent-shaped tears can be easily repaired to bone with minimal tension. U-shaped tears generally have greater tendon retraction medially than crescent-shaped tears, usually extending to the glenoid, or even medial to the glenoid. For large U-shaped cuff tears, the increase in suture tension will affect healing between the bone-tendon or tendon-tendon interface, which will result in a higher failure rate at the sutured site postoperatively both in clinical and experimental settings.

Some techniques for rotator cuff repair, such as suture anchor, margin convergence, tendon transfer or biological scaffold repair have been developed to decrease suture tension and improve the strength of rotator cuff tear repairs. Burkhart *et al.* have advocated that margin convergence be applied to rotator cuff repair as a means of enhancing the security of fixation by decreasing the mechanical strain at the margins of the tear^{1,7–11}. Burkhart

Address for correspondence Shi-yi Chen, MD, PhD, Department of Sports Medicine and Arthroscopy Surgery, Fudan University Sports Medicine Center, Huashan Hospital, Shanghai, China 200040 Tel: 0086-021-52888255; Fax: 0086-021-62496020; Email: cshiyi@163.com

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et al. have reported that U-shaped tears repaired by margin convergence achieve results comparable to those of crescent-shaped tears repaired directly by a tendon-to-bone technique, with good and excellent results achieved in 95% of cases, regardless of tear size¹. Steven and Morgan did a retrospective study on 69 patients with medium to massive rotator cuff tears using the technique of arthroscopic rotator cuff margin convergence⁴. They reported that arthroscopic repair of medium to massive rotator cuff tears has an 88% good to excellent outcome.

Biomechanical evaluation of the failure mode of rotator cuff repairs under cyclic loading has been conducted by Burkhart *et al.*^{1,9}, Rossouw *et al.*¹² and Cummins *et al.*¹³. They found the repaired cuffs underwent progressive failure with constant cyclic loading or increased cyclic loading.

The purposes of this study were to evaluate the effect of margin convergence on rotator cuff repair strength. Three methods of rotator cuff repairs (margin convergence, Mitek GII super suture anchor and margin convergence plus Mitek GII suture anchor) were tested to determine which method was mechanically superior.

Materials and methods

This *ex vivo* biomechanical study was conducted on 18 kangaroo shoulders (age 12–20 months). All kangaroo shoulder specimens were obtained from a local meat distributor within 24 h of death.

Each shoulder specimen was prepared by removing all soft tissue whilst preserving the humerus, scapula, supraspinatus muscle and insertion sites. A standardized template was used to map out a full thickness tendon defect through the supraspinatus tendon adjacent to the humeral insertion site. The size of the defect was 10 mm wide × 15 mm long, which is approximate 3/4 of the area of the exposed supraspinatus tendon in the kangaroo shoulder (Fig. 1). It was hypothesized that this model

Figure 1 A full thickness tendon defect was made in kangaroo shoulders through the supraspinatus tendon, adjacent to the site of humeral head insertion, using a template of 10 mm × 15 mm.

Figure 2 Shoulder repair techniques (a) Group 1, repair with suture anchor only ($n = 6$). (b) Group 2, repair with margin convergence only ($n = 6$). (c) Group 3, repair with margin convergence plus suture anchor ($n = 6$).

simulated a large U-shaped rotator cuff tear in the human shoulder.

The suture material used was No.2 Ethibond suture (Ethicon, Norwood, MA, USA). The suture anchor was the Mitek GII super suture anchor (Mitek Surgical Products, Boston, MA, USA) which has a bullet-shaped titanium-alloy body with an eye for suture attachment and four nitinol wire barbs.

The shoulders were randomly divided into three experimental groups ($n = 6$ for each group) and the supraspinatus tendon was repaired via three different methods (Fig. 2a–c).

Group 1 was repaired with Mitek GII super suture anchors only. The torn cuff was pulled directly to bone

using two Mitek GII super suture anchors set 5 mm apart. Mitek GII suture anchors were inserted at 45 degrees to the surface of the bone adjacent to the articular surface. Each suture was passed through the rotator cuff tendon 1 cm from its free margin, in mattress stitch pattern configuration, and tied manually with a stacked square knot of four throws. The knot was tied over the top of rotator cuff tissue to simulate arthroscopic knot placement.

