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An *in-vitro* study of rotator cuff tear and repair kinematics using single- and double-row suture anchor fixation

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ABSTRACT

Purpose: Double-row suture anchor fixation of the rotator cuff was developed to reduce repair failure rates. The purpose of this study was to determine the effects of simulated rotator cuff tears and subsequent repairs using single- and double-row suture anchor fixation on three-dimensional shoulder kinematics. It was hypothesized that both single- and double-row repairs would be effective in restoring active intact kinematics of the shoulder.

Materials and Methods: Sixteen fresh-frozen cadaveric shoulder specimens (eight matched pairs) were tested using a custom loading apparatus designed to simulate unconstrained motion of the shoulder. In each specimen, the rotator cuff was sectioned to create a medium-sized (2 cm) tear. Within each pair, one specimen was randomized to a single-row suture anchor repair, while the contralateral side underwent a double-row suture anchor repair. Joint kinematics were recorded for intact, torn, and repaired scenarios using an electromagnetic tracking device.

Results: Active kinematics confirmed that a medium-sized rotator cuff tear affected glenohumeral kinematics when compared to the intact state. Single- and double-row suture anchor repairs restored the kinematics of the intact specimen.

Conclusions: This study illustrates the effects of medium-sized rotator cuff tears and their repairs on active glenohumeral kinematics. No significant difference ($P \geq 0.10$) was found between the kinematics of single- and double-row techniques in medium-sized rotator cuff repairs.

Clinical Relevance: Determining the relative effects of single- and double-row suture anchor repairs of the rotator cuff will allow physicians to be better equipped to treat patients with rotator cuff disease.

Key words: Double-row, glenohumeral joint, rotator cuff, single-row, suture anchor repair

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INTRODUCTION

Rotator cuff tears are a common cause of shoulder pain and dysfunction. The prevalence of full and partial thickness defects increases linearly with age after 50 years, and by the age of 80 years, they exist in 80% of the population.[1] Patients with similar rotator cuff pathology manifest with varying symptoms and functional limitations. The influence of rotator cuff pathology on glenohumeral kinematics is not well documented in the literature, although several authors have speculated on the wide disparity of functional abilities of patients with grossly similar pathology.[2,3]

A number of cadaveric studies have examined the effects of rotator cuff pathology on shoulder kinematics.[4-7] Collectively, these studies suggest that increasing the size of the rotator cuff tear will result in an increased alteration of kinematics. Currently, there is little information available on the effect of rotator cuff tears on active kinematics *in-vitro*. Kedgley *et al.* examined the effects of sequential one, two, and three cm

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rotator cuff tears that were created in the supraspinatus tendon and extended into the subscapularis tendon.[8] The humeral head was displaced posteriorly with progressively larger tears of the rotator cuff during active shoulder elevation. The authors concluded that increasing the size of the rotator cuff tear resulted in greater alterations in glenohumeral kinematics.

The goals of surgical repair of rotator cuff tears are to restore the anatomic relationship between the tendons and their osseous footprints on the humerus. Several different repair techniques have evolved since Codman's description in 1934.[9] Common open and arthroscopic techniques include transosseous suture repair or the use of suture anchors in either a single- or double-row repair configuration.[10,11] Superiority of one technique over another has not been established.

Several recent studies have examined the biomechanical properties and clinical outcomes of the different repair techniques. Biomechanical studies have found double-row constructs to be stronger than single-row constructs in both cadaveric[7,12-18] and animal[19-23] models. In addition, double-row repairs can restore the tendon footprint more accurately[15,23-25] and are associated with higher rates of tendon healing than single-row repairs.[26] It has also been suggested that double-row repairs are preferable for cases with retracted tendons.[13] Despite the biomechanical advantage, clinical studies have failed to show a distinct advantage favoring the double-row repair technique.[26-30]

In addition to ensuring mechanical integrity of these reconstructions, the resulting glenohumeral joint motion is also important. However, we are unaware of any studies that have examined the effect of different suture anchor repairs on shoulder translations. Hence, the purpose of this study was to determine active glenohumeral kinematics with simulated 2 cm-sized rotator cuff tears. In addition, the ability of single- and double-row suture anchor repair to restore intact glenohumeral kinematics was also compared. We hypothesized that (1) two cm defects in the rotator cuff would have a minor effect on simulated active glenohumeral kinematics and that (2) both single- and double-row suture anchor fixation would restore normal active intact motion.

