INTRODUCTION
Shoulder separations are common injuries. Controversy exists over the optimal treatment. More importantly, no single reconstruction technique is widely accepted. Current operative management focuses on primary healing or reconstruction of the ligaments using local tissue or free tendon grafts with supplemental fixation. The objective of these techniques is to maintain reduction long enough to allow for healing of the ligaments. Numerous suture materials have been utilized including Mersilene tape, braided PDS suture, and more recently, FiberWire. Clinically and radiographically, it often appears that the reconstructive material “sawed through” the distal clavicle or coracoid. Do certain materials, though stronger in tension, contribute to this mode of failure? Is the clinical failure that we see due purely to tension, or do multiple factors play a role?

Previous studies have focused on failure of various techniques in tension alone. We hypothesize that rotation may play a role in observed failures of the modified Weaver-Dunn reconstruction. No current study has evaluated long axis rotation of the clavicle as a possible mode of failure. This rotation occurs in vivo and must be addressed in a full analysis of construct failure.

OBJECTIVES
• To assess AC joint mechanical response to long axis rotation
• To demonstrate the effects of different suture constructs to the clavicle and coracoid based on the orientation of the repair
• To investigate the relative ability of these suture augmentations to withstand cyclic loading about the long axis of the clavicle

MATERIALS AND METHODS
15 cadaveric shoulders were tested on an MTS servo-hydraulic testing machine in rotation about the long axis of the clavicle. The clavicle was rotated through 50 degrees of motion and torque was recorded for the intact joint. A modified Weaver-Dunn was performed with two different coracoclavicular slings (one passing through bone tunnels in the clavicle and one passing around the clavicle). For each of these configurations, the joint reaction force was again measured. The AC joint was also cycled over 40 degrees of rotation for 15,000 cycles (or until failure) to assess wear characteristics.

Three different suture types were tested in these configurations, namely Mersilene Tape, Braided PDS II and Fiberwire.

RESULTS
In testing, the torque applied over 50 degrees of rotation about the long axis of the clavicle ranged from +1.1 to -2.6 N-m, with positive torques corresponding to the anterior aspect of the clavicle moving in the superior direction. After modified Weaver-Dunn, with either augmentation through drill holes or over the clavicle, 50 degrees of rotation produced torque ranging from 0.2 to -0.3 N-m. It was observed that the use of FiberWire for augmentation resulted in abrasion of the soft tissue and the periosteum overlying the coracoid when looped around the clavicle. The braided PDS II suture resulted in abrasion into the periosteum, but not through the cortical bone of the coracoid process. The Mersilene Tape did not result in any notable wear to the coracoid process. In no case did any suture cut through the coracoid process. With all augmentations, relative motion between the bone and the suture was primarily observed at the coracoid resulting in a sawing motion. It appears that the greater contact area and positioning of the knot on the clavicle led to the biased wear of the coracoid and little slip was observed between the suture and the clavicle. No wear of the coracoacromial ligament was observed in any specimen subsequent to transfer and cycling. In the FiberWire tests, the FiberWire itself was observed to fail in an average of 8213 cycles, with failure initiating along the inferior surface of the coracoid process. There was notable wear in 3 of the 5 Mersilene augmentations with the suture loop construct including 1 failure at an average 12,000 cycles. Failure typically initiated along the inferior surface of the coracoid. No notable wear was observed in the braided PDS II suture.

DISCUSSION
Currently there is no consensus among orthopaedic surgeons on the surgical treatment of acromioclavicular disruptions and many techniques are currently used. One such technique, popularized by Weaver and Dunn in 1972 involves excising 1 cm of the distal clavicle and transferring the coracoacromial ligament to the intramedullary space of the distal clavicle with sutures passed through drill holes. In their original description, no devices were used to augment the reconstruction. More recently, popular modifications of this technique have included augmentations to strengthen the reconstruction while the ligament transfer heals. One of the earliest and most popular forms of augmentation involves the use of a coracoclavicular sling. Suture can be placed around the clavicle or through the drill holes in the clavicle.

Despite numerous options for reconstructions, there is an overall relative paucity of biomechanical data in the literature regarding the acromioclavicular joint and popular reconstructions for this joint. There are reports in the literature of failures of reconstructions including the modified Weaver-Dunn. This has initiated a renewed interest in examining the biomechanical stability of the both the intact and reconstructed coracoclavicular ligament complex, specifically evaluating some of the popular augmentation techniques. However, all of these reports have focused on the failure of augmentation techniques under a unidirectional applied load, specifically looking at ultimate tensile structural properties. Very few reports have examined the role of axial rotation of the clavicle in ultimate failure. Originally described by Codman and later expanded by Inman, the clavicle rotates about its long axis approximately 40-50 degrees with scapular motion, creating a much more complex relationship at the AC joint.

Based on clinical failures, as well as the findings of this study, we feel that the rotation of the clavicle involved in scapular motion may play a role in the relatively high failure rates seen with coracoclavicular reconstruction, possibly secondary to the effects of cerclage sutures eroding through either the clavicle or coracoid from rotatory motion.

Regarding suture selection, the results of this study favor the use of FiberWire when choosing to augment around the clavicle rather than through drill holes. The braided PDS II suture resulted in abrasion into the periosteum, however there was no clear violation of the cortex. While the construct may not offer the strength or stiffness of the FiberWire, it demonstrated its ability to survive 12,000 cycles of loading and without any signs of wear to either the fiber or the coracoid. In contrast, the FiberWire produced notable wear through the level of the periosteum of the coracoid process and ultimately this suture failed at an average of 10,000 cycles at interface with the coracoid when looped around the clavicle. However, a disadvantage of braided PDS includes the additional time required to braid 9 individual sutures and the inconsistencies of such a technique may dissuade the surgeon for opting for this technique. Mersilene tape also proved to be a less reliable material when augmenting around the clavicle. There was notable wear in 3 of the 5 Mersilene augmentations with the suture loop construct including 1 failure at an average 12,000 cycles. Failure typically initiated along the inferior surface of the coracoid.

While suture selection did lead to demonstrable wear of both the suture and the coracoid when the augmentation was looped around the clavicle, this was eliminated by the placement of the suture through opposing drill holes.

CONCLUSION
This study suggests that when using a coracoclavicular suture loop to augment coracoacromial ligament transfer, suture loops secured around the entire clavicle contribute to increased abrasive wear. However, this can be avoided by securing suture loops through opposed drill holes in the clavicle. This study further suggests that while stiffer suture material may have increased tensile properties, associated abrasive properties must also be considered.

These findings have important implications relating to decision making in acromioclavicular joint reconstruction. The biomechanical influence of clavicular rotation should be weighed when selecting augmentation material and deciding whether to place the material through drill holes or around the clavicle.

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