

# Biomechanics in an Incomplete Versus Complete Supraspinatus Tear

## A Cadaveric Study

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**Background:** Degenerative and traumatic changes to the rotator cuff can result in massive and irreparable rotator cuff tears (RCTs).

**Purpose/Hypothesis:** The study objective was to conduct a biomechanical comparison between a small, incomplete RCT and a large, complete RCT. We hypothesized that the incomplete supraspinatus (SS) tear would lead to an incremental loss of abduction force and preserve vertical position of the humeral head, while a complete SS tear would cause superior humeral migration, decrease functional deltoid abduction force, and increase passive range of motion (ROM).

**Study Design:** Controlled laboratory study.

**Methods:** Six cadaveric shoulders were evaluated using a custom testing apparatus. Each shoulder was subjected to 3 conditions: (1) intact/control, (2) 50%, full-thickness, incomplete SS tear, and (3) 100%, complete SS tear. Deltoid abduction force, superior humeral head migration, and passive ROM were measured in static conditions at 0°, 30°, and 60° of glenohumeral abduction, respectively.

**Results:** The intact SS resulted in a mean deltoid abduction force of 2.5, 3.3, and 3.8 N at 0°, 30°, and 60° of abduction, respectively. Compared with the intact shoulder, there was no significant difference in mean abduction force seen in the incomplete tear, while the force was significantly decreased by 52% at 30° of abduction in the complete tear ( $P = .009$ ). Compared with the incomplete tear, there were significant decreases in abduction force seen in the complete tear, by 33% and 48% (0.9 N and 1.1 N) at 0° and 30° of abduction, respectively ( $P = .04$  and  $.004$ ). The intact configuration experienced a mean superior humeral head migration of 1.5, 1.4, and 1.1 mm at 0°, 30°, and 60° of abduction, respectively. The complete tear resulted in a superior migration of 3.0 and 4.4 mm greater than the intact configuration at 0° and 30° of abduction, respectively ( $P = .001$ ). There was a 5° and 10° increase in abduction ROM with 50% and 100% tears, respectively ( $P = .003$  and  $.03$ ).

**Conclusion:** An incomplete SS tear does not significantly alter the biomechanics of the shoulder, while a large, complete SS tear leads to a significant superior humeral migration, a decreased deltoid abduction force, and a mild increase in passive ROM.

**Clinical Relevance:** Our findings demonstrate the effects of large SS tears on key biomechanical parameters, as they progress from partial tears.

**Keywords:** rotator cuff; rotator cuff tear; supraspinatus tear; shoulder; shoulder biomechanics

Recent studies<sup>25,32</sup> show an increasing incidence of rotator cuff (RC) repair. Up to 40% of all repairs are for massive RC tears (RCTs).<sup>2</sup> The definition of a massive tear remains debated. Cofield et al<sup>3</sup> and Gerber et al<sup>7</sup> proposed classification systems that define massive RCTs as anteroposterior size >5 cm and involvement of at least 2 RC tendons, respectively. In a newer classification system, Davidson and

Burkhart<sup>4</sup> define massive tears as those with length and width greater than  $2 \times 2$  cm. Patients affected by large tears commonly experience pain and weakness. In severe instances, an associated loss of the glenohumeral force couples may leave the patient with effective pseudoparalysis.<sup>2,30</sup> Repair outcomes for massive tears are more unpredictable and worse than those for smaller tears.<sup>26</sup> Retear rates after arthroscopic repair range from 25% to 57%, although retears are not always associated with poor functional outcomes.<sup>8</sup> Massive tears that are found to be irreparable intraoperatively are particularly difficult to treat.<sup>2</sup>

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To investigate the effects of tear progression, various biomechanical parameters have been utilized to compare small and large tears. In recent years, superior humeral head translation, deltoid abduction force, and passive range of motion (ROM) have emerged as biomechanically important variables, which are also readily available and utilized clinically.<sup>2,8</sup> Previous studies<sup>9,11,21</sup> have documented the loss of abduction force caused by massive supraspinatus (SS) tears. The few studies that have focused on progression from smaller tears report increasing deltoid requirement and decreasing generated abduction force.<sup>6,9</sup> Superior humeral migration in the setting of a massive tear is well documented by prior biomechanical studies,<sup>10,18,19,24,28</sup> although only 1 prior study<sup>13</sup> focused on this parameter in the setting of tear progression. Similarly, while increased passive ROM was previously noted with massive RCTs,<sup>24</sup> there is a lack of knowledge about passive ROM in the setting of RCT progression.

