Mechanical Engineering
UNIVERSITY OF WISCONSIN–MADISON

# xDI Joint Arthroscopy Manikin for Viable Cartilage

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Client: Dr. Corinne Henak

UW BME Design

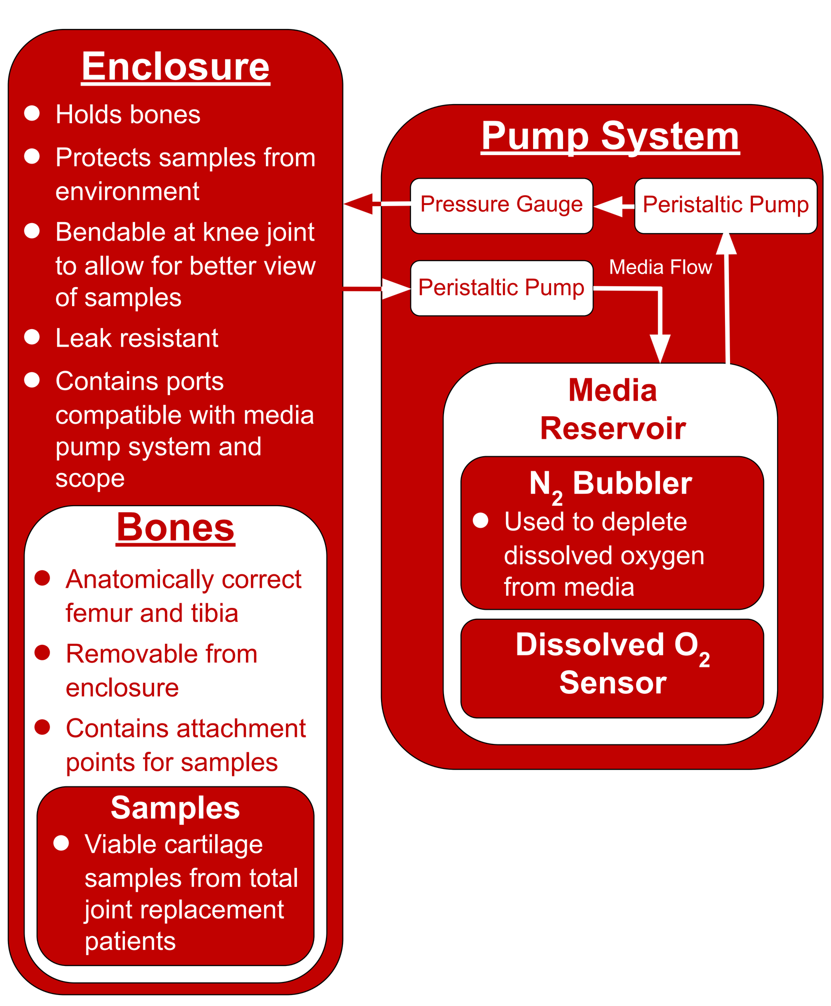
## Background

- **Client Information**:
  - Dr. Corinne Henak's lab
  - Arthroscopic autofluorescent imaging probe
- Arthroscopy: small camera instrument (arthroscope)
  - Visualize joint space [1]
- Surgical procedures —> redox imbalance
  - Reactive oxygen species (ROS)
  - Tissue damage, inflammation, slower recovery [2]
- **Problem Statement:** No system currently exists that allows surgeons to measure tissue health in real time. This manikin will help develop an arthroscopic probe that will help the 4 million patients who undergo knee arthroscopies each year [3]

## Design Criteria

- Biocompatible and reusable
- Maintain cartilage viability
  - 1 hour
- Anatomically correct bones: mid-shaft femur to mid-shaft tibia
- No mechanical stresses on cartilage
- Dissolved oxygen ($DO_2$) concentration of chondrocyte growth medium: 2-10%
- Leak resistant

