Coracohumeral Ligament and Supraspinatus Cord contributions to Shoulder Abduction

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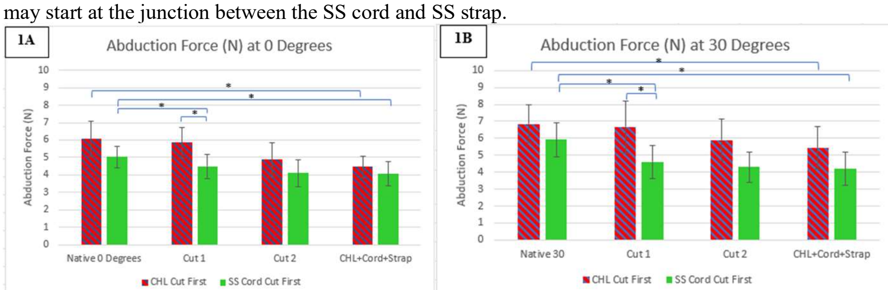
INTRODUCTION:
The Rotator Cuff (RC) consists of ligamentous attachment of the humerus to the scapula and four major muscles: the Supraspinatus (SS), Infraspinatus (IS), Teres Minor (TM), and the Subscapularis (SSc). These muscles serve to rotate the humerus about all three mechanical axes and to keep the Humeral Head in the Glenoid. In rotation, SS, which is known to be important in preventing muscle degeneration of the RC, has two subunits, the SS cord (Anterior SS) and the SS strap (Posterior SS). The Coracohumeral Ligament (CHL) forms a substantial part of the passive RC tissue and acts as the anterior insertion of the rotator cable (RCa). The RCa is often referred to as a "suspension bridge", which has previously been thought to be responsible for stress shielding the Rotator Crescent from SS and IS loads. A recent study has shown that the "suspension bridge" theory may not be accurate (Schmidt 2022). Specifying the crucial structures involved in shoulder abduction will enhance our understanding of the RC's role in force transmission and thereby improve clinical outcomes of RC tear treatment. This study aims to discern the anatomy of the SS cord and CHL and to find their respective roles in shoulder abduction. Our null hypothesis is that the CHL plays a greater role in SS and IS force transmission than the SS cord.

METHODS:
Forty-five fresh frozen cadaver shoulders were obtained with the approval of our university's Committee on Oversight in Research Involving Decedents. Twenty-five shoulders were excluded due to either glenohumeral arthritis or RC tears leaving twenty cadavers for the study. The specimens were randomly assigned to either of two groups: a CHL cut first group, or a SS cord cut first group. The shoulders were dissected to leave only the Humerus, RC with RC muscles and the Scapula. The anterior and posterior borders of the RC muscles and CHL were outlined on the RC using a waterproof marker. The SS cord and SS strap were marked individually. Anteroposterior widths of the RC muscles and CHL were measured using a scientific caliper. Sutures were then added via Krackow whip stitches into the myotendinous junction of the SS cord, SS strap, upper and lower SSc, IS and TM. The specimens were then fixed in a shoulder simulator designed to hold the Scapula in place, load the RC muscles along physiological lines of action and record abduction at the unconstrained distal humerus. A preload of ten Newtons was applied to account for hysteresis. The Humerus was centered in the Glenoid and confirmed to be in place via C-arm imaging. Each specimen was subjected to a sequence of four cuts, with transections of the RC from the humeral insertions of first either the CHL or SS cord followed by the SS Strap, and the IS. Prior to the first cut and after every ensuing cut loading was performed and abduction values recorded at 0 and 30 degrees of abduction. The loading was cyclic at a frequency of 0.25Hz ranging from 10N to physiological load and abduction force was taken at the peak of the fourth cycle. The physiological loads were SS cord 56N, SS strap 24N, IS 90N, TM 97N, upper SSc 108N and lower SSc 127N. The physiological loads were determined using the cross-sectional area of each muscle and electromyographic activity (Kedgley 2007, Omi 2010, Roh 2000). A motion analysis system (Spicatek, SPICA Technology Corp.) was used to track humeral head translation relative to the glenoid via 4 markers on both the Humerus and Scapula. After mechanical testing, the RC tendons were transected from the humeral and the scapular footprints of each RC muscle. The RC tendons/ligaments were then scanned to create a 3D model to measure their footprints, as well as the tendon/ligament thicknesses and areas (FaroArm, Faro, Inc.). Independent t-tests were performed to determine the significance between tendon anteroposterior footprint widths. Two Factor (Abduction angle and cutting case) ANOVA analysis was used to compare the first two cuts. Using the same two factors, a two factor repeated measures ANOVA was used to compare the subsequent cuts. Bonferroni post-hoc analysis was used to compare the IS cut case and SS strap cut case to the native case. The Humeral Head apex movement relative to the glenoid was analyzed using a multifactor repeated measure ANOVA with abduction angle, cutting case, and direction relative to the glenoid centroid as the three factors. Strain was analyzed using repeated measures ANOVA with the two factors being cutting case and strain location.

RESULTS:
Humeral translation was not statistically different in all cases ($p \geq 0.231$). Ligament/tendon thicknesses from anterior to posterior were: CHL 3.4±2.1mm, SS cord 6.1±1.7mm, SS strap 4.6±2.7mm, and IS 5.3±2.0mm. The cross-sectional ligament/tendon areas from anterior to posterior measured: CHL 58.5±39.3mm^2, SS cord 53.5±23.7mm^2, SS strap 61.7±28.4mm^2, and IS was 82.0±36.1mm^2. The A/P footprint widths were: CHL 11.6±2.2mm, SS cord 7.8±1.3mm, SS strap 9.1±1.6mm, and IS 20.4±3.9mm. The A/P distance from the posterior bicipital groove to the anterior SS cord was 3.4±1.4mm and posterior SS cord was 11.2±2.2mm. The mediolateral footprint lengths came out to be: CHL 9.9±1.9mm, SS cord 8.4±1.6mm, SS strap 8.8±1.4mm, and IS 9.1±1.4mm. The humeral insertional area results were: CHL 89.3±29.6mm^2, SS cord 62.4±20.1mm^2, SS strap 76.5±19.1mm^2, and IS 191.1±72.5mm2.

DISCUSSION:
The results show that the SS cord is more important in transferring abduction load than the CHL. Because the CHL is the anterior insertion of the RCa, it appears said RCa plays little to no role in transferring shoulder abduction force. That is, with transection of the cord, the continued application of force through the SS cord to the RC does not lead to force transfer to the CHL by means of the RCa. The insertion area of the CHL (89mm^2) is greater than that of the SS cord (62mm^2) and the SS cord transfers more load. This small insertion area to higher load in the SS cord could be why it is susceptible to tears.

SIGNIFICANCE/CLINICAL RELEVANCE:
Repair priority should be placed on the SS cord to optimize shoulder abduction and there is no mechanical benefit to repairing the anterior RCa. Partial tears may start at the junction between the SS cord and SS strap.



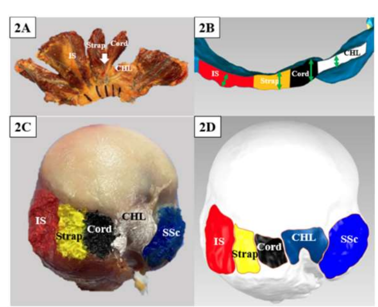


Figure 1. A: Abduction forces at 0 Degrees B: Abduction forces at 30 Degrees. (* $p \leq 0.05$)
Figure 2. A: RC dissected from Humerus and Glenoid B: Scanned RC and Capsule C: Dissected Humeral Head D: Scanned Humeral Head from figure 2C