The objective of the present study was to biomechanically compare cadaveric shoulders with incomplete SS tear to those with large, complete SS tear. To address the gaps in knowledge in existing literature, we measured all 3 of the aforementioned key parameters: functional abduction force, superior humeral migration, and ROM. We hypothesized that the smaller, incomplete SS tear would lead to incremental loss of abduction force, preserving vertical position of the humeral head and passive ROM, while the large, complete RCT would lead to greater superior migration of the humeral head, lower functional deltoid abduction force, and greater passive ROM. Given the active role of the SS in initiation of glenohumeral abduction,<sup>2,8</sup> we believed these effects would be more pronounced at lower abduction angles.

## METHODS

### Specimen Preparation

Six fresh-frozen cadaveric shoulders from 5 donors (age  $66.5 \pm 5.3$  years; 17% male, 83% female; obtained from Science Care) were evaluated. The forearm was disarticulated at the elbow. The overlying soft tissues were carefully removed. Absence of preexisting large RTCs was confirmed via visual inspection. Capsule, coracoacromial ligament, tendinous insertions of the SS, infraspinatus, teres minor, subscapularis, pectoralis major, latissimus dorsi, and the 3 heads of the deltoid were preserved. The tendons were tagged at the insertions using No. 2 FiberWire suture (Arthrex). The scapula was potted in resin and rigidly

affixed to a custom mechanical testing apparatus (Figure 1) using a toothed scapula clamp in 20° anterior scapular tilt and 0° scapular abduction.

### Experimental Conditions

Tagged muscle tendons were loaded via pulleys connected to hanging weights. Two conditions were used. In the balanced condition, tendons were loaded so that all moments in the system were equal, creating no motion. This was achieved through manually controlling the force vectors by manipulating the locations of adjustable pulleys. In the loaded condition, additional force was applied to the deltoid to create an abduction moment. The following loading conditions were used to achieve a balanced system: deltoid, 20 N; pectoralis major, 10 N; latissimus dorsi, 10 N; SS, 10 N; subscapularis, 10 N; infraspinatus, 5 N; and teres minor, 5 N. Then, to create an abduction moment in the loaded condition, the deltoid was loaded with additional 20 N, for a total of 40 N, which was enough to initiate shoulder abduction. For both balanced and unbalanced conditions, the total deltoid load was distributed equally between the 3 heads of the deltoid. The utilized loading protocol was adapted from Mihata et al.<sup>15,18,19</sup>

Each shoulder was subjected to 3 testing conditions: (1) intact RC (control); (2) full-thickness, incomplete, 50% anteroposterior SS tear with the superior capsule and SS insertion incised and detached sharply off the greater tuberosity; and (3) complete SS tear resulting in an irreparable defect extending from the posterior subscapularis to the anterior infraspinatus anteroposteriorly and from the greater tuberosity to the glenoid mediolaterally (Figure 2).

