MECHANICAL BEHAVIOR OF THE CORACOCLAVICULAR LIGAMENT AND NOVEL ANATOMIC RECONSTRUCTION COMPLEXES

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INTRODUCTION

Acromioclavicular (AC) joint separations are common injuries seen in athletes or laborers in which the AC capsule and coracoclavicular (CC) ligaments are both ruptured [1]. Both surgical and conservative treatments have similar outcomes [2], with both treatments having no guidelines for rehabilitation. The CC ligaments, trapezoid and conoid, have greater structural properties than current surgical treatments [3,4], which replace the multi-bundle orientation of the CC ligaments with a single orientation [5]. Recent studies have also reported salvage of failed CC ligament repairs using tendon allografts [6]. Therefore, the objective of this study was to evaluate the mechanical behavior of the CC ligament and novel anatomic reconstruction complexes. This study can provide guidance to improve the outcome of surgical treatment and allow early mobility, accelerated rehabilitation and earlier return to sports for high level athletes or return to work for heavy laborers.

METHODS

Nine fresh frozen human cadaveric shoulders (mean age = 51±13 years, range 21-60) were disarticulated at the glenohumeral joint and dissected free of all soft tissue with the exception of the CC ligament complex. The scapula and the proximal two thirds of the clavicle were potted in epoxy putty and rigidly fixed in an anatomic position to the base and crosshead of a materials testing machine (Instron, Model 4502, Canton, MA), respectively. Superior displacement of the clavicle was described with respect to a coordinate system fixed to the scapula [7].

All tests were performed with a cross head speed of 50 mm/min and initial preload of 5N. Initially, the CC ligament complex was cyclically loaded from 20N to 60N for 100 cycles, followed by one hour of recovery in an unloaded state. Cyclic loading was then repeated with a maximum 90N for a 100 cycles. After another recovery period, a load-to-failure protocol was then performed. The mechanical behavior (cyclic behavior and structural properties) of the CC ligament complex were derived from the load-elongation curves.

After simulating AC joint dislocation, the joint was returned to its anatomic position and the novel anatomic reconstruction was performed (Figure 1). A 7mm diameter hole was drilled through the base of the coracoid process, a 6mm diameter clavicular hole was placed directly superior to the base of the coracoid process and another clavicular hole was placed 1 cm distally. The length of the semitendinosis graft was individualized for each specimen to assure end-to-end contact of the graft on the superior surface of the coracoid. For proper fixation, each end of the tendon was prepared with Arthrex 5-0 FiberWire using standard techniques.

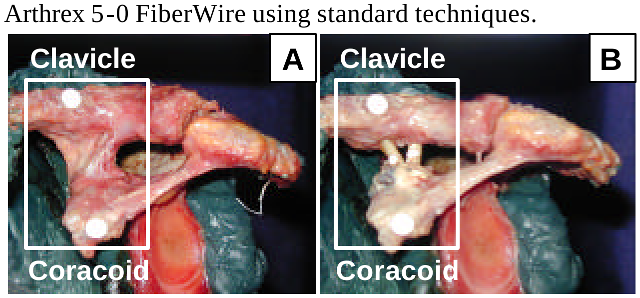

Figure 1. A) Intact AC joint including the CC ligament complex and B) after dislocation with novel anatomic reconstruction.

Each end of the graft was passed inferiorly through separate clavicular holes and then passed simultaneously through the base of the coracoid process to simulate both orientations of the native CC ligaments. The two ends were then fastened end-to-end on the superior aspect of the coracoid process. The same cyclic creep testing and load-to-failure protocol for the CC ligament complex was then repeated for the novel anatomic reconstruction.

Creep was determined to be the amount of elongation between the peaks of the first and last cycle of loading. Permanent elongation was determined to be the difference in elongation after recovery from a cyclic creep test compared to initial length of the complex. A one-way repeated measures analysis of variance was performed with statistical significance set at $p<0.05$ to compare the structural properties of the intact and novel anatomic reconstruction.

RESULTS

The average amount of creep for the CC ligament complex increased from 0.1mm to 0.3mm after increasing the maximum load from 60N to 90N, respectively (Table 1). In contrast, the amount of creep for the novel anatomic reconstruction decreased from 1.9mm to 1.5mm during the cyclic creep test with maximum loads of 60N and 90N, respectively.

