# Failure of the Biceps Superior Labral Complex: A Cadaveric Biomechanical Investigation Comparing the Late Cocking and Early Deceleration Positions of Throwing

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**Purpose:** The goal of the study was to determine which position of the throwing motion, late-cocking or early deceleration, was more likely to produce lesions of the biceps superior labral complex. **Type of Study:** Cadaveric biomechanical model. **Methods:** Ten paired cadaver shoulders were prepared and mounted on a custom testing apparatus in 60° glenohumeral abduction with the humerus in the plane of the scapula. All specimens were loaded with 100 cycles of subfailure external rotation torque (7.9 N-m) with 22 N applied to the rotator cuff tendons and long head of the biceps tendon. One of each pair of specimens was randomly tested in a late cocking position for throwing (>125° external rotation, 60° glenohumeral abduction, in the plane of the scapula). The other was tested in a position of early deceleration (80° external rotation, 60° glenohumeral abduction, 16° horizontal adduction). The biceps was loaded to failure with the shoulder fixed in these positions. The specimens were then examined by 2 experienced shoulder surgeons, blinded to the test protocol, to assess for the presence of a type II SLAP lesion. **Results:** Failure of the biceps superior labral complex occurred at the superior glenoid in 9 of 10 specimens in the late cocking position and in 2 of 10 specimens in the early deceleration position ($P = .055$). Five specimens developed type II SLAP lesions, with more in the late cocking position (4 of 10) than in the early deceleration position (1 of 10; $P = .12$). Load to failure was significantly less for the late cocking position (289 ± 39 N) than for the early deceleration position (346 ± 40 N; $P = .004$). **Conclusions:** These results suggest that the late cocking position may contribute to biceps-superolabral complex injuries in the thrower's shoulder. **Key Words:** Superior labrum injury—Throwing—Biomechanics—Shoulder.

Lesions of the superior labrum in the shoulders of throwing athletes were first described by Andrews et al.[1] in 1985. These authors recognized the role of the long head of the biceps tendon in producing these lesions and speculated that eccentric traction on the long head of the biceps tendon during the deceleration phase of throwing may have a role in their creation. This concept evolved from electromyographic analyses of the biceps muscle during the throwing motion. The analyses showed the biceps to have a peak of activity during the deceleration phase of the throwing motion.[2]

In 1990, Snyder et al.[3] analyzed and classified a large series of superior labral lesions. Lesions in which the biceps anchor and superior labrum were detached were called type II SLAP lesions (an abbreviation for superior labrum, anterior and posterior).[3] These type II SLAP lesions were thought to occur as a result of traction on the biceps tendon.[3] Snyder et

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al.[3] also suspected that deceleration of the arm during throwing may be responsible for the development of these lesions in the throwing athlete.

More recently, Barber et al.[4] and Morgan et al.[5] have investigated the types of SLAP lesions in throwing athletes and have identified a number of different types of biceps superior labral complex injuries. Based on observations during arthroscopy, Morgan and Burkhart[6] suggested that humeral external rotation during the late cocking phase of throwing may be an important contributor to their pathogenesis. Interestingly, electromyographic studies have also shown that high biceps activity occurs during the cocking phase of throwing.[2,7,8] The purpose of this investigation was to study the effect of these 2 arm positions, late cocking and early deceleration, on the propensity to develop and the force required to produce biceps superior labral complex lesions in a reproducible biomechanical cadaver model.

## METHODS

### Specimen Preparation

Twenty healthy shoulders from 10 cadavers (average age, 55.4 ± 21 years, from 5 men and 5 women) were dissected free of soft tissue, retaining only the scapula, humerus, long head of the biceps tendon, coracoacromial ligament, glenohumeral capsular and coracohumeral ligaments, and rotator cuff tendons. Before testing, specimens underwent arthroscopic examination through a standard posterior portal to exclude pairs with pre-existing injury to the labrum or biceps tendon. None of the specimens had rotator cuff tears or visible or palpable signs of degenerative arthritis.