### Experimental Measurements

An electronic force gauge was connected to the humerus via line and pulleys 15 cm distal to the acromion, as measured in the balanced condition and with an intact SS. When additional weight was applied to the deltoid to create the loaded condition, the force gauge measured the perpendicular component of the abduction moment created by the additional weight, representing the abduction force generated by the deltoid. Markers were placed on the anterolateral acromion and on the proximal humerus, inferior to the anterior portion of the greater tuberosity. A digital caliper was used to measure the distance between the markers in both balanced and loaded static conditions to assess superior humeral head migration. We chose the acromion as a

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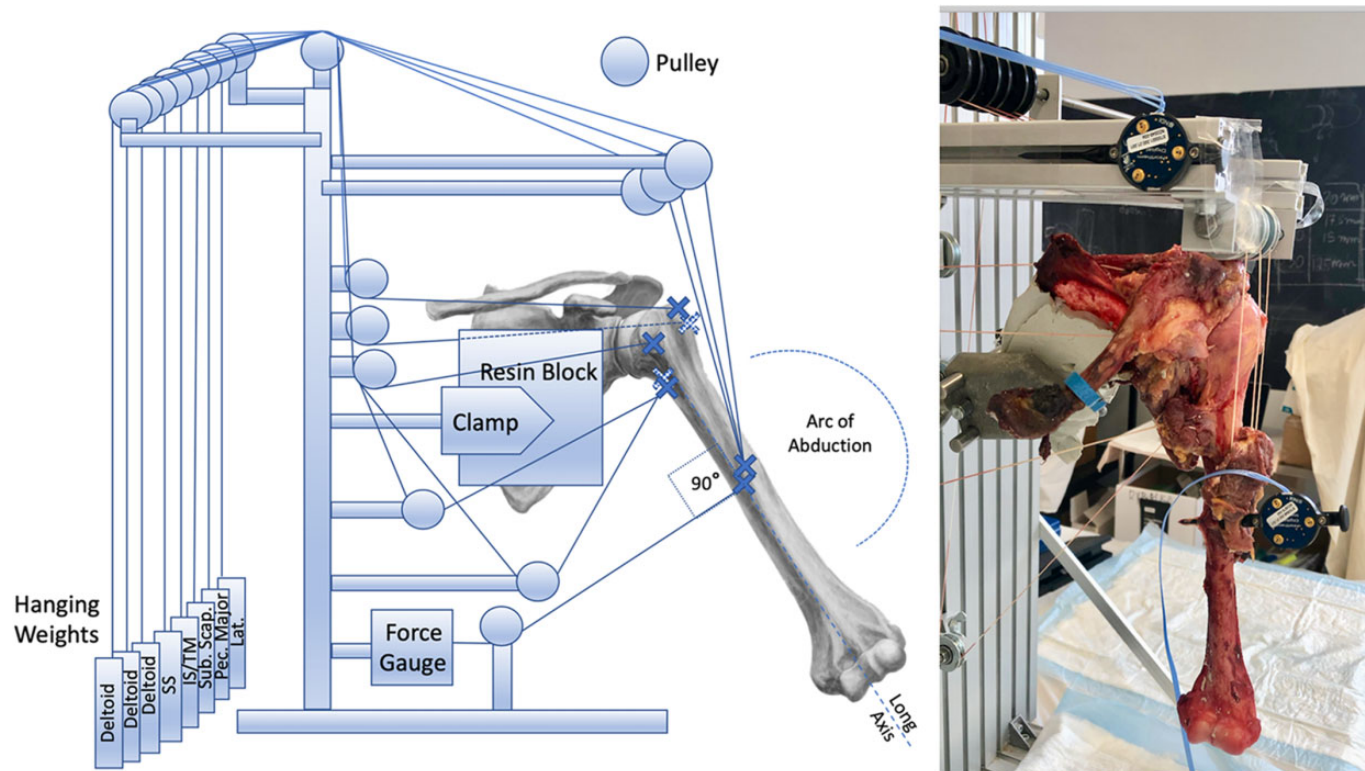
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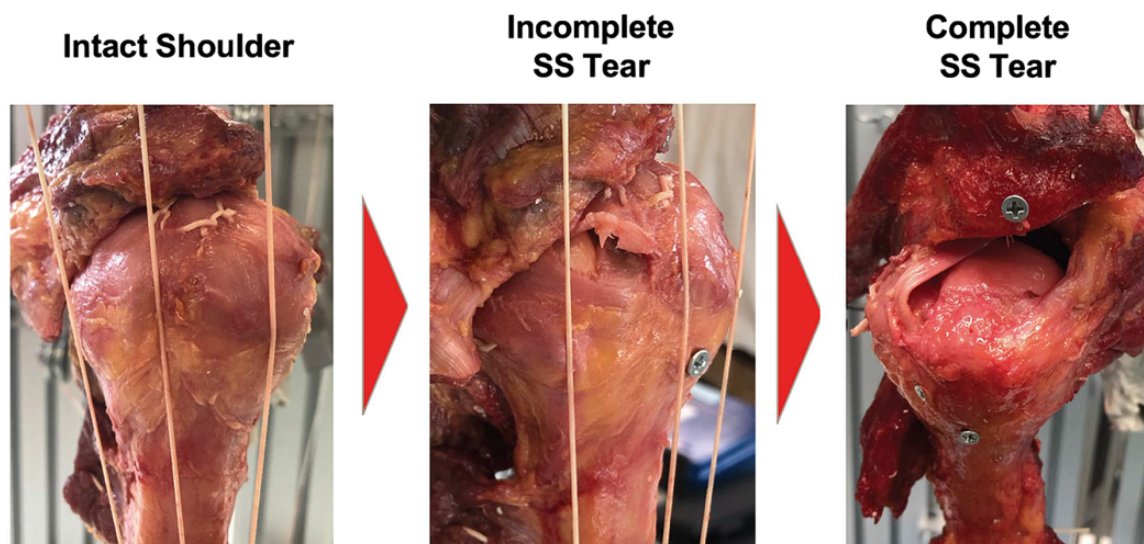
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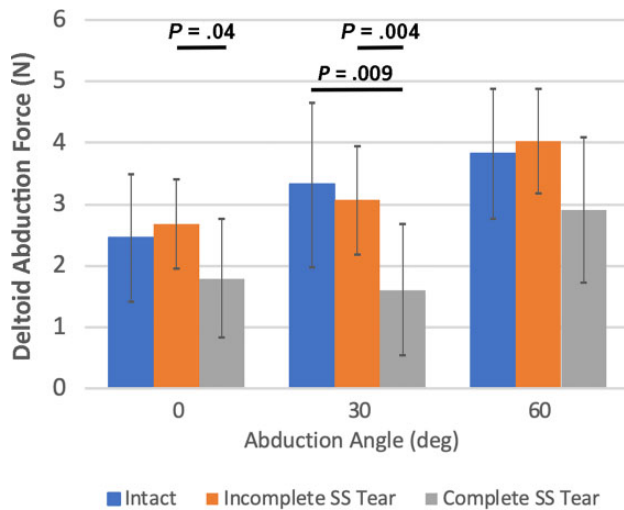
Ethical approval was not sought for the present study.