The 0.2mm of permanent elongation of the CC ligament complex resulted from the cyclic creep test with maximum of 60N; however, no additional elongation occurred following subsequent cyclic creep tests (Table 1). The permanent elongation of the novel anatomic reconstruction also increased 0.9mm and 0.2mm following a rest period after cyclic creep tests with maximums of 60N and 90N, respectively.

The shape of the load vs. elongation curves for both complexes are typical, including an initial nonlinear low-stiffness toe region, followed by a linear region with greater stiffness (Figure 2). The stiffness and ultimate load of the novel anatomic reconstruction were 60% and 20% less than the CC ligament complex, respectively ($p<0.05$, Table 1). However, the elongation and energy absorbed at failure of the novel anatomic reconstruction were 50% and 35% greater than the CC ligament complex, respectively ($p<0.05$).

DISCUSSION

The mechanical behavior of the CC ligament and novel anatomic reconstruction complexes were characterized in this study. Although the amounts of creep and permanent elongation were greater for novel anatomic reconstruction, both measurements are below the level of clinical instability and suggest that early rehabilitation may be possible to allow early range of motion. The large range of standard deviation for permanent elongation of the novel anatomic reconstruction resulted from seven specimens having no permanent elongation. Specimens with permanent elongation greater than zero were likely due to slippage of the initial fixation of the tendon graft. Current repair techniques have comparable structural properties to the novel anatomic reconstruction [3,4]. However, our complex includes the properties of the clavicle and coracoid which have lower stiffness compared to the tendon graft [8]. All techniques have significantly diminished properties compared to the CC ligament complex [3,4]. With the incorporation of biological tissue into the reconstruction, the possibility of tendon-to-bone healing could improve these properties. In the future the kinematics of the AC joint after novel anatomic reconstruction should be determined and compared to the intact AC joint and current repairs and reconstructions.

			CC Ligament Complex	Novel Anatomic Reconstruction
Cyclic Behavior	Creep (mm)	(20-60N)	0.1 ± 0.2	1.9 ± 0.7
		(20-90N)	0.3 ± 0.2	1.5 ± 0.4
	Permanent Elongation (mm)	(20-60N)	0.2 ± 0.4	0.9 ± 1.5
		(20-90N)	0.2 ± 0.6	1.1 ± 1.6
Structural Properties	Stiffness (N/mm)		60.8 ± 12.2	23.4 ± 5.2 *
	Ultimate Load (N)		560 ± 206	406 ± 60 *
	Elongation at Failure (mm)		7.5 ± 3.5	14.8 ± 3.4 *
	Energy Absorbed at Failure (N-mm)		3516 ± 1982	5569 ± 1453 *

Table 1. Mechanical behavior of the CC ligament and novel anatomic reconstruction complexes. (mean±SD, *$p<0.05$)

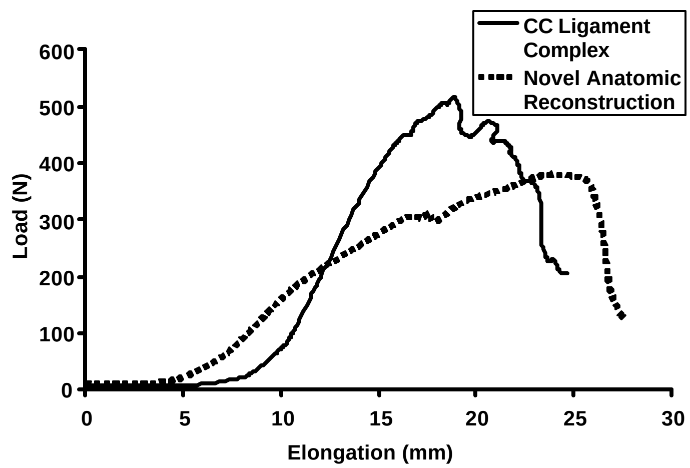

Figure 2. Typical load vs. elongation curves for the CC ligament and novel anatomic reconstruction complexes.

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