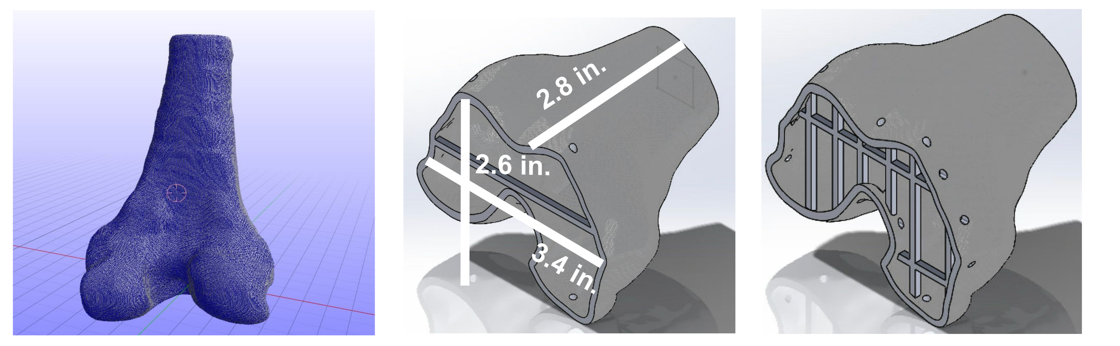
## System Concept



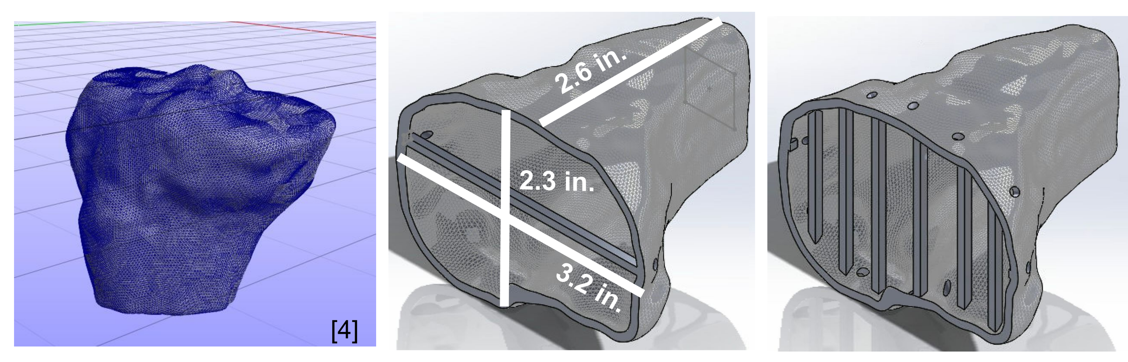

## System Design

### Bones

Femur (001)




Tibia (001)



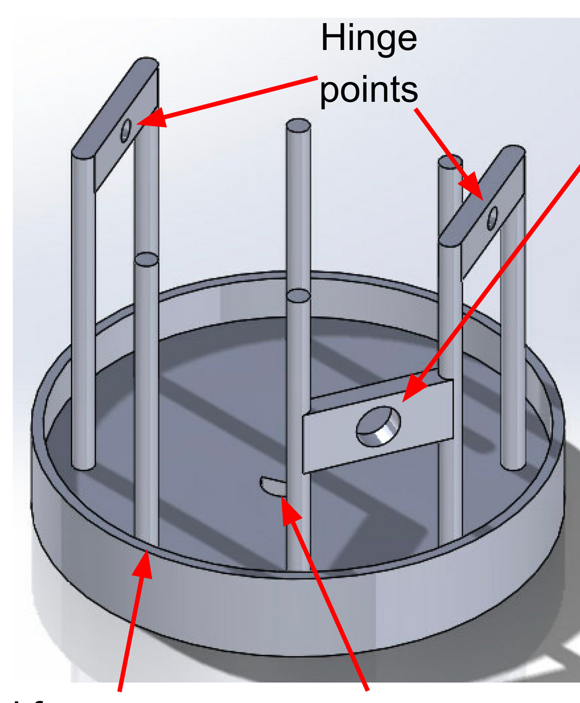
- Anatomically correct
- Modifications: hollow, flat ends, grate, wire holes, magnet
  - 3D printed: Bambu Lab PLA
- Sample attachment: < 5 min, minimize cartilage damage

| | No Pre-Attached Wire | Trial 1 | Trial 2 |
|---|---|---|---|
| **Tibia** | Full: 135 sec | 49 sec | 22 sec |
| **Femur** | ½: 123 sec | 77 sec | 45 sec |