MATERIALS AND METHODS

Eight pairs of fresh-frozen cadaveric upper forequarters (mean age: 66 ± 9 years; range: 46-74 years; 5 male) were used. All specimens had no evidence of previous surgery, trauma, glenohumeral arthritis, or rotator cuff tendonopathy. Specimens were thawed to room temperature (mean 23°C (±2°C)) and were kept moist with 0.9% saline throughout testing.

Testing procedure

A shoulder testing simulator that creates active unconstrained glenohumeral elevation was employed.[31] Specimens were prepared by osteotomy of the distal humerus at mid-shaft, exposure of the anterior deltoid, and exposure of the inferior border of the scapula. A 316 stainless-steel rod, with weights added to be equivalent to the intact arm, was cemented into the distal humeral canal. Equivalence between the intact arm and the weighted rod was verified with a spring scale.[31] Each specimen was mounted to the simulator by securing the inferior pole of the scapula into a custom pot with polymethylmethacrylate. Muscle simulation was achieved by suturing pneumatically actuated cables to the tendons of the rotator cuff muscles – supraspinatus, subscapularis, and infraspinatus/teres minor, and attaching three cables to the deltoid tuberosity to simulate the three heads of the deltoid muscle. Forces were applied to the individual cables using a previously described set of loading ratios.[31] These were based upon electromyographic (EMG) data[32] and the relative physiological cross-sectional areas of the muscles.[33] The forces varied according to the angle of elevation of the humerus and were different for each specimen.[31] The relative motion of the humerus with respect to the scapula was collected with an electromagnetic tracking device (Flock of Birds, Ascension Technologies, Burlington, USA). The receivers for the tracking system were fixed to the superior border of the scapula and the rod that replaced the distal humerus.

Passive glenohumeral elevation in the plane of the scapula was conducted to ensure no impingement occurred as a result of fixation. Initial testing was performed with the rotator cuff intact. Small tone loads of between 20N and 30N were applied to the rotator cuff muscles at the start of each cycle of motion.[31] These loads were selected to ensure that the humeral head was centered in the glenoid socket when the motion began. Five trials of both passive and active motions were conducted to allow quantification of repeatability.[31] Elevation was defined as movement in the scapular plane from approximately 0° to 90° of glenohumeral elevation.

The experimental protocol is given in Figure 1. Following intact testing, a deltoid splitting technique was used to expose the rotator cuff for creation of a 1 cm (mediolateral) by 2 cm (anteroposterior) defect in the anterior supraspinatus, which began at the rotator interval and propagated posteriorly. One centimeter of the supraspinatus tendon was resected to simulate the clinical scenario of tendon retraction. The deltoid muscle and skin incisions were closed with a running suture prior to recording the simulated active motion of the new torn state. Following testing, one shoulder from each of the eight pairs was randomized to undergo rotator cuff repair using a single-row suture anchor technique, while the contralateral shoulder was repaired using a double-row suture anchor technique.[10] All repairs were performed with 5.5 mm threaded metal anchors double-loaded with #2 high strength suture (Arthrex, Naples, USA). The single row repair was performed by placing one anchor into the midportion of the greater tuberosity footprint. The rotator cuff was repaired with simple sutures placed into the lateral edge of the tendon. The double-row repair was performed by placing one anchor adjacent to the articular margin, and a second anchor was placed at the lateral edge of the greater tuberosity.[10] The medial row was repaired using two mattress sutures, and the lateral row was repaired with two simple sutures. Once the repair was completed, motion trials were repeated.

Outcome variables and statistical analysis

Repeatability of the trials was quantified by using the standard deviation of the five trials at each position.[31] A segment-fixed co-ordinate system was created on each of the scapula and humerus to allow calculation of the glenohumeral joint kinematics.[34] The plane of abduction and the position of the humeral head relative to the fixed scapula were analyzed at every 10° of glenohumeral elevation. The relative motion of the humeral head with respect to the scapula was also quantified.

Statistical analyses were performed using a Friedman Repeated Measures Analysis of Variance (ANOVA) on Ranks. The dependent variables considered were the angle of abduction and the torn or repaired state. Statistically significant differences were defined as $P < 0.05$.

RESULTS

Within all pairs of intact specimens, no statistically significant side-to-side differences were observed. Therefore, the measurements for the left and right cases were averaged and included in the Friedman Repeated Measures ANOVA as one entity. In addition, no significant differences were found between passive and active intact glenohumeral elevation of the specimens through the range of motion. Statistical analyses were performed at every 10° of elevation, through an arc of 20° to 80° of glenohumeral elevation.

