Finite Element Modeling of Partial Thickness Rotator Cuff Tears

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Introduction: Shoulder pain is one of the most common musculoskeletal complaints reported to general practitioners in primary care settings. Of shoulder injuries, partial thickness rotator cuff (PTRC) tears are present in roughly 25% of the population. Although frequently asymptomatic, 25% progress into full thickness tears within 3 years. Due to the structural and mechanical inhomogeneity of the supraspinatus tendon, rotator cuff tear pathology is poorly understood, making it difficult to manage clinically. Finite element (FE) modeling is a useful tool to evaluate the mechanical environment of the supraspinatus tendon, which cannot be measured *in vivo*; however, their clinical utility largely depends on the ability to predict tissue deformation accurately. Tendons exhibit a hyper-elastic material response due to the recruitment and alignment of collagen fibers. The aim of this study is to evaluate the internal strains for small- and medium-sized RC tears under daily living and exercise rehabilitation loads to assess the risk for potential tear progression.

Methods: One fresh-frozen intact human shoulders (Medcure, Inc, Providence, RI) with a mean age of 45 was used after verifying no sign of RCT, fraying, or delamination of the rotator cuff tendons. The skin and the muscles, excluding the supraspinatus, infraspinatus, and subscapularis muscles, were removed, and the supraspinatus tendons were then isolated and detached from the humeral head at the insertion site. All tendons were split into thirds to separate the anterior, middle, and posterior regions. These regions were then further split into medial and lateral regions and articular and bursal regions, resulting in 12 samples per tendon that were roughly 5 × 10 × 1 mm. To obtain the mechanical properties (stress-strain curves) for each tendon region, samples were subjected to uniaxial tensile testing (UniVert, CellScale Biomaterials Testing, ON, Canada) to 10% strain to avoid any permanent damage to the samples. After mechanical testing, three 10 µm slices were taken every 250 µm, stained with Masson's trichrome staining, and imaged using a 10× brightfield microscope (Olympus VS120) to quantify the collagen orientation. To characterize the tendon regions to use in an FE model, collagen orientation and the stress-strain curves were used as inputs to fit the Holzapfel-Gasser-Ogden model for soft tissue to determine the appropriate material parameters for FE modeling. Using previously validated supraspinatus-infraspinatus model geometry, crescent-shaped high and low grade PTRC tears were created on the articular and bursal surfaces (Materialise 3-Matic Leuven, Belgium) in the posterior third of the supraspinatus tendon, as this region has recently been thought to be the origin of RC tears. Failure strain was set at 26.1% based on previous cadaveric data that showed this to be the strain the caused critical tear progression.

Results: Maximum principal strains were taken at the anterior and posterior edges of the tear tips and the remaining "intact' tendon where the partial tear stopped. In general, the strain was highest around the anterior tear tip, however failure occurred in the intact tendon, where the tear would likely progress to a full thickness tear. The failure load for the low and high grade articular sided tears was 1015 N and 884 N respectively. The failure load for the low and high grade bursal sided tears was 590 N and 425 N respectively. Suggesting, that Bursal sided tears are at a much higher risk for tear progression than articular sided tears.

Discussion: FE modeling provides insight into the internal strains that the RC experiences that cannot be measured *in vivo* which is valuable to understanding which patients may or not be at risk for tear progression. Clinical guidelines for the management of PTRC tears is incomplete due to not fully understanding how tears alter the mechanical environment of the supraspinatus. We have found that while not only are bursal sided tears at a heightened risk for tear progression, but some physical therapy exercises could also cause tear progression due to the high loads exhibited by the tendon.

Clinical Relevance: Patient-specific FE modeling is useful clinically to determine the risk of tear progression based on patient-specific material properties and tear characteristics. This study supports the current risk management plans for articular sided PTRC tears, however due to the increased strain and lower failure loads for bursal sided tears, these patients should be closely monitored to assess for tear progression.