**Table 1:** Sample attachment results, duration of cartilage exposure

### Enclosure

Version 1

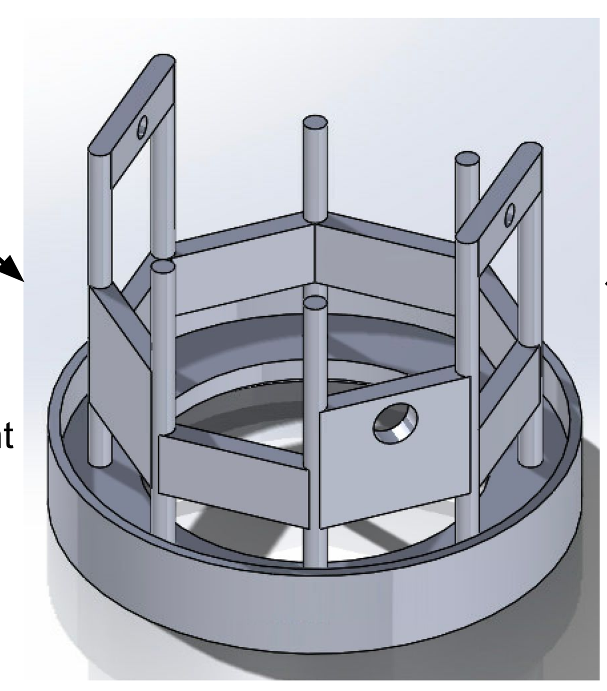



3D printed frame
- Bambu Labs PLA

Magnetic mounting point for connection to bones

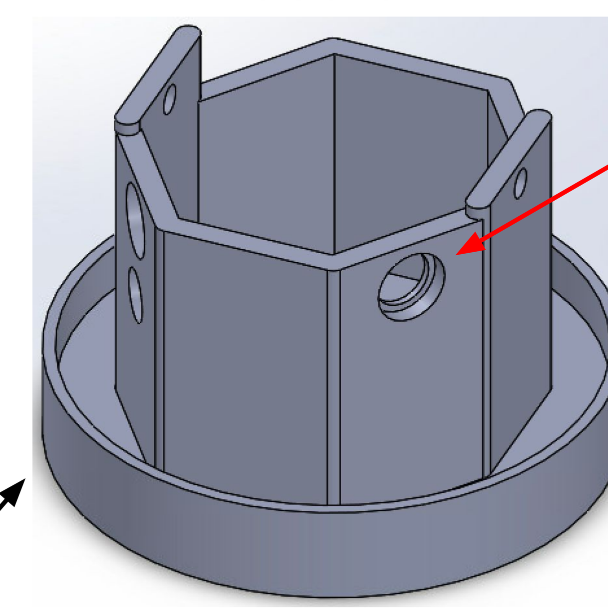
**Version 1 Lessons**
- 20% infill struts too weak
- No easy way to insert samples