### Testing Setup and Experimental Protocol

The humerus and scapula were mounted in a custom shoulder testing apparatus (Fig 1) capable of simulating muscle forces and attached to a servohydraulic testing machine (Model 810; MTS, Minneapolis, MN).[9-13] Low-friction pneumatic cylinders (CM2Q; SMC Pneumatics, Indianapolis, IN), controlled by electropneumatic regulators (VIP; LDI Pneutronics, Hollis, NH), were used to apply simulated rotator cuff muscle forces via Dacron cord (DuPont, Wilmington, DE). The Dacron cord was routed through low-friction pulleys that directed each rotator cuff muscle's line of action through the center of its estimated cross section. This Dacron cord was tied to nylon straps that were sutured to each rotator cuff tendon stump. Because the infraspinatus and teres minor muscles act similarly and share adjacent insertion sites, they were combined as a single external rotator for simplicity. The long head of the biceps was held with a tendon clamp (Synthes, Paoli, PA). Loads of 22 N were applied to the supraspinatus, subscapularis, combined external rotators, and long head of the biceps tendon.

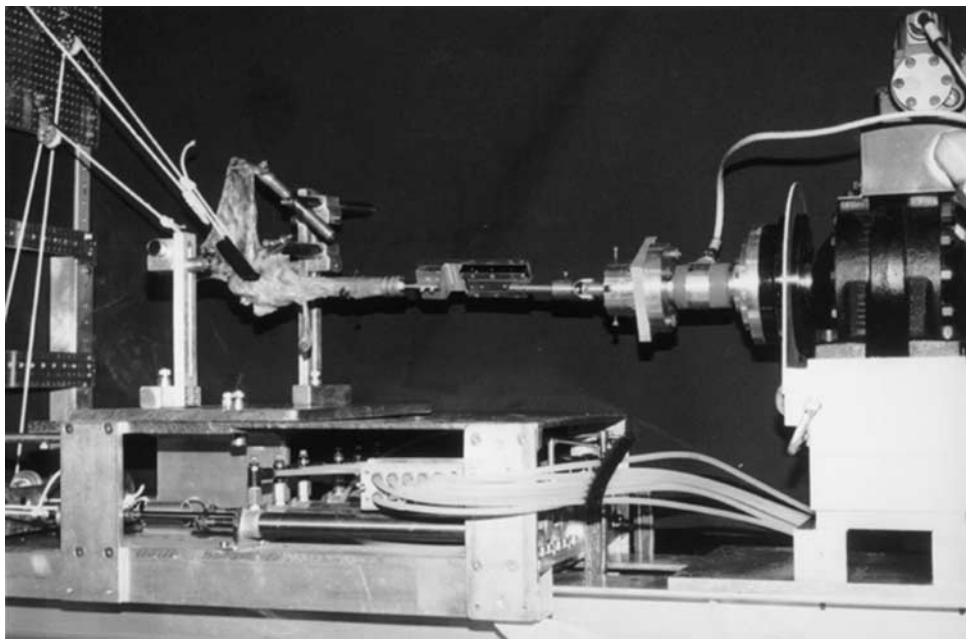

**Figure 1.** Testing apparatus. The scapula is fixed to the testing platform. Rotator cuff forces are applied by Dacron cords secured to the rotator cuff tendons and routed through low-friction pulleys to pneumatic cylinders located under the testing platform. The biceps was loaded during the external rotation loading protocol, and the fixation was changed to a cryogenic clamp for rapid load application to failure via an MTS machine.