Intact versus defect condition

The plane of elevation exhibited was altered between the intact and the simulated tear states ($P = 0.01$) [Figure 2]. The 2 cm defect resulted in posterior angulation of the plane of elevation through the arc of abduction. This was greatest at the mid-portion of abduction (40°-60°) with an overall average of 8° posterior shift when compared to the intact kinematic state. The angle of internal-external rotation of the humerus was not affected by the simulated tear [Figure 3]. Similarly, no differences in the position of the humeral head were observed as a result of the simulated defect [Figure 4].

Defect versus repair condition

Once repaired, a significantly different plane of elevation was achieved [Figure 2]. This was true of both the single row suture anchor repair ($P < 0.001$) and the double-row suture anchor repair ($P = 0.001$). In both cases, the plane of elevation was shifted anteriorly by the repair. The internal-external rotation angle and position of the humeral head were not altered by the repair [Figures 3 and 4].

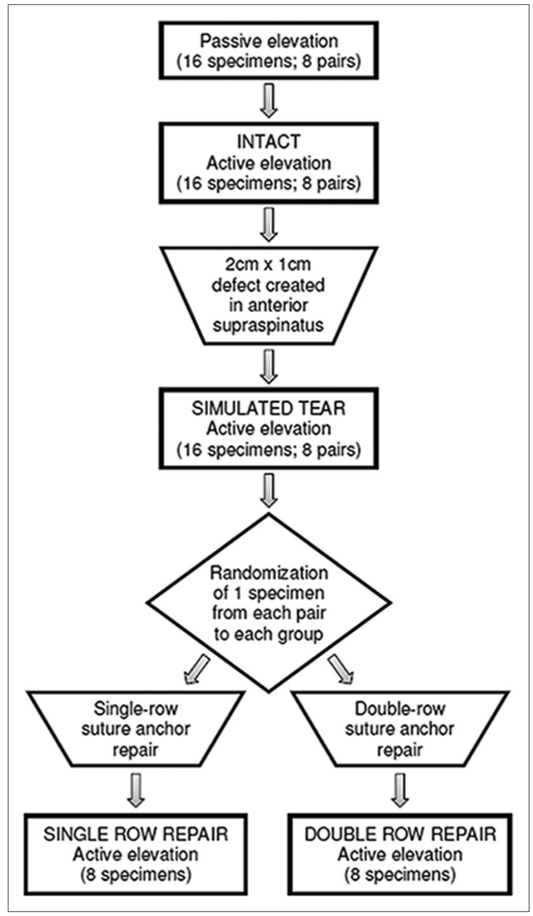

Figure 1: An overview of the experimental procedure

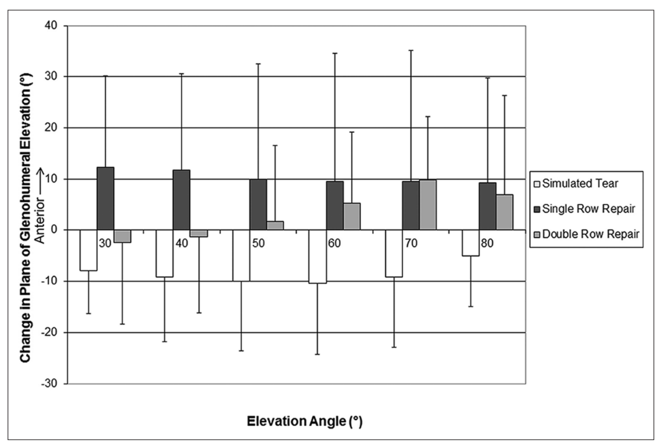

Figure 2: Change in plane of glenohumeral elevation from the intact state as a function of elevation angle for all states. Mean (±1 SD) for all specimens presented for 30° to 80° of elevation

Intact versus repair condition

Single- and double-row suture anchor repairs were able to restore the intact kinematic state of the glenohumeral joint for 2 cm rotator cuff defects ($P = 0.10$) [Figure 2]. Single row suture anchor repair resulted in a slightly anterior angulation of the plane of elevation on average when compared to the intact kinematic state. Double-row suture anchor repair