**Version 2 Lessons**
- 100% infill struts too weak even with support band



Version 2

Version 3

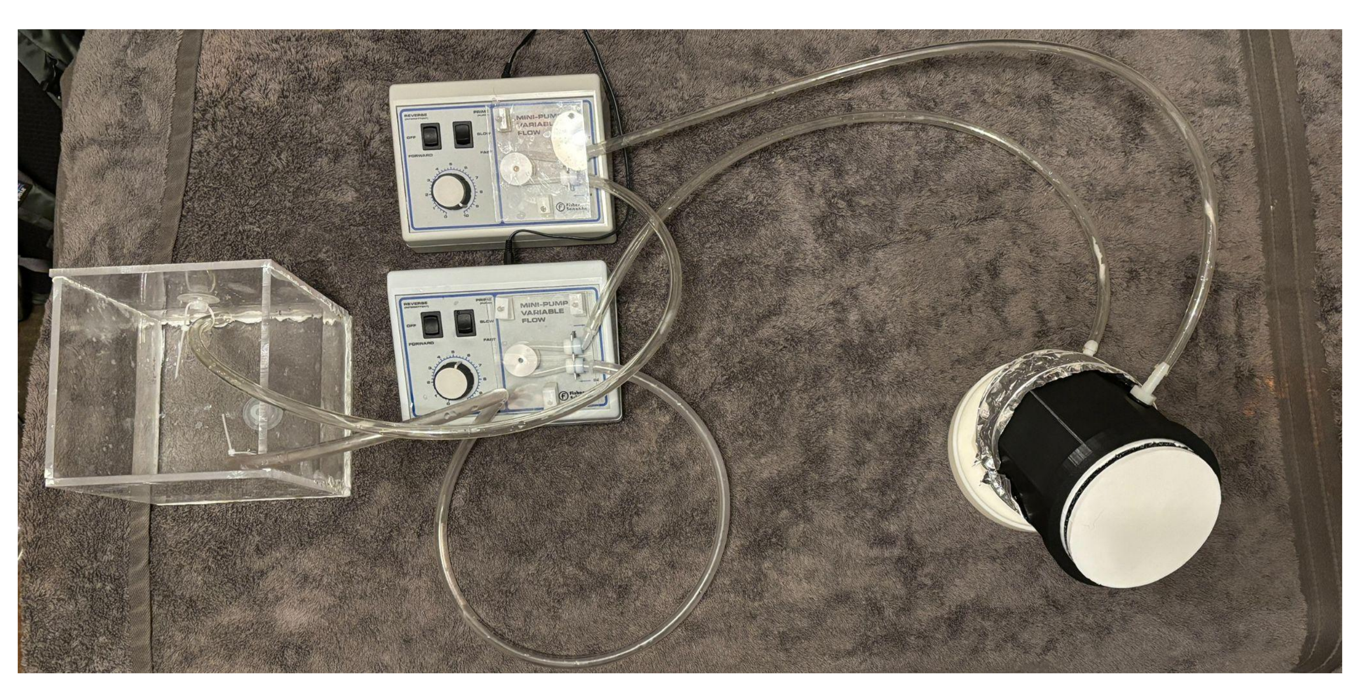



**Version 3 Lessons**
- 100% infill shell sufficient
- Setup is arduous
  - Polyethylene bag
  - Silicone
  - Polyurethane foam
  - Port insertion
  - Clamps

