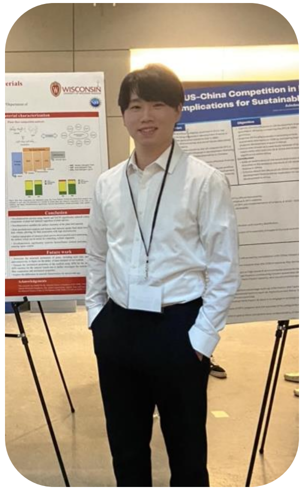
Midyear Review

FC Bioreactor

xDI: ME 351 & BME 400

Griffin Radtke (ME)
ME Lead



Chanul Kim (BME)
BSAC

Sydney Therien (BME)
BME Lead

Jeffery Guo (ME)
Accountant & Admin

Emilio Lim (BME)
Communicator

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Introduction

Motivation
Initial Problem Statement
Client Need and Design Specifications

Midyear Progress

Support and Conclusions

Scientific Literature
Industry Equivalents
Review of Work and Future Aims

Introduction

Motivation

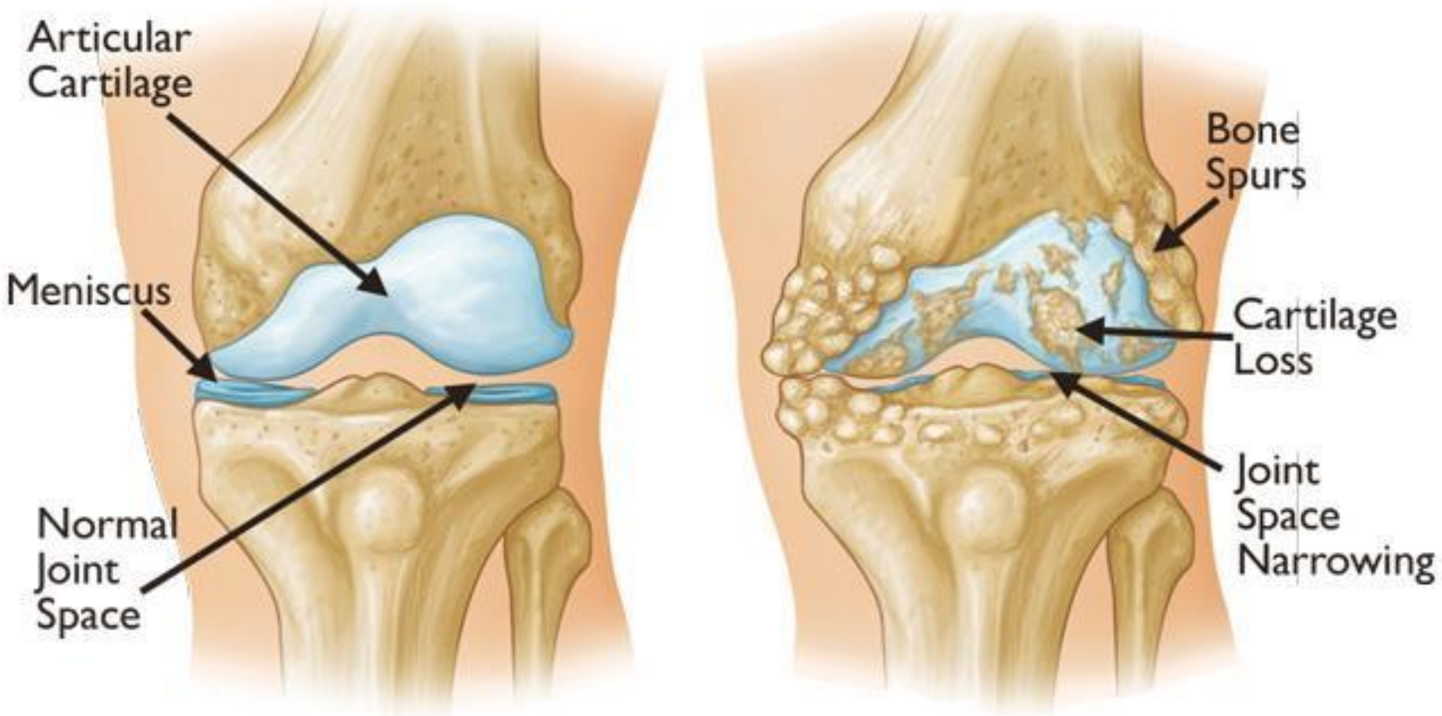
Initial Problem Statement

Client Need and Design Specifications

Osteoarthritis (OA) impacts 7% of the global population.

