Team 34: Real Time µCT Analysis of the Deformation of Knee Joint Cartilage

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Background

Problem Statement: There is no current device that can apply physiological loads to the knee joint or osteochondral cores while allowing for concurrent µ-CT imaging

- 50% of individuals w/ ACL tear develop Post-Traumatic Osteoarthritis (PTOA) within 10-20 years[4]
- ACL reconstruction does not restore normal joint biomechanics[4]
- Current testing methods lack ability to measure joint mechanics and cartilage response under physiological loading conditions[5]
- Glycosaminoglycans (GAGs): hydrophilic components of cartilage[1]
- Low GAG → low osmotic pressure in tissue[1]
- Hexabrix: CT contrast agent to assess GAG spatial distribution[2]
- Stretch ratio: $\lambda = L/L_0$ (new length/original length)[6]

Knee Loading Device

Objectives

- Apply physiological loads (10-45 N) to rabbit knee joint
- Allow adjustment of
  - Knee Angle (60° - 150°)
  - Total Load on Knee (0 N - 45 N)
- Micro-CT compatible
- Compact (110 mm Diameter x 300 mm Height)

Experimental Design

Design Features

- Adjustable load via hex nut
- Load assessed via displacement of spring
- Adjustable angle of leg via index plate

Turnable Hex Nut
Guide Rod
Spring
Nylon Threaded Rod

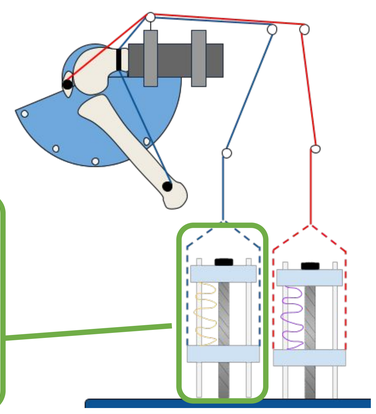
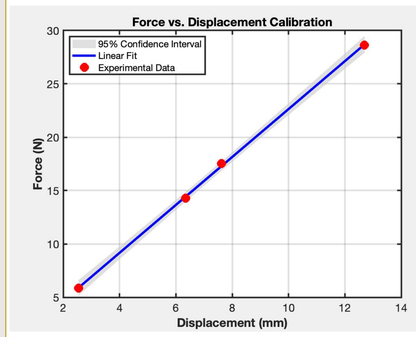


Figure 1. Labeled Compression Device

Figure 2. Diagram of Loading Device

Results

Force transmission is proportional to displacement



- $R^2 = 0.9997$

Theoretical Spring Constant	Experimental Spring Constant
2452 N/m	2245 N/m

- p-value = 0.018

Figure 3. Displacement of spring (mm) vs. measured force (N)

Discussion

- 0.018 < 0.05: Difference in force transmission unlikely to be caused by random factors alone
  - Error in spring constant likely due to miscalibration of plastic springs
- Loading device is capable of applying adjustable physiological loads at varying angles

Conclusion

Limitations:

- Friction in the threaded rod when compressing spring
- Bruker-Poseidon X4 remains in construction (no µ-CT analysis conducted yet)

Future Direction:

- Addition of linear bearing to reduce spring buckling/friction
- Alternate material for threaded rod to reduce creep
- Transition to external loading system

Core Compression

Objectives

- Apply compression of 10%, 20%, and 30%
- Fit within 50 ml tube
- Allow Micro-CT imaging during compression to assess
  - [A] Thickness
  - [B] Grayscale Variation (Hexabrix → GAG)

Experimental Procedure

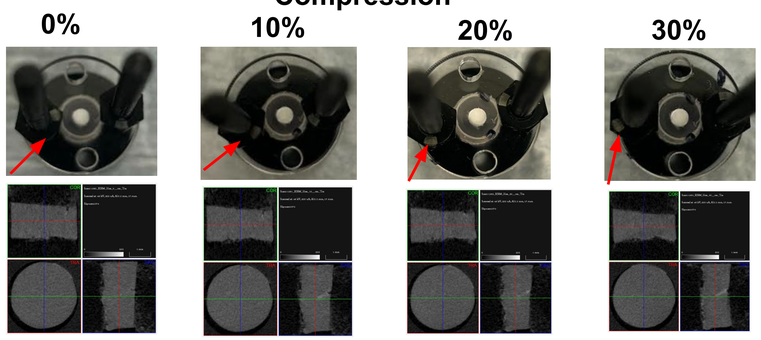


Figure 4.Compression using Hex nuts rotation with µ-CT images

Experimental Design

Design Features

- Displacement Control
- Confined compression
- Porous Polyethylene Platens
- Bioinert
- Micro-CT Compatible

Hex Nuts
Neon Threaded Rods
Polycarbonate Compression chamber
Acrylic Plates

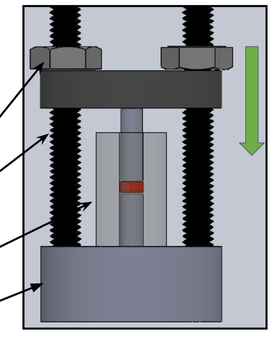


Figure 5. CAD model of core compression with final prototype

Results

% Hexabrix in cartilage decreases after compression

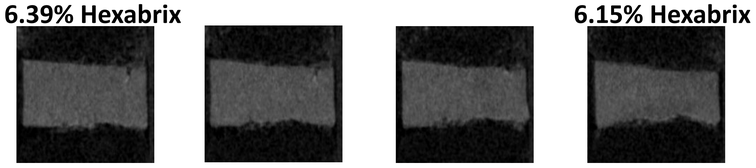


Figure 6. µ-CT images of cartilage at compression stages

Discussion

- Actual cartilage compression is less than expected which may be because of the porous polyethylene platens which are soft and may deform during compression
- % Hexabrix decreases after compression which indicates that there are more GAGs in cartilage after compression (as expected)

Conclusion

- Cartilage can be compressed using our device and µ-CT images reveal change in GAG distribution

Limitations:

- Hex nuts must be turned manually
- Osteochondral core diameter must be ≤ 3.2 mm to fit in device

Future Directions:

- Platens: PEEK Chromatography frits
- Improve Python image analysis code

Acknowledgements

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References

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