The Evaluation of Shoulder Abduction with and without rotation on the Supraspinatus Tendon and Labrum: A Finite Element Study

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INTRODUCTION
Subacromial Impingement Syndrome (SIS) is thought to be the most common cause of isolated shoulder pain. SIS is the abnormal contact of the soft tissues of the subacromial space with the inferior aspect of the anterolateral acromial arch. There are multiple clinical studies suggesting that subacromial decompression of the anterolateral acromion can lead to pain relief and reduce stresses on the rotator cuff tendon. But the actual in vivo pathophysiology of subacromial impingement is still not well-understood. Current biomechanical studies have evaluated different shoulder motions causing impingement, but they are limited to clinical subacromial impingement tests and evaluated strains at the coracoacromial ligament [1, 2]. In the present study, we provided an in-depth analysis of various shoulder motions on the soft tissues of the shoulder, particularly the supraspinatus tendon and labrum, through finite element analysis (FEA) utilizing a novel three-dimensional shoulder model. We hypothesize that the results will confirm previous mechanical studies on impingement and labral pathology, but bring a greater in vivo understanding of the stresses on these soft tissues.

MATERIALS AND METHODS
The geometry of the shoulder model was created from CT and MRI scans, and consisted of bones, ligaments, cartilage, labrum, and supraspinatus muscle and tendon (Figure 1). Isotropic elastic material properties were used for bones and cartilage, and other soft tissues were modeled as Ogden hyperelastic material properties [3]. We then simulated 90° of abduction followed by 30° of internal rotation, 90° abduction with 30° of external rotation, 90° abduction, and 90° forward flexion. These movements have been theorized to result in the most contact between the supraspinatus and the acromial arch. Hwang et al previously conducted a similar study to provide initial validation [3]. The maximum von Mises stresses at the supraspinatus tendon and labrum were calculated and compared in all tested motions.

RESULTS
The stresses at the supraspinatus muscle were similar for 90° abduction with 30° of internal rotation, 90° abduction with 30° of external rotation, and 90° abduction, (28 to 33 MPa) but were less for 90° forward flexion (22 MPa) (Table 1). Stress values at the labrum were highest for 90° abduction with 30° of external rotation (22 MPa), but stresses for 90° abduction, 90° abduction with 30° of internal rotation, and 90° forward flexion were 22%, 50% and 90% less compared to abduction with external rotation (17 and 2 MPa), respectively. The stresses at the labrum were concentrated at superior and posterior labrum (Table 1).

DISCUSSION
Current studies suggest different causal mechanisms of SIS. It is not clear whether it is primarily due to mechanical or intrinsic degeneration [2]. Our results show higher stresses on the supraspinatus tendon at 90° abduction with and without ± 30° of internal and external rotation. Our analyses pertain to quasi static motions but the biomechanical effects may increase under repetitive motion. Our results also show that increased superior labrum stresses take place during 90° abduction, and 90° abduction with 30° of external rotation, which could have clinical relevance for understanding SLAP (superior labrum anterior posterior) pathology.

SIGNIFICANCE
This study provides insight in understanding the various shoulder motions that may lead to SIS and SLAP pathology. To date there is no such study to our knowledge that utilizes FEA to analyze such in vivo properties of the rotator cuff and labrum. This novel model will be applied to future studies assessing the effect of various acromion morphologies on SIS. Additional motions will be applied with and without rotator cuff pathology to provide further insight. Surgical simulation will also be applied to assess the impact of intervention on the rotator cuff and labrum.

REFERENCES