DESIGN OF A FORCE-CONTROLLED CARTILAGE BIOREACTOR

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Background & Motivation

Osteoarthritis (OA) impacts 7% of the global population, with that percentage increasing every year [1].

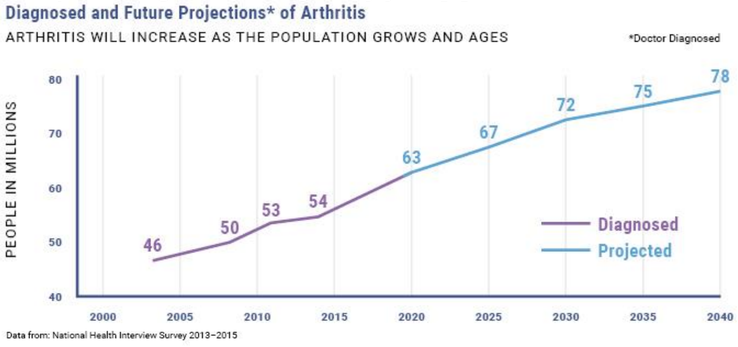


Figure 1. OA global impact.

Image sourced from: https://oaaction.unc.edu/oa-module/oa-prevalence-and-burden/

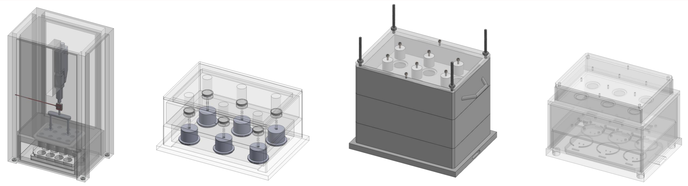
OA is mechanically mediated [2]. Mechanical loading influences cartilage metabolic state, with dysfunction leading to osteoarthritic disease progression (i.e., degradation of articular cartilage).

The Henak Lab investigates the relationship between cartilage metabolism (or redox balance) and disease state.

To research the link between long-term mechanical loading and cartilage metabolic balance, **Dr. Henak has requested a device capable of applying cyclic loading* to a cartilage explant culture over several days or weeks.**

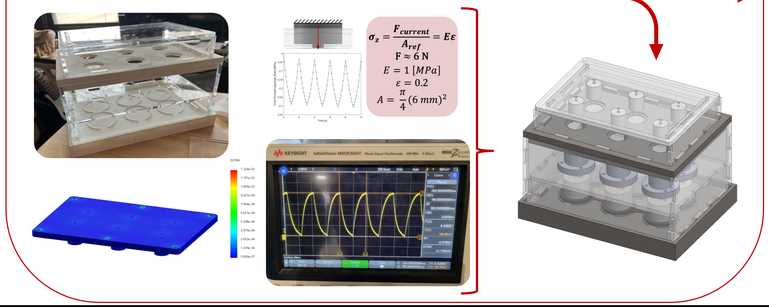
**Due to the poroelastic properties of cartilage, this loading must be force-controlled to avoid sample lift-off.*

Design Evolution



Final design was iteratively informed and optimized through calculation, design matrix comparison, testing and prototyping.

Figure 2. Evolution of design, illustrated by the many analytical prototypes evaluated by the team.



Final Design & Supporting Criteria

Overall, the bioreactor consists of three components: housing, actuation, and the supporting circuitry.

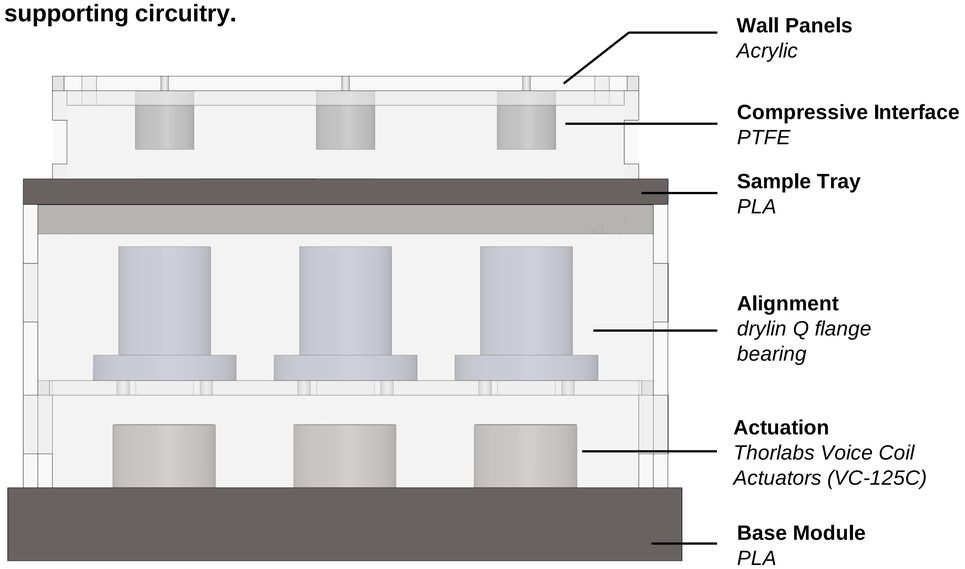


Figure 3. Schematic overview of the final bioreactor design.