These muscle forces were chosen to maintain joint congruity.[9-13] Limitations in tendon fixation prevented the simulation of the high rotator cuff forces generated during throwing. A similar method has been used previously by our group to assess the role of joint subluxation in the creation of type II SLAP lesions.[9]

The humerus was positioned in 60° of glenohumeral abduction in the plane of the scapula. This position was chosen to simulate the shoulder position encountered during the cocking phase of throwing, which has been found to be approximately 90° of thoracohumeral abduction.[14,15] To achieve maximal external rotation, the glenohumeral joint of each specimen was loaded with 100 cycles of external rotation torque at a rate of 1.1 N-m/s using 7.9 N-m of force. Pilot data using 5 specimens had shown this torque to be less than the lower boundary for the 95% confidence interval for failure in this testing mode. All specimens were treated with this protocol. All of the specimens tested achieved at least 125° of external rotation.

Pairs of specimens were then randomly divided into 2 different test positions. Randomization was performed by assigning 6-digit numbers to each specimen. These 6-digit numbers were then assigned to a test position using a computer-generated randomization table. For evaluating the late cocking phase of throwing, the humerus was fixed in 60° of glenohumeral abduction in the plane of the scapula and was externally rotated until the glenohumeral capsule became taught (134° ± 8°). This position corresponds to the position of the humerus during the late cocking phase of throwing.[14,15]

For evaluating the early deceleration position, the humerus was fixed in 60° of glenohumeral abduction, in 16° of horizontal adduction, and in 80° of external rotation. This corresponds to the position 10 ms after ball release, at which time biceps activity peaks during deceleration on electromyographic studies of throwing athletes (S. Werner, personal communication).

A cryogenic tendon clamp was used to secure the biceps tendon, which was attached via a steel cable in its line of action through a pulley and then connected to the MTS load cell. This provided a stable attachment to the distal biceps tendon for rapid, large load application throughout the duration of testing. Tissue adjacent to the cylinder was not frozen, and a temperature gradient was noted from the frozen tendon to the highest visible portion of the extra-articular biceps tendon. This temperature gradient prevented a possible stress riser at the tendon–frozen tendon junction.

Data acquisition and MTS control were synchronized with LabView software (National Instruments, Austin, TX) on a personal computer. Load cell force and MTS displacement were sampled at a rate of 1000 Hz, and the biceps tendon was tensioned along its anatomic axis at a rate of 12.7 cm/s to a final displacement of 7.62 cm. Failure load, defined as the first major decrement in biceps force and reflecting initial damage to the biceps-labral complex, was recorded from the force-displacement data. Following testing, the inferior capsule of the glenohumeral joint was opened to expose the glenoid and superior labrum. Two experienced shoulder surgeons (J.E.K., R.B.B.), masked to the throwing phase position, evaluated the resulting injury in each shoulder. The outcome parameter was the presence or absence of a type II SLAP lesion, as defined by Snyder et al.[3]

### Statistical Design and Analysis

A 1-sample paired $t$ test was used to test for a difference in the load to failure. For other comparisons, a binomial test using a matched design was used. The association between testing position and development of type II SLAP lesions was assessed using an exact test (the type I error probability was computed for a matched design using the binomial distribution with equal odds of a pair of shoulders sustaining a type II SLAP lesion only in late cocking position and a pair of shoulders sustaining a type II SLAP lesion in the deceleration position). Two-sided tests were used, and critical test statistics were selected for a statistical significance of $P = .05$.

## RESULTS

The 100 cycles of subfailure external rotation load produced an increase in external rotation of 21° ± 13°, to achieve a maximal external rotation of 134° ± 8°. Table 1 reports the failure load and outcome for the 10 pairs of specimens in this study. The biceps superior labral complex failed with significantly less force in the late cocking position (289 ± 39 N) than in the early deceleration position (346 ± 40 N; $P = .004$). Failure of the biceps superior labral complex at the superior glenoid occurred in 9 of 10 specimens in the late cocking position and in only 2 of 10 in the early deceleration position ($P = .055$). All other specimens failed in the midsubstance of the extra-articular biceps tendon near the bicipital groove on the humerus (Table 1); none of the failures occurred at the cryogenic tendon clamp. Of the 20 specimens tested, 5 type II SLAP lesions as defined by Snyder et al.[3] were