**Figure 1.** Cadaveric shoulder mounted in the custom biomechanical testing apparatus. In preparation, the overlying soft tissues were removed. The capsule, coracoacromial ligament, and tendinous insertions of the 3 heads of the deltoid, the rotator cuff tendons, pectoralis major, and latissimus dorsi were preserved. The scapula was potted in resin and rigidly affixed to the custom mechanical testing apparatus using a toothed scapular clamp. The tendons were tagged at the insertions with suture. Acrylic wire tied to the suture was used to load the tendons with hanging weights. Adjustable pulleys were used to anatomically direct the force vectors. IS, infraspinatus; SS, supraspinatus; TM, teres minor.

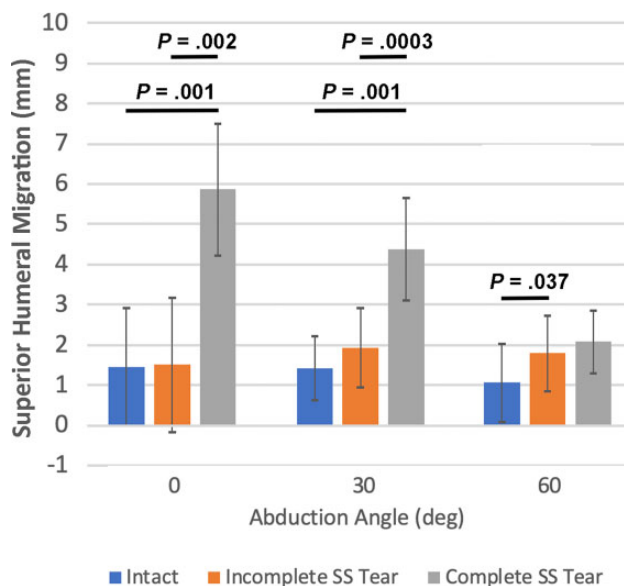


**Figure 2.** Experimental conditions. The intact rotator cuff served as the control. Then, a 50% supraspinatus (SS) tear was created and investigated. A 100% SS tear spanning the entire anteroposterior width of the SS tendon insertion with an irreparable mediolateral defect served as the final experimental condition.

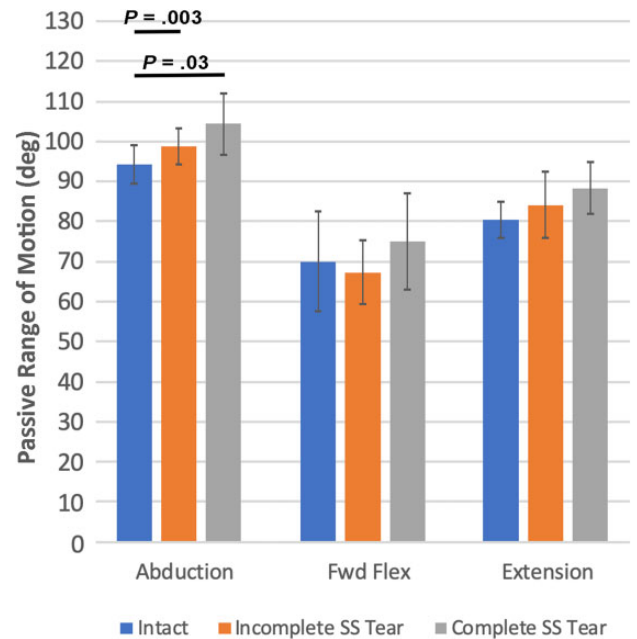


**Figure 3.** Results comparing the deltoid abduction force between the intact rotator cuff, incomplete supraspinatus (SS) tear, and complete SS tear. Deltoid abduction force was preserved with the incomplete tear; it was significantly decreased with the complete tear at 30° of abduction, compared with the intact state ( $P = .009$ ). The complete tear resulted in a significantly lower abduction force compared with the partial tear configuration at 0° and 30° of abduction ( $P = .04$  and  $.004$ ).

reproducible static point of reference. All of the



**Figure 4.** Results comparing superior humeral translation between the intact rotator cuff, incomplete supraspinatus (SS) tear, and complete SS tear. The incomplete tear did not lead to a significantly different humeral head migration. The complete tear resulted in superior migrations that were 4.4 and 3.0 mm greater than the intact configuration values at 0° and 30° of abduction, respectively ( $P = .001$  for both).



**Figure 5.** Results comparing passive range of motion between the intact rotator cuff, incomplete supraspinatus (SS) tear, and complete SS tear. Passive abduction increased from the intact model with incomplete and complete tears, by 5° for incomplete tears ( $P = .003$ ) and by 10° for complete tears ( $P = .03$ ). No significant differences in forward flexion and extension were observed.

mentioned parameters were measured at 0°, 30°, and 60° of glenohumeral abduction. Maximal passive glenohumeral abduction, forward flexion, extension, and axial rotation (internal rotation [IR] and external rotation [ER]) were recorded for each experimental condition using a digital protractor in the balanced static condition. Rather than utilizing an optical tracking system, we chose to measure the distance and rotation with digital calipers and protractor, respectively. In our experience, such instruments result in sufficiently accurate and precise measurements in this setting.