Incubator-Safe

Fits within 20 x 21 x 25 [in^3] incubator

Can operate within 37 ºC, humid environment

Aseptic technique friendly

Physiological Force Output

Capable of inducing 20% ε_{engr} on cartilage samples

Applied displacement must be force-controlled

Cyclic loading profile (0.1 – 10 [Hz])

Budget-Friendly

In total, housing, actuators, and circuitry must cost ≤ $5000

Figure 4. Specifications used to inform and guide design.

Circuitry Design & Testing

Comparison of Potential Circuit Designs

Criterion	PCB	H-Bridge	Transistor
Functionality (15)	1 (3)	5 (15)	5 (15)
Ease of Use (10)	2 (4)	3 (6)	4 (8)
Space (10)	2 (4)	3 (6)	5 (10)
Price (5)	5 (5)	1 (1)	1 (1)
Total (40)	**16**	**30**	**34**

Figure 5. Setup to control VCA with triangle voltage generator PCB

Figure 6. Setup to control VCA with H-bridge circuit and Arduino

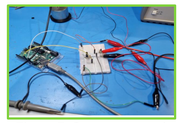


Figure 7. Setup to control VCA with transistor circuit

Final Circuit Design

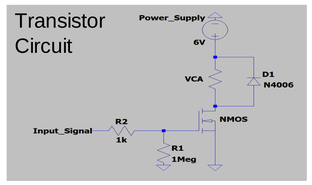


Figure 8. Schematic of the transistor circuit, the final design

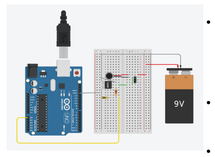


Figure 9. Illustrative depiction of the transistor circuit, the final design

Components

- **National Instruments Data Acquisition System** (i.e., NI DAQ) provides input signal
- **NMOS transistor** to enable on and off switching
- **Diode** to protect the actuator
- **Power supply** to power the actuator

Results & Discussion

Load Cell Testing

Objectives

1. Validate consistent force output over long durations of operation (15-30 mins)
2. Validate correct force output
3. Determine any deviations from the desired force value and percent overshoot

Findings

1. Force is relatively consistent, with minimal variation over time
2. Successfully outputs 6 N of force
3. There is overshoot occurring roughly every 15 s; needs to be quantified

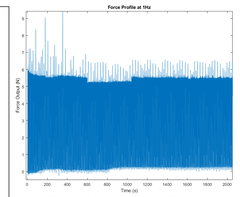


Figure 10. Force profile when operating VCA at 1 Hz

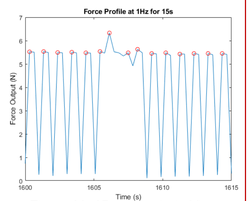


Figure 11. 15 s snapshot of force profile when operating VCA at 1 Hz

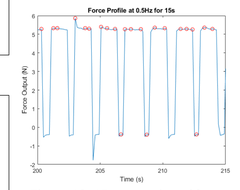


Figure 12. 15 s snapshot of force profile when operating VCA at 0.5 Hz

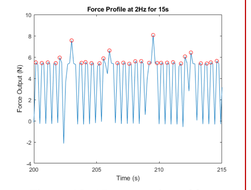


Figure 13. 15 s snapshot of force profile when operating VCA at 2 Hz

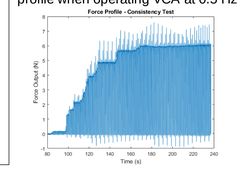


Figure 14. Force profile during first force consistency test

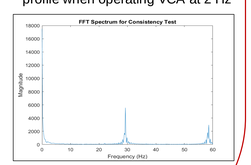


Figure 15. FFT of force profile during first force consistency test

Summary and Future Work

To analyze the relationship between mechanical loading over long timescales and cartilage osteoarthritic degradation, a bioreactor was designed and built.

Semester Accomplishments

Designed and built a 1D actuator and circuit system to specifications

Built a housing prototype that can be used for experimentation

Next Steps

1. Test the unit in an experimental setting with full assembly
2. If testing goes well, order and print the components to scale up the bioreactor to include remaining samples
3. Machine the housing out of aluminum (hire TeamLab staff)

References and Acknowledgements

[1] Hunter, D. J., March, L. & Chew, M. Osteoarthritis in 2020 and beyond: a Lancet Commission. *The Lancet* **396**, 1711–1712 (2020).
[2] Mohd Yunus, M. H., Lee, Y., Nordin, A., Chua, K. H. & Bt Hj Idrus, R. Remodeling Osteoarthritic Articular Cartilage under Hypoxic Conditions. *International Journal of Molecular Sciences* **23**, 5356 (2022).

See our project page for more info!

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