**TABLE 1.** *Specimens, Testing Positions, and Load to Failure*

| Specimen/Side Age/Sex | Position Tested | Maximum Failure Load | Site of Failure | Mode of Failure and Location of Failure (Intra-articular *v* Extra-articular) | Type II SLAP? |
|---|---|---|---|---|---|
| 1R 32/F | Cocking | 169 N | Intra-articular | Type II SLAP | Yes |
| 1L 32/F | Deceleration | 267 N | Intra-articular | Biceps failure at superior glenoid, labrum intact | No |
| 2R 83/F | Cocking | 207 N | Intra-articular | Type II SLAP | Yes |
| 2L 83/F | Deceleration | 294 N | Extra-articular | Biceps tear at bicipital groove | No |
| 3R 79/F | Deceleration | 287 N | Extra-articular | Biceps tear at bicipital groove | No |
| 3L 79/F | Cocking | 192 N | Intra-articular | Biceps failure at glenoid, labrum mostly intact | No |
| 4R 21/M | Deceleration | 575 N | Extra-articular | Biceps tear at bicipital groove | No |
| 4L 21/M | Cocking | 500 N | Extra-articular | Biceps tear at bicipital groove | No |
| 5R 37/M | Cocking | 525 N | Intra-articular | Biceps failure from superior glenoid, labrum damaged | No |
| 5L 37/M | Deceleration | 564 N | Extra-articular | Biceps tear at bicipital groove | No |
| 6R 73/M | Deceleration | 318 N | Extra-articular | Biceps tear at bicipital groove | No |
| 6L 73/M | Cocking | 263 N | Intra-articular | Type II SLAP | Yes |
| 7R 42/M | Cocking | 256 N | Intra-articular | Biceps failure from glenoid, labrum intact | No |
| 7L 42/M | Deceleration | 366 N | Extra-articular | Biceps tear at bicipital groove | No |
| 8R 65/M | Deceleration | 223 N | Extra-articular | Biceps tear at bicipital groove | No |
| 8L 65/M | Cocking | 243 N | Intra-articular | Biceps failure at superior glenoid, labrum intact | No |
| 9R 58/F | Cocking | 279 N | Intra-articular | Type II SLAP | Yes |
| 9L 58/F | Deceleration | 326 N | Intra-articular | Type II SLAP | Yes |
| 10R 64/F | Deceleration | 238 N | Extra-articular | Biceps tear at bicipital groove | No |
| 10L 64/F | Cocking | 255 N | Intra-articular | Biceps failure from superior glenoid, labrum intact | No |
| *P* values cocking *v* deceleration | | Load to failure: $P = .004$ | | Location of failure: $P = .055$ | Type II SLAP? $P = .12$ |

generated. Of these 5, 4 occurred in the late cocking position and 1 in the early deceleration position ($P = .12$). Figure 2 shows a pair of tested specimens after removal of the humerus. The specimen in Fig 2A was tested in the early deceleration position and demonstrates a normal glenoid-biceps-superior labral complex. In this specimen, the failure occurred in the midsubstance of the biceps tendon. The specimen in Fig 2B, which is contralateral to the specimen shown in panel A, was tested in the late cocking position and shows a Type II SLAP lesion as defined by Snyder et al.[3]

## DISCUSSION

The type II SLAP lesion, in which the biceps anchor and superior labrum are avulsed from the superior glenoid is the most common type of superior labral lesion.[3,16] A variety of mechanisms may be responsible for their production.[9,6,16] Throwing athletes seem particularly predisposed to the development of type II SLAP lesions.[1,4] Other lesions of the biceps superior labral complex have also been identified in the shoulders of throwing athletes.[4,5] The pathogenesis of these lesions in throwers has been speculative, because experimental work has been lacking. Traction on the long head of the biceps tendon is thought to be a critical component for the development of type II SLAP lesions in throwing athletes;[1,3,5] however, the position of the arm when this traction occurs has never been made clear.

