In Vivo Measurement of Rotator Cuff Tear Tension: Medial Versus Lateral Footprint Position

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Abstract

We conducted a study to evaluate in vivo tension applied to the rotator cuff tendon positioned at the medial versus lateral footprint during arthroscopic rotator cuff repair.

We evaluated 20 consecutive patients who underwent arthroscopic rotator cuff repair. During repair, a grasper was inserted through a lateral portal, and a digital weigh scale was attached. The tendon was grasped and translated to the medial footprint, and tension recorded. After a relaxation period, the tendon edge was translated to the lateral footprint, and tension recorded.

Mean (SD) tension was 0.41 (0.33) pound when tendons were positioned at the medial footprint and 2.21 (1.20) pounds when they were positioned at the lateral footprint, representing a 5.4-fold difference ($P < .0001$). For smaller tears (≤20 mm anterior-posterior), 7.6 times less tension was applied to the tendons when pulled to the medial versus lateral footprint. For larger tears, 4.1 times less tension was applied to the tendons when pulled to the medial versus lateral footprint.

This study demonstrated a significant, 5.4-fold increase in tension when the tendon edge was reduced to the lateral as opposed to the medial footprint in vivo.

Although recent clinical results of arthroscopic rotator cuff repair (RCR) have been encouraging, achieving anatomical healing of full-thickness rotator cuff tears remains a challenge.[1-4] Several factors influence rotator cuff healing after repair.[1,3-8] Patient-related factors include advanced patient age, tear size, tear chronicity, and amount of fatty infiltration.[1,3,5,6,8-10] Tension applied to the repair construct is a significant factor as well.[11,12]

In the literature, limited consideration has been given to repair tension.[13] The majority of studies have focused on other factors, mainly repair technique. Some surgeons advocate use of a double-row repair construct in which the rotator cuff tendon is pulled to the lateral margin of the footprint.[14-19] Double-row techniques, which include the transosseous-equivalent (TOE) construct, are biomechanically superior to other repairs.[20-26] Another purported benefit of double-row repair is more complete restoration and pressurization of the rotator cuff footprint.[21,24,27,28]

Rotator cuff tears typically occur near the dysvascular region of the diseased musculotendinous unit, often leaving a stump of tissue attached to the tuberosity and ultimately a shortened tendon.[29] In addition, full-thickness tears often retract over time. Meyer and colleagues[29] recently demonstrated that this shortening is irreversible. Snyder[30] and Sostak and colleagues[31] suggested that pulling a shortened, degenerative rotator cuff tendon to the lateral margin of the footprint results in increased tissue tension compared with that produced with a more medially based repair just off the articular margin. In our opinion, the possible increase in tension during a laterally based repair, whether single- or double-row, may place excessive strain on the diseased tissue as well as the surgical construct, potentially contributing to repair failure.

We conducted a study to evaluate the difference, if any, in tension applied to the rotator cuff

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tendon positioned at the medial versus lateral margin of the footprint during arthroscopic RCR. We hypothesized significantly more tension would be placed on the rotator cuff tendon when positioned at the lateral versus medial footprint.

Methods

After obtaining Institutional Review Board approval for this study, we collected data on a consecutive series of patients who underwent arthroscopic RCR performed by Dr. Getelman at a single institution. Only patients with primary full-thickness tears of the supraspinatus and/or infraspinatus were included. Exclusion criteria included revision rotator cuff surgeries, partial-thickness tears, concurrent subscapularis tears requiring anchor fixation, and any tears that could not be mobilized to the lateral footprint without interval slides or margin convergence. The 20 identified patients constituted the study group.

Demographic factors, including age and preoperative length of symptoms, were recorded after chart review. Magnetic resonance imaging (MRI) was performed for all patients before surgery and was retrospectively reviewed. Dr. Getelman assigned each patient a modified Goutallier score, based on MRI, to assess for fatty infiltration/atrophy.[32]

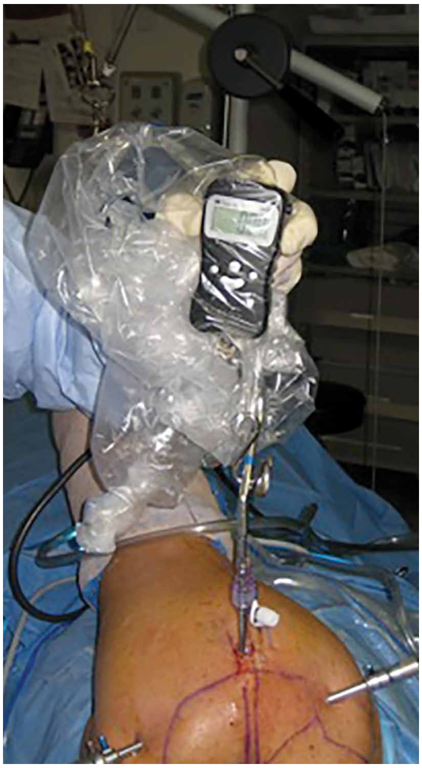

Figure 1. With patient in lateral position, arthroscope is inserted in posterior portal, and arthroscopic grasper is inserted through lateral portal. After being placed in sterile bag, digital weigh scale is attached to grasper with S-hook.