**Statistical Analysis**

Deltoid abduction force measurements were performed twice for each experimental angle, and the values were averaged. Data for all analyzed parameters were averaged between the 6 tested shoulders. The 3 experimental conditions were statistically compared with regard to deltoid abduction force, superior humeral migration, and passive ROM. Normality of the data sets was assessed using Kolmogorov-Smirnov and Shapiro-Wilk testing, and appropriate paired Student *t* testing or Wilcoxon signed-rank testing was then conducted depending on the results of normality testing. Statistical significance was set at  $P < .05$ .

TABLE 1  
Results Comparing IR and ER Between the Intact Rotator Cuff, Incomplete Supraspinatus Tear, and Complete Supraspinatus Tear<sup>a</sup>

Angle	Internal Rotation, deg			External Rotation, deg		
	Intact	Incomplete	<i>P</i>	Intact	Incomplete	<i>P</i>
0°	25.0 (14.3-35.7)	22.0 (11.0-33.0)	.070	41.0 (14.3-35.7)	37.4 (11.0-33.0)	.163
30°	21.0 (12.7-29.3)	31.0 (22.6-39.4)	<b>.004</b>	71.8 (12.7-29.3)	60.0 (22.6-39.4)	.065
60°	22.0 (10.6-33.4)	21.0 (10.5-31.5)	.749	73.4 (10.6-33.4)	79.0 (10.5-31.5)	.292
90°	12.4 (4.5-20.3)	10.8 (0.4-21.2)	.491	71.0 (4.5-20.3)	77.0 (0.4-21.2)	<b>.033</b>
	Intact	Complete	<i>P</i>	Intact	Complete	<i>P</i>
0°	25.0 (14.3-35.7)	27.0 (9.6-44.4)	.717	41.0 (14.3-35.7)	41.8 (9.6-44.4)	.864
30°	21.0 (12.7-29.3)	27.6 (11.8-43.4)	.209	71.8 (12.7-29.3)	70.0 (11.8-43.4)	.702
60°	22.0 (10.6-33.4)	27.4 (14.3-40.5)	.325	73.4 (10.6-33.4)	83.0 (14.3-40.5)	.142
90°	12.4 (4.5-20.3)	25.0 (14.6-35.4)	<b>.011</b>	71.0 (4.5-20.3)	76.0 (14.6-35.4)	.142
	Incomplete	Complete	<i>P</i>	Incomplete	Complete	<i>P</i>
0°	22.0 (11.0-33.0)	27.0 (9.6-44.4)	.298	37.4 (11.0-33.0)	41.8 (9.6-44.4)	.496
30°	31.0 (22.6-39.4)	27.6 (11.8-43.4)	.562	60.0 (22.6-39.4)	70.0 (11.8-43.4)	.285
60°	21.0 (10.5-31.5)	27.4 (14.3-40.5)	.311	79.0 (10.5-31.5)	83.0 (14.3-40.5)	.477
90°	10.8 (0.4-21.2)	25.0 (14.6-35.4)	<b>.026</b>	77.0 (0.4-21.2)	76.0 (14.6-35.4)	.704

<sup>a</sup>All rotational data are presented as mean (95% CI). IR significantly increased with the incomplete tear and with the complete tear, compared with the intact shoulder, at 30° and 90° of abduction, respectively. ER significantly increased with the incomplete tear, compared with the intact shoulder, at 90° of abduction. Compared with the incomplete tear, the complete tear resulted in greater IR at 90° of abduction. Statistically significant *P* values are indicated by bold font. ER, external rotation; IR, internal rotation.

RESULTS

The intact SS had a mean deltoid abduction force of 2.5, 3.3, and 3.8 N at 0°, 30°, and 60° of abduction, respectively. Compared with the intact state, deltoid abduction force was preserved with the incomplete tear, and it was significantly decreased by 52% (1.7 N) with the complete tear at 30° of abduction (*P* = .009). There was a trend toward decreased abduction force by 24% at 60° for the complete tear compared with the intact state, although this was not statistically significant (*P* = .17). The incomplete tear produced a mean abduction force of 2.7, 3.1, and 4.0 N at 0°, 30°, and 60° of abduction, respectively. Compared with the incomplete tear, the complete tear significantly lowered the abduction force by 33% and 48% (0.9 and 1.1 N) at 0° and 30° of abduction, respectively (*P* = .04 and .004) (Figure 3).