Early electromyographic studies of the biceps demonstrated that 1 peak of biceps activity occurs in the early deceleration phase of throwing.[2,7,8] Researchers have suggested that eccentric loading of the biceps tendon during this phase of throwing may be responsible for the generation of biceps superior labral complex lesions.[1] Interestingly, peak biceps activity at this time reaches only 44% of the maximal voluntary contraction,[7] which would seem to be inadequate to generate the force required to produce a type II SLAP lesion.

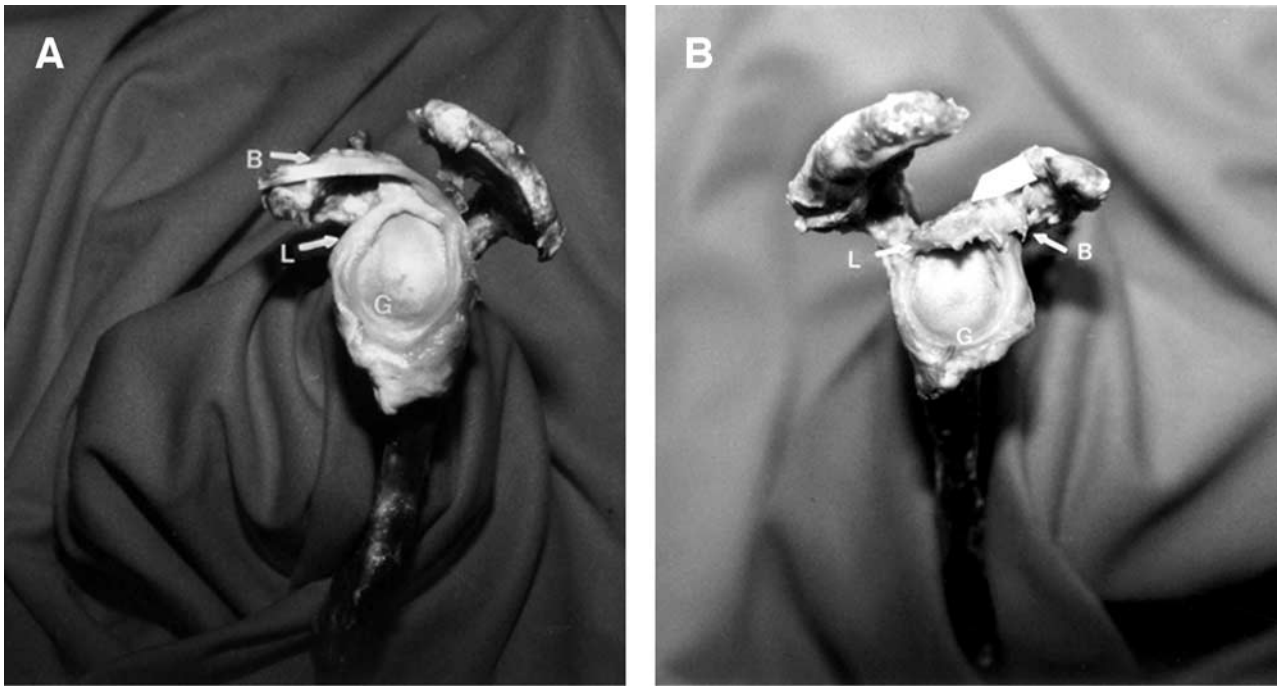


**FIGURE 2.** Typical pair of specimens. (A) A left shoulder was tested in the early deceleration position and failed at the extra-articular portion of the biceps tendon. The biceps-labral complex is intact. The failure site of the biceps is in the bicipital groove and is seen draped over the coracoid process. (B) The contralateral shoulder of the pair was tested in the late cocking position, and a typical type II SLAP lesion is seen. The large arrow is pointing to the superoglenoid rim clearly visible above the detached superior labrum. (B, long head of biceps tendon; L, superior labrum; G, glenoid.)