Each patient was placed in the lateral decubitus position with the operative arm in balanced suspension at 70° of abduction. Standard glenohumeral and subacromial diagnostic arthroscopy was performed. The rotator cuff tear was gently debrided back to a healthy-appearing margin in preparation for repair. The tear was then measured in the anterior-posterior (A-P) and medial-lateral (M-L) planes using a premeasured, marked suture, as previously described.[33] Complete bursal and articular-sided releases were performed to allow for appropriate mobilization of the tendon. The tear was classified as crescent-shaped, U-shaped, or L-shaped.

Viewing from the posterior portal, the surgeon inserted a tissue grasper through the lateral portal. The tendon was grasped at multiple points along its edge, anterior to posterior, and was translated laterally to assess its reducibility; the apex of the tear correlated with the point of maximal excursion and coverage of the footprint. Once confirmed, the rotator cuff tear apex was clamped with a tissue grasper. After placement in a sterile arthroscopic camera sleeve (DeRoyal camera drape with perforated tip), a calibrated digital weigh scale (American Weigh Scales model H22 portable electronic hanging scale, with accuracy of 0.01 lb) was attached to the tissue grasper with an S-hook (**Figure 1**). The tendon edge was first translated about 3 mm lateral to the articular margin (the *medial footprint* position), and tension was recorded (**Figures 2A, 2B**). After a 1-minute relaxation period, the tendon edge was translated to the lateral edge of the rotator cuff footprint (the *lateral footprint* position), and tension was recorded again (**Figures 2C, 2D**). A medially based single-row RCR with triple-loaded sutures and bone marrow vents placed in the lateral tuberosity was then completed, regardless of tension, tear size, or tear morphology.[31] Typically, 1 anchor was used for every 10 to 15 mm of A-P tear length.

SAS software was used for statistical analysis, the Wilcoxon signed rank test for continuous or ordinal data comparisons between paired groups, and the Mann-Whitney test for continuous or ordinal data comparisons between independent, unmatched groups. One-way analysis of variance (ANOVA) was used to compare means among the 3 groups of morphology subtypes. Linear regression was performed to assess the simultaneous relationship between potential predictors (age, sex, length of symptoms, Goutallier score, tear size) and medial or lateral tension, where medial tension was included as an additional potential predictor for lateral tension. Restricted cubic splines were fit to assess linearity. Predictors were retained in multivariate regression using backward variable retention. Because of inadequate sample size, additivity was assumed except for sex. Statistical significance was set at $P < .05$.

Results

Of the 20 rotator cuff tears evaluated (**Table 1**), 13 were crescent-shaped, 5 were U-shaped, and 2 were L-shaped. Mean (SD) A-P tear size was 17.7 (5.8) mm, and mean (SD) M-L tear size was

19.1 (8.6) mm. Mean age of the 20 patients (15 men, 5 women) was 57.9 years (range, 44-72 years). Mean (SD) length of symptoms was 12.9 (12.4) months (range, 3-48 months). Mean (SD) modified Goutallier score was 1.4 (0.7; range, 0-3).

Mean (SD) rotator cuff tension for all tears approximated to the medial footprint was 0.41 (0.33) pound, and mean (SD) cuff tension for all tears approximated to the lateral footprint was 2.21 (1.20) pounds—representing a 5.4-fold difference ($P < .0001$).

No statistically significant differences were detected in the ANOVA comparing tensions at medial and lateral positions among tear morphologic subtypes (all *P*s >.05).

Subgroup analysis (**Table 2**) was performed for smaller (≤20 mm A-P) and larger (>20 mm A-P) tears. For smaller tears, mean (SD) tension was 0.27 (0.24) pound applied with the cuff tendon pulled to the medial footprint and 2.06 (1.06) pounds applied with the tendon pulled to the lateral footprint—a 7.6-fold difference ($P < .0018$). For larger tears, mean (SD) tension was 0.58 (0.37) pound applied with the tendon pulled to the medial footprint and 2.38 (1.4) pounds applied with the tendon pulled to the lateral footprint—a 4.1-fold difference ($P < .005$).