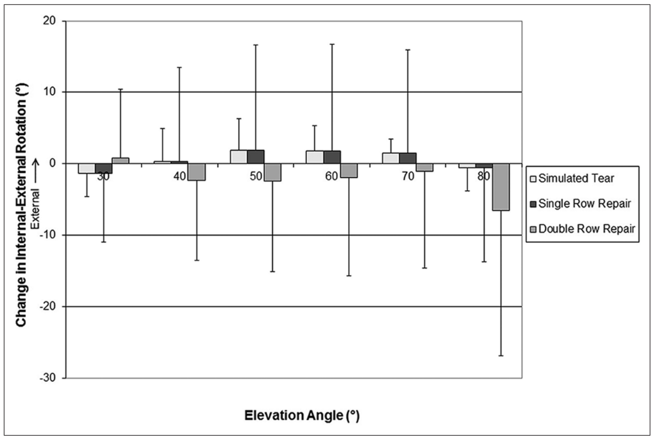

Figure 3: Change in internal-external rotation angle from the intact state as a function of elevation angle for all states. Mean (±1 SD) for all specimens presented for 30° to 80° of elevation

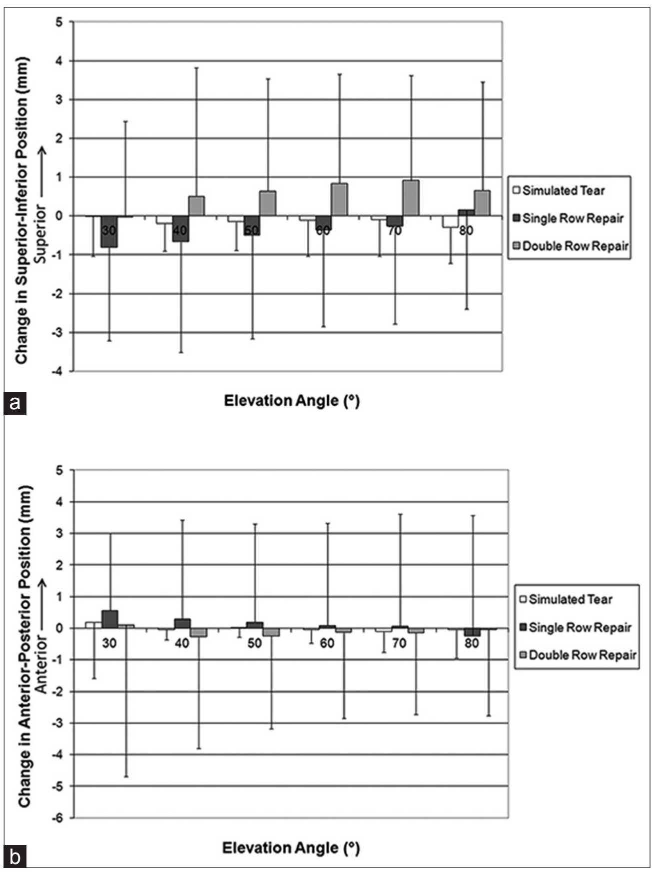

Figure 4: Change in (a) superior-inferior and (b) anterior-posterior position of the humeral head from the intact state as a function of elevation angle for all states. Mean (±1 SD) for all specimens presented for 30° to 80° of elevation

resulted in a similar plane of elevation as that observed in the intact state ($P = 1.00$). No differences in the plane of elevation were observed between the two repairs ($P = 0.10$). Both single- and double-row repairs resulted in increased variability in the change of the internal-external rotation angle of the humerus [Figure 3], but no statistically significant differences were observed. Likewise, the position of the humeral head was not altered as a result of the repairs. The results of all the comparisons are summarized in Table 1.

Table 1: Differences in the plane of glenohumeral elevation summarized for all specimens in all angles of elevation. No differences were observed in the internal-external rotation angle, superior-inferior position, and anterior-posterior position

Test Condition	Simulated tear	Single-row repair	Double-row repair
Intact	P=0.01	No difference	No difference
Simulated tear		P<0.001	P=0.001
Single-row repair			No difference

DISCUSSION

Over the last decade, arthroscopic shoulder techniques and equipment have improved the ability to perform minimally invasive repairs to the rotator cuff tendons. The literature has demonstrated that single- and double-row repairs are safe and effective.[11,35] The purpose of this study, unlike prior biomechanical studies that examined the relative strength double-row cuff repair,[13,14,16-18] was to illustrate the kinematic effects of single- and double-row suture anchor repairs of 2 cm supraspinatus tears on simulated active glenohumeral joint kinematics.

