xDI Joint Arthroscopy Manikin for Viable Cartilage

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UW BME Design

Background

- Client Information:
  - Dr. Corinne Henak: Principal Investigator Henak Lab studying orthopedic biomechanics
- Arthroscopy is a minimally-invasive surgical procedure using a small camera instrument, an arthroscope, to visualize and access a joint space [1]
- Approximately 4 million arthroscopic knee procedures are performed each year [2]
- Surgical procedures lead to redox imbalance with the accumulation of reactive oxygen species [3]
- Maintaining redox homeostasis is crucial to minimize tissue damage, inflammation, and promote postoperative recovery [3]
- This will help the wellbeing of around 2 million patients undergoing arthroscopic knee procedures [3]

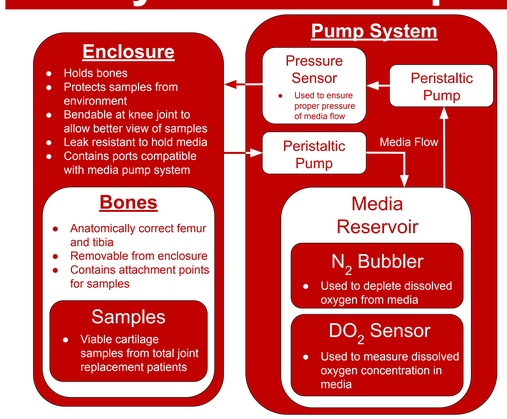
Problem Statement

- Currently, no system exists to allow surgeons to optically measure redox imbalance
- Existing manikins mainly focus on training procedures and don't allow for the housing of viable cartilage [4]
- The end users of the device will be researchers who wish to use autofluorescent imaging to measure redox imbalance in viable cartilage

Design Criteria

- All components of the manikin must be biocompatible
- The manikin should be reusable
- The manikin should be able to hold viable cartilage and maintain its viability for up to one hour
- The bones in the manikin must be anatomically correct, spanning from mid-shaft femur to mid-shaft tibia
- Cartilage samples should not be placed under any mechanical stress while being loaded into the manikin
- Dissolved oxygen (DO_2) content of the PBS media circulating through the manikin should be maintained between 2 and 10 percent.

System Concept



System Design

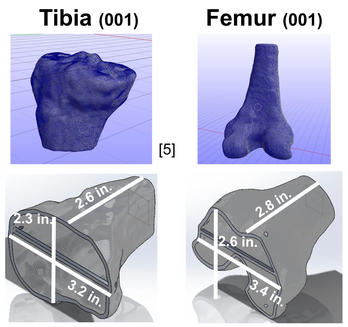
Bones

- Anatomically correct tibia and femur; mid-shaft, no cartilage
- Open Knee(s) public source database from Cleveland Clinic [5]
  - Finite Element models of various patients' knees via MRI scans

Patient	Leg	Sex	Age	Race	Height (m)	Weight (kg)	BMI (kg/m^2)
001	R	Male	71	White	1.83	77.1	23.1
003	L	Female	23	White	1.73	68.0	22.8

[5]

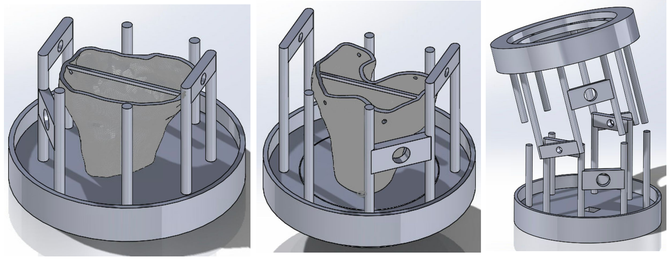
Tibia (001) Femur (001)



- Modifications: hollowed, flattened ends and cut wire holes for sample attachment, decreased femur shaft length to minimize excess material, added magnet attachment point
- 3D printed: Formlabs Clear (prototyping) → Formlabs BioMed Clear

