Introduction
The mechanical properties of articular cartilage are known to change during the development of osteoarthritis. The main viscoelastic properties of articular cartilage, the aggregate modulus and permeability are critical to understanding the health of the tissue. One of the common methods used to find these properties is stress relaxation testing which involves compressing the tissue to a given strain and observing the change in stress over time. The purpose of this study is to determine a relationship between the aggregate modulus and permeability of human knee tissue at various stages of tissue degradation.

Objective
- To determine relationships between tissue damage and changes in the aggregate modulus and permeability of articular cartilage

Hypothesis
- The aggregate modulus will decrease and the permeability will increase significantly (P < 0.05) with increased tissue damage.

Materials & Methods
With IRB approval, 8 mm diameter osteochondral plugs (n = 62) were created from tissue collected from total knee arthroplasty patients. The samples were then subjected to a stress relaxation test on the Instron 8821a materials testing device. During stress relaxation testing, samples were compressed to 80% of the original cartilage thickness (measured using a needle probe thickness testing) at a rate of 0.1 mm/s. This rapid rate helps to ensure that the full stress relaxation curve is preserved for accurate characterization. The tissue was then held at a constant strain for 120 seconds while time-force data was collected. This data was fitted to an equation for confined compression from Mow 1980:

\[ \sigma(t) = H \frac{E}{t} \frac{t^2}{t^2 + \alpha t} \]

This equation was selected for its relevance to our testing set up as well as its simplicity and accuracy. The ‘fminsearch’ function built into the MATLAB optimization toolbox, which uses the Nelder-Mead algorithm, was used due to the lack of restrictions on the potential values of the aggregate modulus and permeability. This was done to ensure that a narrowly constrained range of variables wasn’t responsible for forcing favorable data from the optimization.

Once the aggregate modulus and permeability were found, the cartilage surface integrity was assessed using India ink staining. In addition, tissue proteoglycan (GAG) and collagen (HP) content was assessed using biochemical assays. The GAG/HP ratio was used as a measurement of tissue degradation.

The biomechanical and biochemical data was compiled in Microsoft Excel, and a simple regression analysis was run to determine the significance of the relationship between GAG/HP ratio and India ink determined qualitative tissue damage and the aggregate modulus and permeability. Graphs were also created to visually represent the relationships between these properties (Figure 2).

Results
- The optimization produced an extremely close match between simulated results for the stress relaxation test and acquired data.
- Tissue permeability had a weakly significant \( r^2 = 0.134 \) and \( P < 0.05 \) correlation to the GAG/HP ratio and amount of India ink stain in the tissue.
- The aggregate modulus of the tissue had a weakly significant \( r^2 = 0.074 \); \( P < 0.05 \) correlation to the amount of India ink staining the tissue but a statistically insignificant link to the GAG/HP ratio.
- Subjectively, there was a clear trend between amount of tissue damage and the tissue aggregate modulus and permeability in each patient.

Discussion
This study aims to quantify the relationship between biomechanical properties of articular cartilage and varying levels of tissue damage. While other studies have investigated the relationship between osteoarthritis and mechanical properties, our study provides a method to achieve accurate and rapid results from a single test on a given sample while minimizing the impact of extraneous factors such as varied strain and pore compression which are common issues in creep tests. The results of our optimization show the expected change in aggregate modulus and permeability with tissue damage and provide the first step in determining a concrete, quantitative relationship between these properties.

Conclusions
- This data reveals a clear trend between the mechanical properties of articular cartilage and tissue damage.
- This study provides a basis for creating computational methods to determine the relationships between biochemical properties and progression of OA.

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