The intact configuration experienced a mean superior humeral head migration of 1.5, 1.4, and 1.1 mm at 0°, 30°, and 60° of abduction, respectively. The incomplete tear was only significantly different from the intact configuration at 60° of abduction, where it shifted the humeral head superiorly by an additional 0.7 mm (*P* = .037). The complete tear resulted in superior migrations that were 4.4 and 3.0 mm greater than the intact configuration values at 0° and 30° of abduction, respectively (*P* = .001 for both) (Figure 4).

The intact configuration achieved a mean passive abduction, a forward flexion, and an extension of 94°, 70°, and 80°, respectively. Compared with the intact model, passive abduction significantly increased with incomplete and

complete tears, by 5° (*P* = .003) and 10° (*P* = .03), respectively. Forward flexion and extension were not significantly affected. No significant differences in mean abduction, forward flexion, or extension were observed between the incomplete and complete tears (Figure 5).

Passive axial rotation in the intact configuration resulted in a mean total arc of 66°, 96°, 93°, and 74° at 0°, 30°, 60°, and 90° glenohumeral abduction, respectively. There was a trend toward an increased total arc of motion with a complete tear at 60° and 90° of abduction, although this was not statistically significant (*P* = .059 and .071). There were no significant differences in the total rotational arc between incomplete and complete tears at any abduction angle.

Individual IR and ER data were collected for 5 of 6 shoulders. Compared with the intact condition, IR significantly increased at 30° of abduction in the incomplete tear (21° vs 31°; *P* = .004), and it also increased at 90° of abduction in the complete tear (12° vs 25°; *P* = .011). ER significantly increased from the intact to the incomplete tear condition at 90° of abduction (71° vs 77°; *P* = .033). Compared with the incomplete tear, the complete tear resulted in greater IR by 14° at 90° of abduction (*P* = .026) (Table 1).

DISCUSSION

The present study aimed to investigate the effects of RCTs on key parameters, as the tears progress from smaller to massive. We measured superior humeral migration,<sup>10,13,19,22,24,28</sup>

abduction strength,<sup>11,12,28,29</sup> and passive ROM,<sup>24</sup> as these measurements are both clinically significant and biomechanically feasible.

We found that the incomplete SS tear preserved deltoid abduction force, while the complete tear caused a 52% reduction at 30° of abduction only. Compared with the incomplete tear, the complete tear decreased the abduction force by 33% and 48% at 0° and 30° of abduction, respectively. Loss of abduction force in the range of 30%-60% with simulated massive SS tears has been documented by prior biomechanical studies.<sup>1,6,9,11,21</sup> However, fewer studies<sup>2,5,27</sup> investigated tear progression and modeled a full-thickness, irreparable tear, which has been shown to cause superior humeral translation and impairment of shoulder dynamics. Halder et al<sup>9</sup> demonstrated the effects of progressive of SS tears on deltoid abduction force with the arm in neutral position. They found a decrease of 10% with partial (50%) tears and 58% with complete, irreparable tears, analogous to those used in our study. Dyrna et al<sup>6</sup> investigated multi-tendon tears and demonstrated increasing deltoid force requirements with incrementally larger RCTs, 6-8 cm in size. In agreement with preceding literature, we found more pronounced effects of the SS tears in early abduction, where the SS plays its greatest role via the SS-deltoid force couple.<sup>2,8</sup> Unlike cadaveric studies, *in vivo* analyses have demonstrated no association of abduction strength with tear size,<sup>14,20</sup> while many patients with massive RCTs achieve full shoulder abduction.<sup>2,8</sup> This may be because of compensatory forces exerted by the deltoid, the remaining RC, and the other shoulder muscles,<sup>12,29</sup> which were not evaluated in our cadaveric study.