A statistically significant difference in tensions was found between small and large cuff tears positioned at the medial footprint (0.27 vs 0.58 lb; $P = .0367$); no difference was found between groups with the tendon at the lateral footprint (2.06 vs 2.38 lb; $P = .284$).

Univariate and multivariate analyses were per-

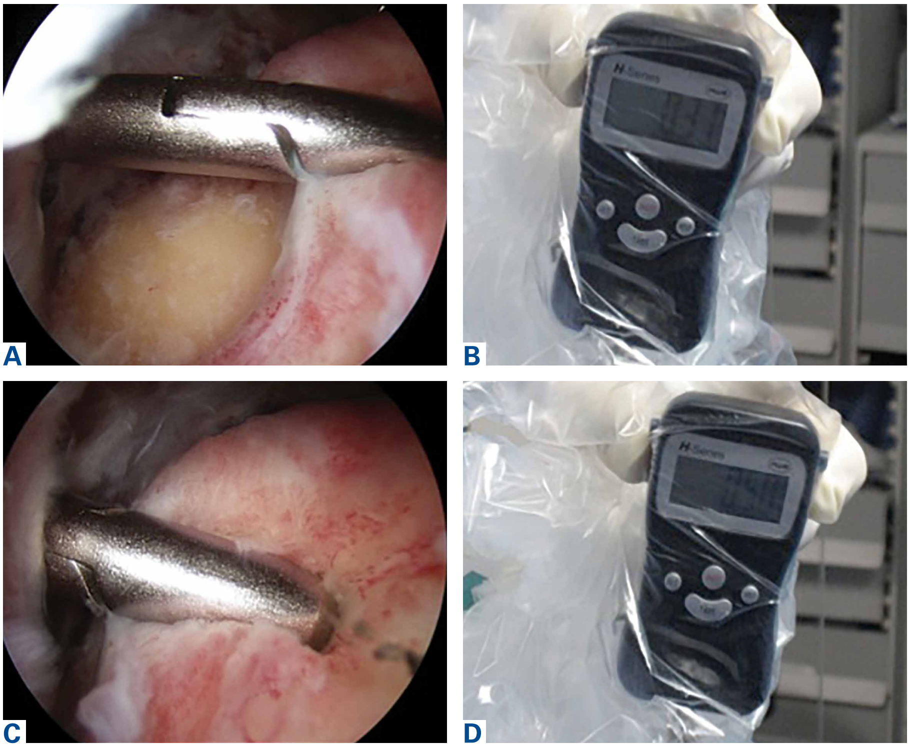

Figure 2. (A) With patient in lateral position and camera in posterior portal, arthroscopic view shows tissue grasper attached to edge of cuff tendon, which is pulled to its resting position at medial footprint. Note exposed bone of footprint. (B) Digital weigh scale displays amount of tension applied to tendon during medial placement: 0.31 pound. (C) With patient in lateral position and camera in posterior portal, arthroscopic view shows tissue grasper attached to edge of cuff tendon, which is pulled to lateral footprint. (D) Digital weigh scale displays amount of tension applied to construct during positioning at lateral footprint: 0.50 pound.

Table 1. **Comparison of Tension Differences for Rotator Cuff Tear Morphologies With Tendon Edge Positioned at Medial Versus Lateral Footprint**

	Distance, mean (SD) mm		Tension at Footprint, mean (SD) lb		
Rotator Cuff Tear Morphology	**A-P**	**M-L**	**Medial**	**Lateral**	**Difference in Tensions**
Overall (20)	17.7 (5.8)	19.1 (8.6)	0.41 (0.33)	2.21 (1.20)	5.4× $P = .0001$
Crescent-shaped (13)	17.6 (6.0)	17.0 (4.8)	0.49 (0.40)	1.91 (1.17)	3.9× $P = .0004$
U-shaped (5)	18.0 (6.8)	18.1 (5.9)	0.35 (0.05)	2.87 (1.20)	8.2× $P = .0016$
L-shaped (2)	22.0 (0)	33.5 (21.9)	0.60 (0.13)	1.65 (0.91)	3.9× $P = .25$

Abbreviations: A-P, anterior-posterior; M-L, medial-lateral.

formed using linear regression analysis (**Table 3**). During univariate analysis for medial footprint position, A-P tear size and Goutallier score both positively correlated with increasing tension; for lateral footprint position, no factors statistically correlated with lateral tension, though there was a positive trend for medial tension and female sex. During multivariate analysis for medial footprint position, only A-P tear size positively correlated with increasing tension; for lateral footprint position, both age (in nonlinear fashion as function of age + age^2) and medial tension positively correlated with increasing tension.