Group 2 was repaired with margin convergence only. The rotator cuff was repaired with three side-to-side sutures to converge the free margin of the rotator cuff tear at 3 mm intervals. Each suture was tied manually with a stacked square knot of four throws each. The knot was tied over the top of rotator cuff tissue to simulate arthroscopic knot placement.

Group 3 was repaired with margin convergence plus suture anchor. The rotator cuff tear was repaired first by margin convergence as described in Group 2. The free tendon margin was then attached to bone using two Mitek GII super suture anchors as described in Group 1.

Fixation and loading of specimen

The shaft of the humerus was fixed to the base of an INSTRON tensile testing system (Instron Limited, High Wycombe, UK) using a vice. The scapula, pre-mounted in an aluminum box section with dental stone (Agrirock, Agribond Dental Laboratory Supplies, Victoria, Australia), was connected to the load cell and actuator via a universal joint. The universal joint allowed free movement of the scapula except in the direction of loading. The repaired cuff was tensioned along the line of supraspinatus contraction, which simulated an *in vivo* isotonic shoulder abduction situation.

Biomechanical testing

Each specimen firstly underwent cyclic loading (10–180 N) at 33 mm/s, with a two second hold period at maximum tensioning and relaxing, until 100 cycles were reached. The specimen was then loaded to failure at a constant rate of 5 mm/min. Force, displacement and time data was collected.

Digital vernier calipers were used to measure progressive gap formation at the repair site. This was recorded separately with the number of cycles and mode of failure. A 5 mm gap was classed as 50% failure and a 10 mm gap as complete failure (the original defect had a length of 10 mm). If complete failure had not occurred after 100 cycles, the size of the gap was recorded before the ultimate failure load was determined under the 5 mm/min constant loading. Ultimate failure was defined as 10 mm gap

formation with or without any breakage of the suture-tendon, suture-anchor, bone-tendon, or tendon-muscle interface.

Statistical analysis was processed using ANOVA (analysis of variance). Fisher's LSD (Least Significant Difference) multiple comparisons test of the means was applied when the F test in ANOVA was significant ($P < 0.05$). The statistical significance level was set at $P \leq 0.05$ for all tests.

Results

Cyclic load test and gap formation

Progressive gap formation was noted in each repaired specimen. Group 1 attained 50% failure (5 mm gap formation) at an average of 34 cycles, Group 2 at 75 cycles and Group 3 at 73. There were significant differences between Groups 1 and 2 ($P \leq 0.001$), as well as Groups 1 and 3 ($P \leq 0.001$), and no statistical difference between Groups 2 and 3.

By 100 cycles, the size of the gap formed was an average of 6.8 mm, 6.2 mm and 4.7 mm for Groups 1, 2 and 3, respectively. There was a significant difference between Groups 1 and 3 ($P \leq 0.015$) and Groups 2 and 3 ($P \leq 0.035$), and no difference between Groups 1 and 2 (Fig. 3).

The above results indicate more rapid gap formation in the rotator cuff repair in Groups 1 and 2 than that in Group 3, and no difference in gap formation at 100 cycles between Groups 1 and 2.

Ultimate failure load

All specimens reached the ultimate failure point (10 mm gap formation with or without any breakage of

Figure 3 Gap formation measured at 100 cyclic loading for Groups 1, 2 and 3. There is a significant difference between *Groups 1 and 3 ($P \leq 0.015$), #Groups 2 and 3 ($P \leq 0.035$).

Figure 4 Ultimate failure load. Ultimate failure occurred at 374 ± 13 N for Group 1, 415 ± 37 N for Group 2 and 464 ± 63 N for Group 3, respectively. *A significant difference between Groups 1 and 3 ($P = 0.019$).

suture, tendon, or anchor pull-out). Ultimate failure occurred at 374 ± 13 N for Group 1, 415 ± 37 N for Group 2 and 464 ± 63 N for Group 3, respectively (Fig. 4). Statistical analysis showed that there was a significant difference in ultimate failure load between Groups 1 and 3 ($P = 0.019$) but no difference between Groups 2 and 3 ($P = 0.098$), or between Groups 1 and 2 ($P = 0.239$).