Biceps activity is also high during the late cocking phase of throwing.[2,7,8,17,18] Recently, Morgan and Burkhart[6] visualized a large series of superior labral lesions in overhead athletes during arthroscopy and discovered that passive positioning of the arm in abduction and external rotation allowed the posterosuperior labrum to "peel-back" from the glenoid in patients with type II SLAP lesions.[4,5] The authors suggested that the cocking phase of throwing might have a role in the production of these lesions in throwing athletes.[6] Data from our experiment suggest that biceps superior labral lesions can be created in both positions; however, these lesions occur at a greater rate and require significantly less force to produce in the late cocking position than in the early deceleration position.

Throwing requires an extreme amount of external rotation of the abducted arm, with baseball pitchers achieving approximately 165° of external rotation.[15,18-21] This amount of external rotation must place the bicipital groove in a position far behind the glenohumeral joint. The intra-articular tendon of the long head of the biceps would probably experience substantial tensile force as it wraps around the lesser tuberosity (Fig 3). Moreover, this position would load the biceps at angles that deviate from the normal fiber orientation of the biceps-labral complex. Studies investigating the microscopic anatomy of the biceps-labral complex have shown that biceps fibers continue into, and make up the bulk of, the posterior labrum.[22,23] The orientation of these fibers empirically suggests that the biceps-labrum complex is adapted to resist traction forces when the biceps is pulled anteriorly.

In the thrower's shoulder, abduction with maximal external rotation changes the orientation of the load application at the biceps superior labral complex, possibly contributing to the likelihood of failure (Fig 3). Recently, Pradhan et al.[24,25] applied linear transducers to the superior labrum in a cadaver model. They found that external rotation of the abducted humerus simulating the late cocking position of throwing produced significant increases in the measured strain on the labrum, particularly the posterior labrum. Other positions of the arm simulating other phases of the throwing motion did not generate statistically significant increases of the measured labral strain. This study supports our findings and lends more evidence to

