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Developing Novel Imaging Technology for Earlier Detection of Osteoarthritis

In Collaboration with the Joint and Osteoarthritis Imaging with Novel Imaging Technology Group (JOINT) and Stanford's Soft Tissue Biomechanics Lab (STBL)

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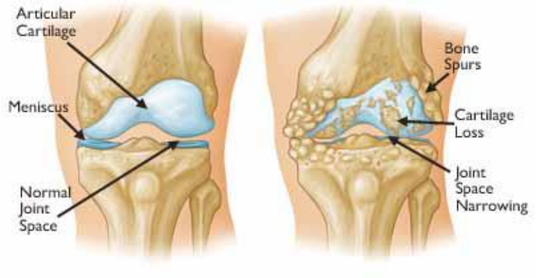
Motivation & Goals

Osteoarthritis (OA) is the most recurring form of arthritis in the US, affecting over 27 million adults in its most common form: hand, hip, and knee[1], with the Center for Disease Control (CDC) estimating an economical impact of over $28 billion every year[2]. The disease is characterized by degeneration of articular cartilage (AC), presence of osteophytes, and the narrowing of the joint space[3]. Methods for detecting it before it is too late are not available. By the time it is found in a patient, joint replacement is often necessary. This is both a painful and expensive process.



The goal is to develop a method for detection of early stages of OA. In order to accomplish this the JOINT Group and the STBL are in collaboration in order to

1. study the structure-function relationship of the meniscus by understanding how changes in the osmotic environment effect the swelling stress and osmotic equilibrium time constant of Meniscus Fibrocartilage (MFC) tissue explants[4]

2. working on methods to develop time-dependent cartilage deformation in vivo during weight bearing in order to scan and see if that can be a functional indicator of cartilage health in OA[5]

Once we understand the mechanics of the meniscus and how a healthy meniscus is supposed to deform under a specified weight-bearing load, we will be able to compare this standard to in-vivo scans performed on patients. The idea is that if a meniscus is deformed, it will take less time to reach a compressed state than a healthy meniscus.

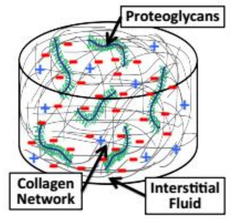
Acknowledgments: Dr. Marc Levenston, Dr. Gary Gold, Dr. Waldo Hinshaw, Gabriela Baylon, Marianne Black, Mary Hall, Dr. Lozano and Stanford SURF

References: [1] Lawrence+ (2008) Arthritis Rheum 58(1):26–35. [2] CDC (2015) www.cdc.gov/arthritis. [3] Arden+ (2006) Best Prac Res Clin Rheum 20(1):3–25.
[4] Baylon et al. (2014) *Characterization of the role of osmotic swelling stress in the mechanical behavior of meniscus fibrocartilage.* [5] J.-H. Choi et al. (2016) *TIBIAL CARTILAGE CREEP DURING WEIGHT BEARING: IN VIVO 3D CT ASSESSMENT*

Background: Meniscal Mechanical Testing

Meniscus is a thin fibrous cartilage that acts as a connective tissue present between bone to bone articulation. It exhibits mechanical properties just as a connective material used in common engineering practice would, allowing us to perform necessary mechanical tests in order to understand its properties.

MFC is compromised primarily of:
- Water (60-70%)
- Charged Proteoglycan Molecules (1-2%)
- Collagen (15-25%)



Due to these characteristics, MFC in the human knee will at any given time be in a different swelling state, thus affecting the mechanical properties. Swelling, a common occurrence in the knee due to varying amounts of weight-bearing activities the average person participates in, affects the mechanical stress on the cartilage itself.

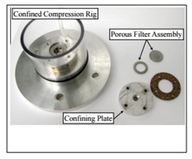
Methodology

MFC samples are extracted from the bovine knees degraded in solution to mimic effects of arthritis.

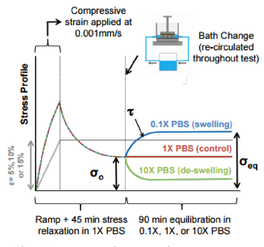
1. Biopsy sample into 4mm plugs
2. Load with the Instron Microtester to either 5%, 10%, and 15% strain.
3. Hold sample at a strain level in control PBS (salt) solution of 1x concentration for 45 min
4. Solution bath change – 0.1x, 1x (control), or 10x concentration solution to swell or de-swell the sample. Hold for 90 min. The change in stress is recorded and graphed.

- Swelled Samples had an increase in stress*
- De-swelled samples had a decrease in stress*

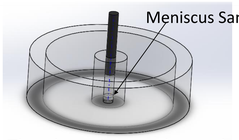
Instron MicroTester



1 N Load Cell



The image above shows the predicted behavior of swell states[4]

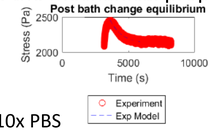


The above image shows the custom made Compression Rig and inserted Indenter that restricts the deformation in the confining plate to just the vertical direction and allows for direct comparison of swelling to stress regardless of macroscopic degradation.

Current Results

The findings are showing predicted trends for the meniscus. The next step would be to test more samples, compute an average, and compare the mechanical properties to the cartilage sample results.

.1x PBS



10x PBS

Background: CT Imaging

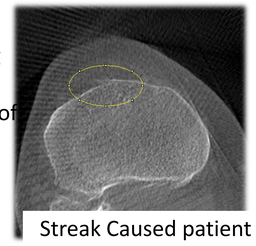
The Stanford JOINT Group is studying ways to develop new 3D imaging methods for knee cartilage/meniscus compression that employs a C-arm-based (shown right) cone-beam CT (CBCT) system capable of scanning standing patients. This creates a more realistic environment for the knee than the more common method of scanning supine (lying flat on the back).[5]

In order for the group to analyze the images as accurately as possible, they had to have as little CT artifact as possible.

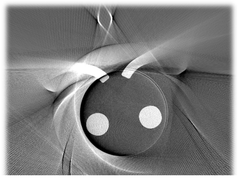
Problem

Unfortunately, many of the images acquired by the JOINT Group had some form of artifact in them. The images below are examples of unwanted artifact that can be caused by one of several reasons:

1. PVC creates artifacts in current imaging
2. The current stand employs an inverted U-shape, which is inconsistent in the field of view and makes for poor 3D image reconstruction.
3. Patients place too much weight on the support, causing them to oscillate and creating inconsistencies in the final scan.



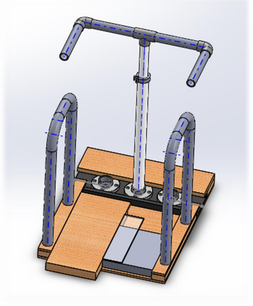
Streak Caused patient movement



Streaks Caused by PVC

Possible Solutions and Results

Seeing as many of the problems were in some form caused by the current support system, a structural redesign was called into action. After many iterations, the support was redesigned to look like this:



The changes consisted of:
1. A 'T'Shape vertical support so it is consistent in the field of view
2. The replacement of PVC in favor of Carbon Fiber due to its radiolucent properties. It is also more rigid than PVC.
3. Removable side-supports for additional comfort

Tests were run to ensure that Carbon Fiber indeed created less artifact than PVC did. After testing several samples of PVC, one in particular (sample 5) created a significantly smaller gray scale distribution vs the PVC.