Failure site

For Group 1 the failure site varied, with two specimens demonstrating suture breakage at the anchor, two had tendon-suture ruptures, and the remaining two failed at the muscle-tendon junction. All Group 2 specimens failed at the muscle-tendon conjunction except for one failure with knot loose. In Group 3, three of six specimens demonstrated tendon failure, two were muscle tear and one failed at the suture anchors.

Discussion

We have recently examined ten kangaroo shoulders and made comparisons with the human shoulder on both arthroscopic and gross inspection. Although smaller in size, the kangaroo shoulder is strikingly similar to the human shoulder. Bone and soft tissue structures are essentially the same. Differences are related to a more internally rotated scapula in the kangaroo. Specific to the rotator cuff, the kangaroo has a smaller and shorter tendon but the same origin/insertion sites as the human, with similar muscle development and tendon quality. We believe that the kangaroo is an excellent model for the human rotator cuff in open, as well as arthroscopic studies (Shi-yi Chen *et al.* unpublished data, 2004).

The strength of rotator cuff fixation has traditionally been assessed by loading rotator cuff repair to failure by a single pull to the ultimate load. Burkhart *et al.* used a constant cyclic loading, at the rate of 33 mm/s, and maximal load of 180 N, duration of 5 s each cycle, to reach failure in their rotator cuff repair study^{9,10}. Rossouw *et al.* introduced increased cyclic loads at first from 0 to 50 N at 50 mm/min for ten cycles, then increased to 100 N for another ten cycles, and by 50 N for each subsequent set of ten cycles until failure¹². Rossouw *et al.* have indicated that future testing for strength of rotator cuff repair should include cyclic as well as static loading. To our knowledge, most clinical rotator cuff re-tears occur as a result of repetitive shoulder movement or an acute overload incident. We used combined loading, first with cyclic loading following by steady pull force to failure to simulate these *in vivo* loading conditions.

For rotator cuff repair, suture anchors have the advantage of providing the surgeon with quick and easy reattachment of the torn cuff tendon. However, after massive tear tendon retraction this method can result in tension concentration both at the anchor-suture and tendon-suture interface^{9,14–16}. The margin convergence methodology proposed by Burkhart *et al.* facilitates changing a big tear into a small one, which results in sutures with less tension^{1,9–12}. In biomechanical studies, Burkhart *et al.* have shown the importance of balancing the force couples between the anterior and posterior margins of the torn tendon. When this is done appropriately, a balanced shoulder is maintained, establishing a stable fulcrum of glenohumeral motion. This technique has been shown to be especially effective in those with a large U-shaped tear.

Burkhart *et al.* have evaluated 62 patients with either crescent shaped or U-shaped tears¹. The size of the tears ranged from small to massive. Fifteen of their patients were treated with margin convergence suturing only. Overall, 56 of 59 patients who were followed up had good or excellent results in the UCLA scoring system. Burkhart *et al.* indicate that complete closure of the defect is not necessary for a good and excellent result. The key point is to restore the force couples, and this determines the final result.

In our study, it is apparent that the use of suture anchors alone to directly repair cuff tendon to bone results in inferior mechanical properties. Gap formation reached its maximal size after limited cyclic loading, and ultimate failure occurred at lower loads than with the other two techniques. This would increase the probability of early construct failure. We think that this early failure can be attributed to increased tension concentration resulting in suture failure at the anchors and/or tendon (failure at 374 N). However, the rotator cuffs repaired with margin

convergence or margin convergence plus suture anchor were much stronger, as demonstrated by the much higher loads (415 N and 464 N) required to induce ultimate failure. We believe this greater strength is because of reduction in the suture tension.

Comparing the technique of margin convergence with the technique of margin convergence plus suture anchor, there was no statistically significant difference between the two techniques with respect to ultimate failure loads except in gap formation at 100 cycles. However, we noticed that progressive gap formation after cuff repair, regardless of technique^{1,4,9,13}, is present after a number of loading cycles, suggesting that gap formation would inevitably occur after repair of rotator cuff tears. This presents the surgeon with the dilemma of whether to protect a repair by immobilization or to preserve function by early mobilization to prevent stiffness and weakness. The question therefore is: what postoperative treatment regime will protect the repair and still allow enough movement to improve range of movement.

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