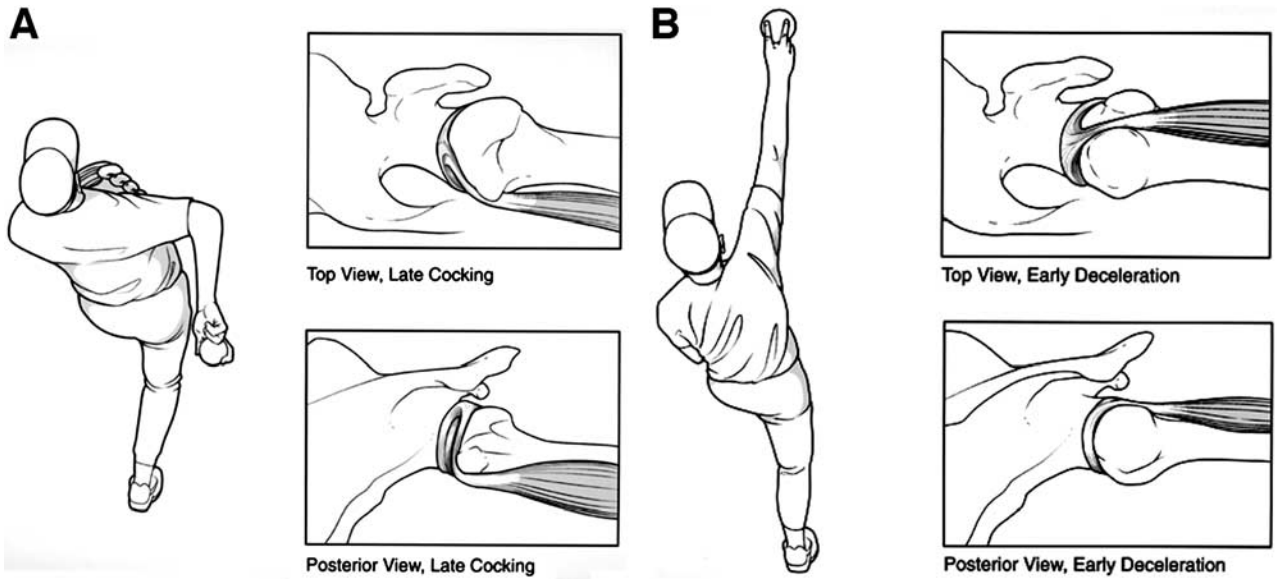


**FIGURE 3.** Position of the biceps groove in the late cocking position and in the early deceleration positions. In the cocking phase, the long head of the biceps is oblique to the orientation of its fibers that invest in the posterosuperior labrum, possibly making failure more likely. (A) Position of biceps tendon in late cocking. (B) Position of the biceps tendon in early deceleration.

suggest that the position of extreme external rotation during throwing may be important in the development of superior labral tears.

It is important to note that a great amount of anatomic variation exists in the biceps superior labral complex.[22,23] In this study, paired specimens were used with the assumption of symmetrical variation to reduce the effect of anatomic variation. Nevertheless, the anatomic variation between specimens may explain why type II SLAP lesions, as defined by Snyder et al.[3] were produced in only 5 of the 20 specimens tested. This clearly limits the statistical power of our experiment.

Other limitations of this model relate to the complexities associated with simulating the throwing shoulder using a cadaver model. In this experiment, we did not attempt to generate the large rotator cuff forces that occur during throwing. Instead, load values were used that have been shown to maintain joint congruity and are consistent with those used in previous cadaveric biomechanical shoulder models.[9-13] With regard to the biceps load, our rate of load application was relatively fast for cadaver models (12.7 cm/s); however, this may be slower than the load that the biceps experience during the throwing motion. Subphysiologic loads, while used in laboratory studies, may not reproduce the mode of failure seen with higher forces in the rotator cuff. The application of high loads to the biceps and subphysiologic loads to the rotator cuff produces dynamic forces across the joint that do not replicate the normal throwing state. This may affect the injury pattern produced in a cadaveric model. Other concerns with cadaver models include the age of the specimens. Greater age may introduce pathologies (pre-existing biceps tendinopathy) that would not be seen in a younger, athletic population and may affect the mechanical properties of the tissues studied.

Our specimens could only achieve an average of 134° of glenohumeral external rotation without the potential for damage. Our specimens averaged 55 years, and younger specimens may have allowed more external rotation. Throwing athletes are capable of achieving approximately 165° of external thoracohumeral rotation.[15,18-21] Although some of this rotation results from hyperextension of the spine and torsion of the humeral shaft, it is likely that throwing athletes achieve more glenohumeral external rotation than produced in our model. It is also important to realize that the positions used in this experiment were estimates based on whole-body kinematics because the precise position of the glenohumeral joint during throwing is unknown. Finally, the biceps tendon in this cadaver model was loaded rapidly through 1 cycle to failure. The biceps superior labral complex injuries in throwing athletes probably result from rapid and cyclic loading of a pretensioned biceps tendon through the entire throwing motion. Therefore, other positions of

throwing may certainly contribute to the formation of a superior labral tear.

Despite these limitations, this biomechanical model is capable of creating biceps superior labral injuries while eliminating multiple variables, which allows for the comparison of different mechanisms considered to be important in the development of these injuries.[6] In addition, recent experiments in our laboratory have demonstrated that the long head of the biceps acts as an important dynamic restraint to external rotation of the abducted arm.[11] Based on this evidence and the results of this experiment, we believe that biceps superior labral complex injuries may be generated in the throwing shoulder through failure of this dynamic restraint in extremes of external rotation, and that early deceleration may be less important in their creation.

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