Enclosure

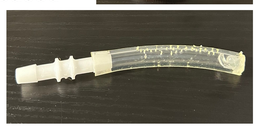
- 3D printed frame
  - Tough PLA (prototyping)
  - Polycarbonate
- Wrapped in silicone and foam
- Sealed with silicone caulk
- Magnetic mounting point for connection to bones
- Ports compatible with pump system for media inlet and outlet



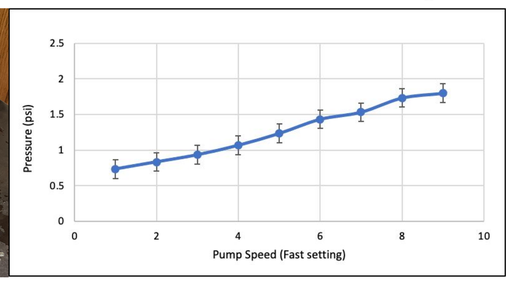
Pump System

- Dual peristaltic pumps
  - Placed near inlet and outlet of the media reservoir
  - Variable speed to control pressure
- Analog pressure gauge at inlet
- ¼" inner diameter tubing connects all components

- Large reservoir holding excess PBS
  - Has threaded ports for PBS inlet/outlet and nitrogen inlet for threaded barb tube fittings
  - Port for DO_2 probe
- N_2 gas will be bubbled into reservoir
  - Hold DO_2 content between 2-10%
- DO_2 probe
  - N_2 will be adjusted by hand based on this reading

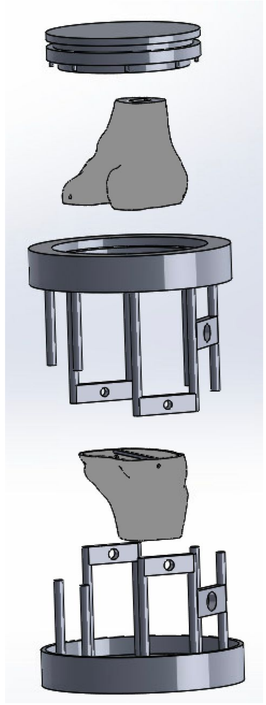


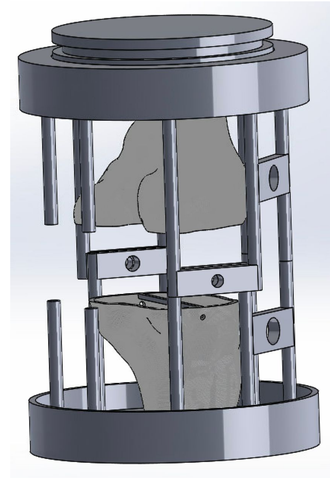
Testing



- Pressure values were found experimentally using a semi-closed volume bottle, pressure gauge, and peristaltic pump
- Three replicates were completed and averaged to obtain the plotted data

Prototype





Right: Complete assembly of bones and enclosure

Left: Exploded view of completed assembly

Key Takeaways

- A more accurate pressure measurement system is required
- Difficult to articulate full knee movement
- Silicone alone may be sufficient for the enclosure
- Enclosure requires larger tolerances

Future Work

- Silicone caulk for material attachment to enclosure cage
  - Avoid leakage
- Assemble complete enclosure including silicone, frame and bones
- Design and fabricate media reservoir with DO_2 probe and N_2 bubbler
- Conduct user testing with completed assembly as soon as possible

References

[1] E. M. Berkson *et al.*, "Knee," *Pathology and Intervention in Musculoskeletal Rehabilitation*, pp. 713–773, 2016, doi: https://doi.org/10.1016/b978-0-323-31072-7.00020-8.
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[5] S. Chokhandre, A. Schwartz, E. Klonowski, B. Landis, and A. Erdemir, "Open Knee(s): A Free and Open Source Library of Specimen-Specific Models and Related Digital Assets for Finite Element Analysis of the Knee Joint," *Annals of Biomedical Engineering*, Sep. 2022, doi: https://doi.org/10.1007/s10439-022-03074-0.

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