The effects of a simulated 2 cm defect in the supraspinatus tendon in this study were similar to the results found previously by Kedgley *et al.*[8] As theorized, no changes were found in the internal-external rotation of the humerus or the position of the humeral head with elevation, though the 2 cm defect did result in an alteration in the plane of elevation with a mean change of 8° posteriorly. These results would perhaps be expected; however, compensation likely occurs *in-vivo* with a medium-sized tear such as this. Glenohumeral subluxation was not expected,[8] and did not occur.

Our observations did not demonstrate any significant differences in the plane of elevation between single- and double-row repairs. These findings are in agreement with clinical findings in the literature. Sugaya *et al.*, in a retrospective cohort study, compared the functional and structural outcomes of single-row versus double-row rotator cuff repair.[30] At a follow-up 35 months, no statistically significant differences in clinical outcome could be appreciated between the two different repair techniques. Franceschi *et al.*, in a randomized controlled clinical trial, compared 30 patients who received a single-row repair and 30 patients who received a double-row repair. At two years follow-up, there was no clinically significant difference between the two different repair techniques.[28] In this study, there are a number of possible reasons that may account for the results.

First, all rotator cuff repairs were performed with suture anchors that create focal sites of tendon reattachment to the greater tuberosity. In an *in-vitro* study, integration of the tendon to the tuberosity does not occur, and restoration of normal force distribution from a pennate muscle across the tendon-bone interface is unlikely. In both repair conditions, the focal sites of tendon reattachment were similar. *In-vivo* repair studies may be capable of identifying kinematic differences among repair techniques that result in proportionately different rates of healing at the bone-tendon interface.

Second, there was variability in the size of the cadaveric specimens that were tested. A 2 cm defect may behave differently in a small specimen than in a large specimen and may have affected our ability to detect a change following the simulated tears. Simulating tears that are proportional to the size of the specimen rather than based on an absolute dimension may have resulted in more physiologically relevant results, although they should not have influenced the comparison of the repair types. This supports the generalized trend toward more accurate restoration of the intact glenohumeral kinematics was seen in double-row suture anchor repair for a 2 cm defect of the supraspinatus.

Third, rotator cuff pathology is often a chronic and progressive disorder that may occur in conjunction with adaptive changes in adjacent muscles.[3] In contrast, this study examined the kinematics of an acute lesion, and repair of the rotator cuff and may not accurately reflect the more common clinical scenario seen in patients with chronic rotator cuff disease. The primary factors that contribute to shoulder stability remained functional, including the glenohumeral articular structures and capsulolabral complex. In a clinical situation, this would likely not be the case, as some degree of degradation would have occurred throughout the cuff tissue.[36] However, had the specimens already exhibited pathology of the rotator cuff, we would have been unable to compare the repaired and intact states.

Fourth, this study simulated a chronic clinical scenario by creating an acute defect in the rotator cuff to mimic tendon retraction. Shortening the tendon may have inadvertently created the anterior angulation seen in the plane of elevation with our suture anchor repairs. However, there are also theories that a biochemical mediator may cause a damaged rotator cuff to retract.[37] Similarly, the re-attachment of the tendon most likely imposed the observed increased variability in the internal-external rotation angle of the humerus.

Unfortunately, the use of a deltoid split to produce the rotator cuff tear may not represent the same biomechanics, as that which would be observed had an arthroscopic approach been taken. However, no deltoid failures occurred during testing, and a previous study showed very little alteration of glenohumeral kinematics with a 1 cm rotator cuff tear created in the same way.[8]

There are some noteworthy strengths of this study. The paired, randomized, and controlled nature of this study did generate results of significant merit. Furthermore, a unique, validated shoulder simulator capable of simulating active glenohumeral joint motion using a physiologically-based muscle loading protocol was employed.

CONCLUSIONS

In summary, a 2 cm defect in the supraspinatus alters the kinematics of the glenohumeral joint by moving the humeral plane of elevation posteriorly. Both single- and double-row repair techniques resulted in restoration of normal kinematics when compared to the intact state. We did not find a significant difference in glenohumeral kinematics between the two repair techniques. Further studies are warranted to ascertain which repairs afford patients optimal functional and clinical results. With an improved understanding of the kinematics of the glenohumeral joint, physicians will be better equipped to treat patients with rotator cuff disease.

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