The loss of glenohumeral force couples causes superior humeral migration in massive and irreparable tears, leading to degenerative changes. This phenomenon is attributed to impaired stability of the humeral head in the glenoid fossa caused by large RC tears, which allows the deltoid force to shift the humerus superiorly.<sup>2,8</sup> We found that the incomplete SS tear resulted in no clinically significant humeral head migration. The complete SS tear produced superior migration 4.4 and 2.5 mm greater than the incomplete tear at 0° and 30° of abduction, respectively. In the setting of a massive, irreparable RCT, increased superior humeral translation on the order of 3-6 mm has been demonstrated by prior biomechanical studies.<sup>10,18,19,24,28</sup> In accordance with our findings, Mihata et al<sup>18,19</sup> and Singh et al<sup>28</sup> found this effect to occur in early- and midabduction. Keener et al<sup>13</sup> found that superior humeral head migration clinically correlates with increasing tear size, but only for large tears (>175 mm<sup>2</sup>). This is in agreement with our findings of minimal effect of the incomplete tear on superior migration. Other authors<sup>23</sup> investigating only massive, irreparable tears found a similar correlation.

With regard to passive ROM, we found that incomplete and complete tears increased the abduction by 5° and 10°, respectively, without significant differences in forward flexion or extension. Neither the incomplete nor the complete SS tears significantly affected the total rotational arc, although we found isolated minor increases in IR and ER with both types of tears. Compared with the incomplete tear, the complete tear resulted in slightly greater IR at

90° of abduction. Based on our findings, it appears that neither small nor large SS tears cause a clinically significant change in passive ROM. Minor increases in passive ROM with massive RCTs, also noted by Oh et al,<sup>24</sup> are likely because of acute untethering of the humeral head from the SS tendon. This, however, can be interpreted as the loss of the stabilizing effect of the SS tendon and superior capsule that is more pronounced with a larger SS tear. Such findings may be expected with an acute tear, without degenerative changes. However, a mild increase in passive ROM is typically overshadowed by reduction in active ROM seen in acute massive tears.<sup>2,8</sup>

The current literature presents very few biomechanical assessments of RCT progression that incorporate, individually, measurements of abduction force, humeral migration, and ROM. Such measurements are routinely and readily available in the clinical setting and are used to evaluate patients with RCT. By assessing all 3 of these key biomechanical parameters, which have previously been studied only separately, and by using varied methodology, we aimed to enhance the understanding of RCT progression and staging.

The present study is not without limitations. Inherent in all studies of biomechanical nature, we were limited to investigating time-zero effects of the SS tears, where no healing or compensatory mechanisms have occurred. Second, we utilized static loading conditions to control independent variables and increase reproducibility. This is in accordance with previously reported biomechanical literature, including recent studies by Oh et al,<sup>24</sup> Williamson et al,<sup>31</sup> and Mihata et al.<sup>15-18,19</sup> For similar reasons, our cadaveric model did not incorporate scapulothoracic motion. Finally, while most massive tears involve multiple cuff tendons,<sup>2,8</sup> we were limited to simulating only an SS tear. Concurrent subscapularis and SS tears resulted in joint instability that precluded biomechanical testing. Thus, our findings may not correlate with the effects of multitendon tears. It is important to note that our results for deltoid abduction force,<sup>1,6,9,11,21</sup> superior humeral migration,<sup>10,18,19,24,28</sup> and passive ROM<sup>24</sup> are generally consistent with similar biomechanical studies, given the variable methodology employed by the authors.

## CONCLUSION

In our comparison of small and large SS tears, we found that an incomplete, repairable SS tear did not significantly alter the biomechanics of the shoulder, while a complete SS tear decreased the deltoid abduction force, increased the superior humeral translation, and mildly increased the passive ROM. Our findings demonstrate the effects of large SS tears on key biomechanical parameters, as the tears progress from partial to complete.

## ACKNOWLEDGMENT

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