Discussion

Our results indicated that significantly more tension is placed on the torn rotator cuff tendon when it is reduced across the footprint from a medial to a more lateral position in vivo. More tension was required for all tears to be reduced to the lateral footprint compared with the medial footprint. As expected, compared with smaller tears, larger tears required significantly more tension in order to be reduced to the medial footprint. Interestingly, no statistical difference was found between tensions required to reduce either small or large tears to the lateral footprint, which suggests that, regardless of tear size, more force must be applied to reduce the torn tendon to the lateral footprint compared with the medial footprint.

Hersche and Gerber[34] were the first to report rotator cuff tension measurements in vivo. Although their study did not specifically compare cuff tensions reducing the tear to the medial versus lateral footprint, it did examine tension at displacement of 10 and 20 mm. Tension increased from 27 N to 60 N, correlating with a 2.2-fold difference between the 2 distances. Domb and colleagues[35] also compared in vivo rotator cuff tension differences between the medial footprint and the lateral

Table 2. **Comparison of Tension Between Smaller (≤20 mm A-P) and Larger (>20 mm A-P) Rotator Cuff Tears With Tendon Edge Positioned at Medial Versus Lateral Footprint**

Rotator Cuff Tear Size	Tension at Footprint, mean (SD) lb: Medial	Lateral	*P*	Difference
≤20 mm A-P	0.27 (0.24)	2.06 (1.06)	.0018	7.6×
>20 mm A-P	0.58 (0.37)	2.38 (1.4)	.005	4.1×

Abbreviation: A-P, anterior-posterior.

Table 3. **Linear Regression Analysis of Patient Factors in Relation to Tension During Placement of Rotator Cuff Tears at Medial or Lateral Footprint**

Patient Factor	Medial Tension		Lateral Tension	
	Univariate Analysis *P*	Multivariate Analysis *P*	Univariate Analysis P	Multivariate Analysis *P*
Age	.27	.96	.24	.034
Age + age^2	—	—	—	.018
Sex	.99	.64	.078	.063
A-P tear size	.0048	.0048	.36	.14
M-L tear size	.060	.59	.43	.13
Length of symptoms	.83	.78	.14	.36
Goutallier score	.014	.16	.21	.17
Medial tension	—	—	.061	.0091

Abbreviations: A-P, anterior-posterior; M-L, medial-lateral.

footprint in 4 patients. Mean tension applied to the cuff during reduction to the articular margin was 27 N, or 6 pounds. Mean tension needed to reduce the cuff to the lateral tuberosity was 76 N, or 17 pounds, for a 2.8-fold difference. Tears were not measured but were described as massive and retracted.

Although repair tension has long been recognized as a crucial factor in RCR healing, little clinical research has focused on the effects of excess tension. Davidson and Rivenburgh[11] prospectively followed the clinical outcomes of 67 consecutive cuff repairs after intraoperative tension measurement and found that high-tension repairs (>8 lb) had significantly lower clinical outcome measures. However, the authors did not report on correlations with radiologic healing and stated, "Functional outcome is inversely proportional to rotator cuff repair tension." Further study of the in vivo effects of increased tension on clinical and radiologic outcomes is needed.

Several animal studies have been conducted on the effects of tension on RCRs. Gerber and colleagues[36] reported that the force needed to produce 1 cm of sheep supraspinatus tendon excursion increased 7-fold, from 6.8 N to 47.8 N, after 40 weeks of tendon tear. Coleman and colleagues[37] compared the modulus of elasticity in sheep supraspinatus tendon after 6 weeks and 18 weeks of detachment and reported increases of 60% and 70%, respectively. Gimbel and colleagues[38] showed that, in a rat model, "repair tension rapidly increased initially after injury followed by a progressive, but less dramatic, increase with additional time." Of note, we did not identify any correlation between chronicity of symptoms and the tension needed to reduce the tendon medially or to a more lateral position on the footprint.

In acute tears, the cuff tissue is more compliant and mobile and can be pulled laterally across its anatomical footprint with minimal tension.[39] In contrast, cuff tissue in the more commonly encountered chronic tear is less compliant and is not mobile enough to be pulled to the lateral margin of the footprint without added stress.[30,34,35] In large, acute tears in which there are minimal tissue degeneration and retraction, a laterally based footprint-restoring technique may be performed with minimal tension. This technique may have advantages over a medially based repair. In the literature, more attention needs to be directed toward the biomechanics and biology of chronic rotator cuff tears, as these are more commonly encountered.

