Finite Element Analysis and 3-D Printing of the Shoulder Joint and Glenohumeral Labral Tears

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I. Introduction

Glenohumeral labral tears adversely affect the mobility of the shoulder joint and are commonly associated with rotator cuff injuries, suffered by more than 4.1 million patients annually [1]. This project aims to analyze the stresses experienced along the edge of the labrum and print a model for use in visualizing and explaining the effect of tears.

II. Literature Review and Background

The shoulder is comprised of three bones: the clavicle, scapula, and the humerus, in addition to the ligaments, tendons, and muscles that accompany each bone. The glenoid labrum is a rim of fibro-cartilaginous tissue along the edge of the glenoid cavity where the scapula meets the humerus, and serves to deepen the shoulder socket and provide additional stability to the shoulder.

The stability of the shoulder is created using the combination of the glenoid cavity and labrum, while also being stabilized by the rotator cuff muscles and the glenohumeral ligaments that connect the scapula to the humerus. These combine to prevent the dislocation of the shoulder due to the wide range of movement in day-to-day use.

The most common form of tear is known as a superior labrum antero-to-posterior (SLAP) lesion. Although there are many different types of SLAP tears depending on which section of the labrum is injured, the most common lesion is the Type II, where the superior labrum and biceps tendon detach from the glenoid.

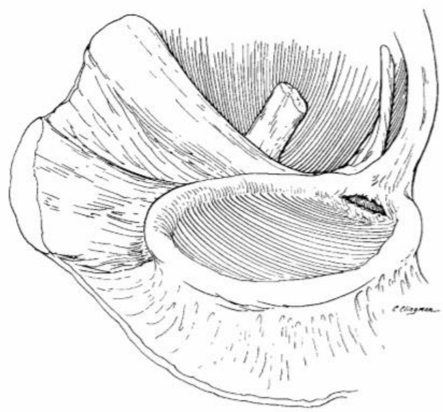

Figure 1. Type II SLAP lesion [2]

If therapy and stretching do not alleviate the tear, general treatment for SLAP tears comes down to some form of arthroscopic repair, tenodesis, or tenotomy, all forms of surgery. Age and physical activity were the main criteria for determining which treatment was appropriate.

III. Methodology

A. Finite Element Analysis

Many simplifying measures were taken in construction of the finite element model due to the complexity of the shoulder joint itself. First, some pieces of the shoulder joint were not modelled, including the bursae, nerves and blood vessels which all do not affect the motion of the shoulder. Additionally, the muscles and tendons were assumed to provide the constant force experienced by the bones and created perfect stability of movement. This assumption allowed me to model the bones, the labrum itself, and the motion each experiences as accurately as possible.

When modelled with a type II SLAP tear, the labrum experiences larger stresses at the point of the tear, and the head of the humerus comes into contact with the glenoid cavity. These can both result in the pain experienced by patients who have labral tears.

Various forms of movement were necessary to check, with abduction resulting in the greatest stressed because of the large amount movement against the top edge of the torn labrum. Additionally, lateral rotation in the direction opposite of the tear results in large stresses at the tear edge.

B. 3-D modelling

When developing the model for printing, it was essential to consider both the size of the model and the materials used. Because this model would be used for something and not as a full size example, I decided to downsize it. Materials were chosen such that the ratio of strength between the bones and labrum were kept intact, so it acted much the same way as a real shoulder's individual parts would together.

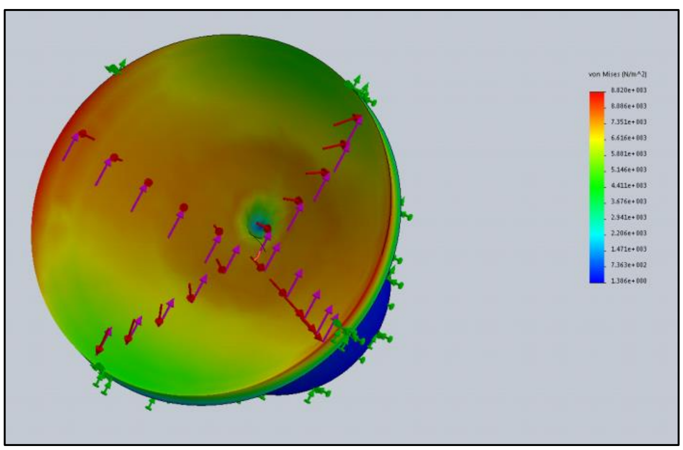

Figure 2. Von Mises stresses of full labrum for abduction

IV. Conclusions

This analysis clears up the picture on what kinds of forces are experienced in the labrum itself during basic movements with a tear. Assumptions made likely make the results slightly incorrect, but in principle the forces

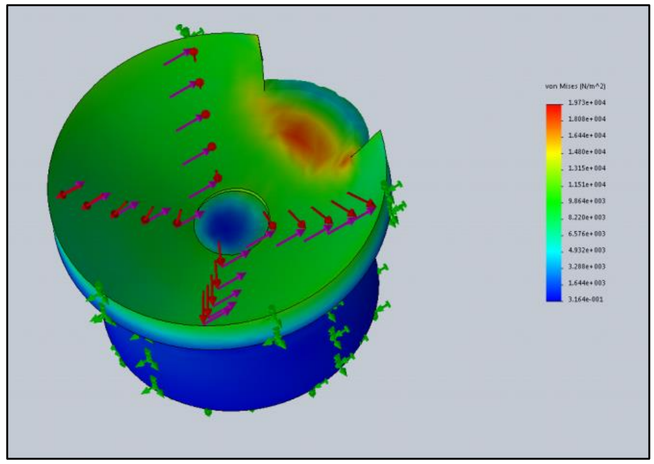

Figure 3. Von Mises stresses of Type II SLAP tear for abduction

experienced by the labrum should be consistent in pattern. Investigation into other forms of SLAP tears would likely result in different patterns of stresses and would be the next step in this project.

Research could also be done into what different parameters can be changed and how they can modify the results. For example, how would a larger humerus head affect the contact surface with the labrum and how the stress is distributed. The rotation and loading condition on the arm can also be investigated. Different loading conditions and movement patterns can possibly propagate the tear and should be investigated.

The SLAP tear itself is not completely understood, with a wide variety of injuries being called SLAP tears, each one with different conditions and repairs necessary. Even tears on a different sector of the labrum experience different stresses because the strength of the labrum varies around the edge and experiences different motions.

Acknowledgment

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References

[1] Oliva, Francesco, Leonardo Osti, Johnny Padulo, and Nicola Maffulli. "Epidemiology of the Rotator Cuff Tears: A New Incidence Related to Thyroid Disease." Muscles, Ligaments and Tendons Journal. CIC Edizioni Internazionali, 17 Nov. 2014. Web. 23 Feb. 2017.

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