**Assembled Enclosure**

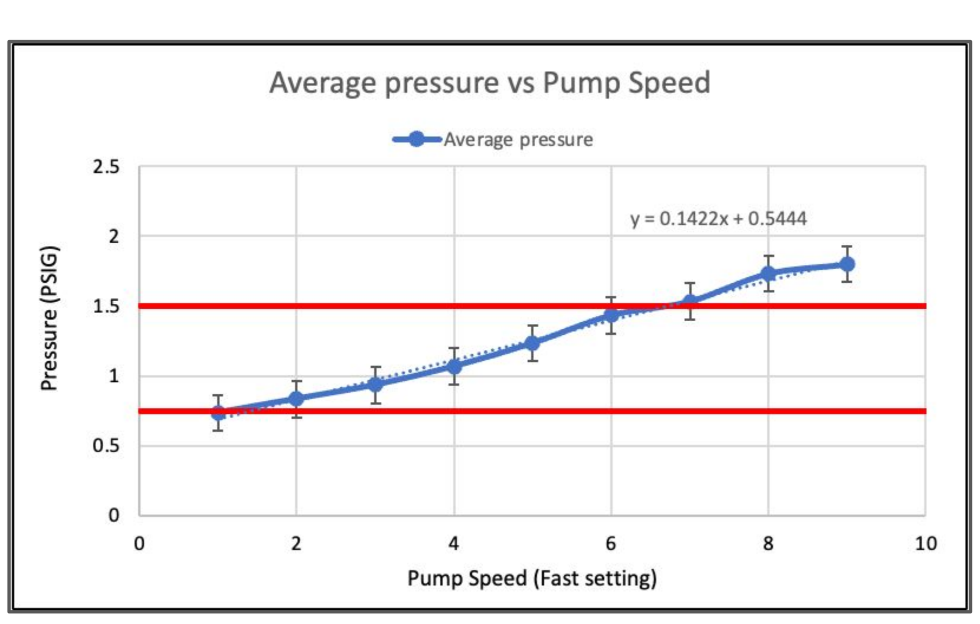
### Pump System

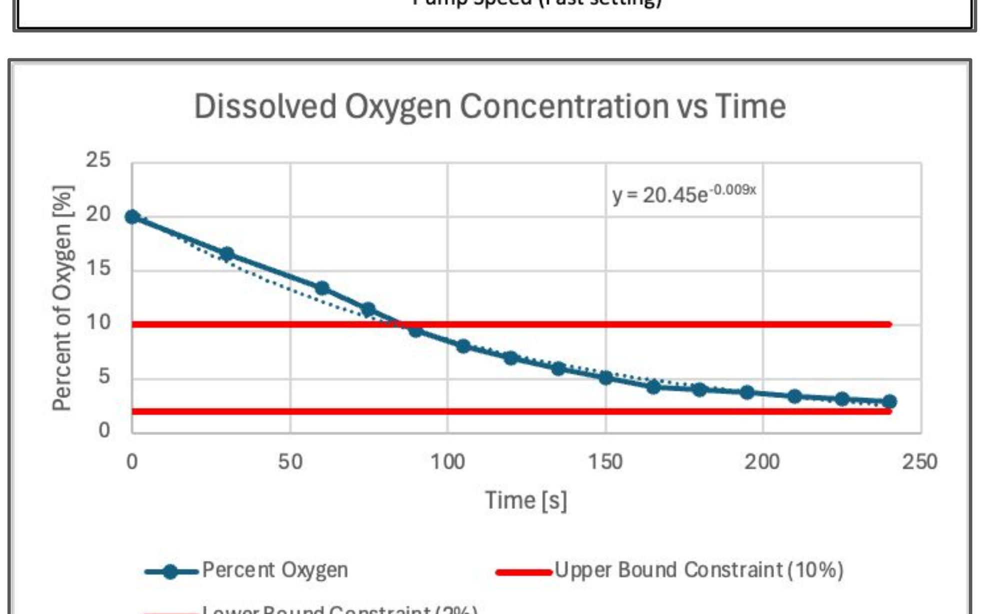
- Circulate chondrocyte growth medium through enclosure
- Dual peristaltic pumps
  - Variable speed to control pressure
- Large reservoir holding excess media
  - $N_2$ gas will be bubbled into reservoir
  - $N_2$ flow adjusted by hand based on $DO_2$ probe reading



## Testing

### Fluid Pressure and $DO_2$




### Full System

- Testing goals
  - Minimize leakage
  - Allow bending while still holding a desired angle
  - Minimize light penetration
  - Replicable experimental setup

- Wrapped in silicone
- Not enough protection from clamps
- Bags ripped

- Wrapped in silicone and foam
- Bags around inlet/outlet ports tore as ports were screwed in
- Too rigid

- Silicone/foam only at clamps
- O-rings added to ports
- Nuts hold joint space at desired angle
- Dryer vent material in midsection

## Functionality

- Leak resistant
- Pressure
  - 0.75 - 1.5 psi
- $DO_2$ content
  - 2 - 10 %
- Anatomical correctness
  - Femur, tibia
  - Flexion range
- Cartilage attachment
- Biocompatible

## Key Takeaways

- Understanding of design
  - Anatomical correctness
  - Flexion mechanism
- FE analysis
- Testing with Henak Lab using live tissue samples

## 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.
[2]Arthroscopic Surgery." Accessed: Dec. 06, 2023. [Online]. Available: https://mhealthfairview.org/treatments/Arthroscopic-Surgery
[3] Z. Li, D. Xu, X. Li, Y. Deng, and C. Li, "Redox Imbalance in Chronic Inflammatory Diseases," *BioMed Research International*, vol. 2022, pp. 1–3, Apr. 2022, doi: https://doi.org/10.1155/2022/9813486.
[4] 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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