Almost all of the prospective studies that have compared single- and double-row RCR have found no significant differences in MRI healing rates or clinical results at follow-up up to 2 years.[14,16,40-45] Detailed analysis of the surgical techniques used in all these studies revealed that the rotator cuff tendons were repaired back to the *lateral* footprint in both the single- and double-row constructs.[14,16,40-45] Although no clinical studies have compared medially and laterally based single-row repairs, our data suggest that medially based repairs have lower tensions and therefore should not be considered equivalent. Sostak and colleagues[31] and Murray and colleagues[46] have shown that a medially based single-row RCR can achieve excellent clinical and anatomical results, likely partly because of the lower tension applied to the torn cuff tissue.[31,46] Studies are needed to compare medially and laterally based repairs, including single- and double-row repairs.

The vast majority of recent research has aimed to counteract construct tension with stronger biomechanical constructs.[20-26] Surgeons have also aimed to improve biological healing by pulling the tendon laterally across the footprint to achieve complete footprint coverage, ultimately increasing the surface area for tendon–bone healing. This has led to the development of various double-row repair techniques, in which the cuff tendon is pulled to the lateral margin of its footprint. One row of anchors is placed in the medial aspect of the footprint, while a second is placed in the lateral aspect; the cuff is reduced and compressed to the tuberosity with various suture configurations. The TOE technique was developed to improve pressurization of the cuff tendon across the footprint by linking the 2 rows with bridging sutures. In doing so, however, the potentially deleterious effects of increased tension introduced by pulling the tendon laterally may have been overlooked. Nevertheless, the biomechanics and stress distribution likely differ between single-row repair and TOE repairs, and direct comparisons cannot be made at this time. The medial row of a double-row or TOE construct may stress-shield or "unload" the more lateral tissue. Studies are needed in order to better understand the tension differential and stress distribution of various double-row constructs.

Recognizing tear morphology is crucial in maximizing chances of healing after cuff repair. For example, a crescent-shaped tear is reduced to the tuberosity with direct lateral translation of the apex of the tear, which is also the deepest or most displaced part of the tear. On the other hand, reducing an L- or reverse L-shaped tear to the tuberosity is not as direct; reducing the deepest or most displaced part of the tear would lead to overreduction and overtensioning of the tendon. However, often the exact "elbow" of the tear is not obvious and appears more rounded; therefore, it is crucial for the surgeon to examine the mobility of the torn tendon along its entire length to minimize tension. Study is needed to assess tension along the entire length of the tear for different tear morphologies and sizes.

Although our results showed that increased tension was needed to reduce a torn tendon to its lateral footprint, no study has indicated exactly how much is "too much" tension. As stated earlier, use of stronger biomechanical constructs, including TOE constructs, may overcome the increased tension associated with laterally based repairs. In addition, laterally based repairs, either single- or double-row, may be best suited for tears with lower tension, whereas medially based repairs may be best suited for higher tension tears. It is also possible that the difference in tensions noted in this study is not significant enough to have a clinical impact on choice of construct or on anatomical healing. We need studies that correlate anatomical healing rates with repair tension in order to better guide surgeons on when to use a medially or laterally based repair.

Other possible effects of increased tension associated with laterally based repairs, including beneficial effects, must be considered as well. Viscoelastic properties of human rotator cuff tendon may dissipate increased tension over time through a variety of mechanisms. Stress relaxation, gap formation, creep, and the hysteresis effect, all associated with cyclical loading in the early healing period, may lead to dissipation of force over time.[47,48] These more complex biomechanical properties of RCR constructs are yet to be clearly defined.

This study had several weaknesses. Its data represent a static measurement of time-zero rotator cuff tension, which greatly simplifies the biomechanics of the torn rotator cuff and repair construct as well as changes that occur with healing. During cuff repair, forces typically are distributed through several fixation points in stepwise process and are not focused on a single point of tissue with a grasper. Therefore, the findings of this study may not directly correlate with medially versus laterally based repairs in vivo. Furthermore, as this is a time-zero measurement, we could not determine whether the tension differential between the 2 repair positions remained static over time. Current literature suggests that muscle atrophy, fatty infiltration, and loss of elasticity of the musculotendinous unit are relatively irreversible.[35,37,49] In addition, determining the precise apex of a cuff tear can be difficult, so error may have been introduced during this process. Last, although placement of the cuff tissue at the medial or lateral footprint position was based on visual estimation by an experienced and skilled arthroscopist, error may have been introduced based on this imprecise technique.

Conclusion

This study demonstrated a significant, 5.4-fold increase in in vivo time-zero rotator cuff tension with the tendon edge reduced to the lateral footprint rather than the medial footprint.

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