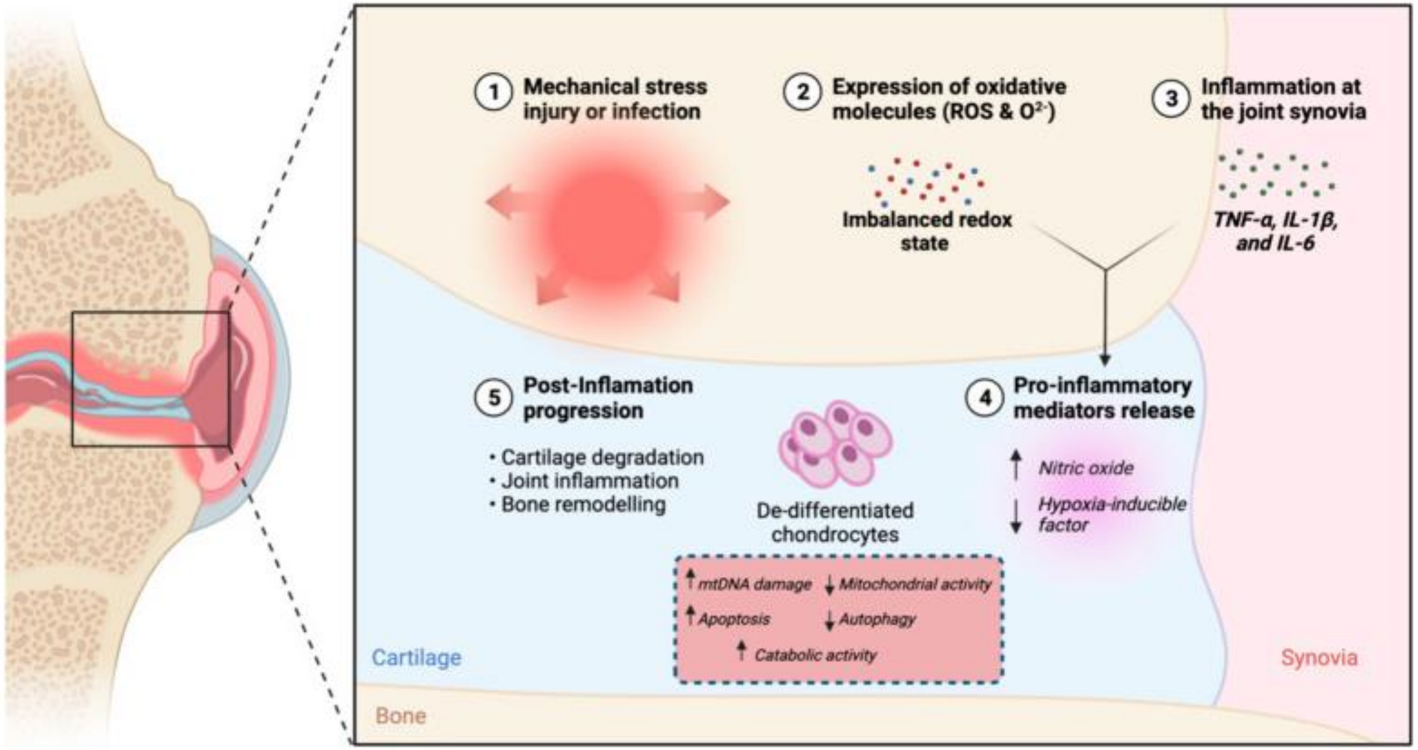
More than 22% of adults older than 40 are estimated to have knee OA.

The mechanisms underlying OA disease progression remain largely unknown



Depiction of cartilage degradation in knee OA.

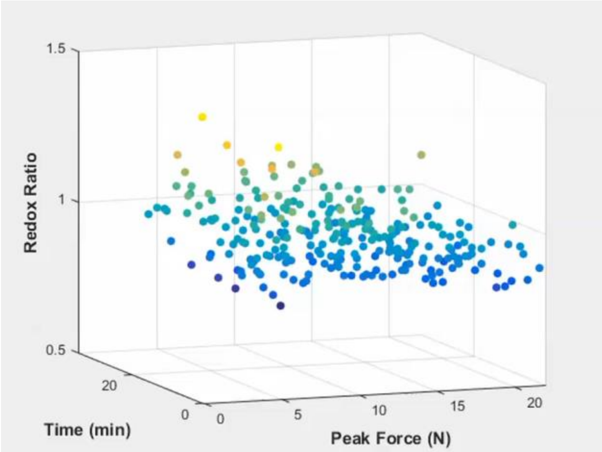
[1]



Mechanical loading has been implicated in metabolic dysregulation, which in turn plays a significant role in OA progression.

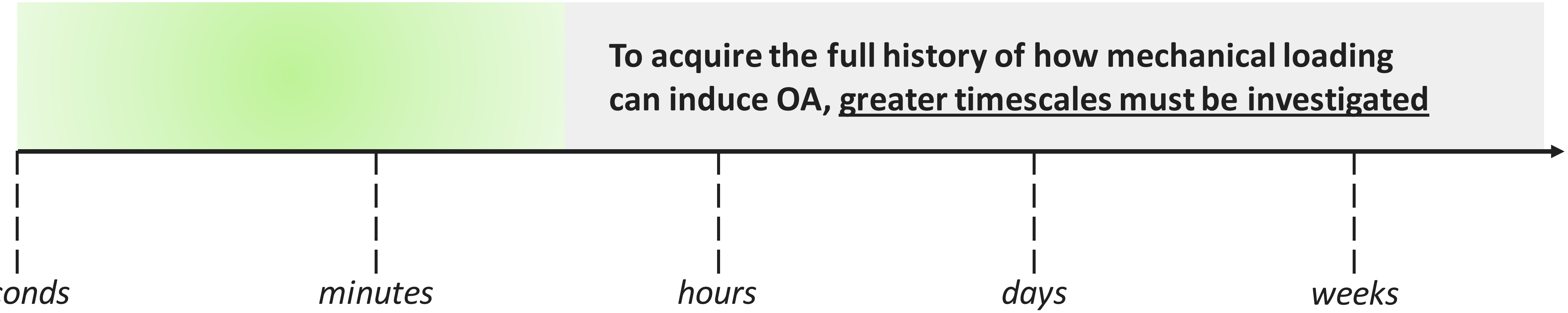
Mechanical Loading $\xrightarrow{?}$ **OA**

[2]



Walsh, S. K., Skala, M. C. & Henak, C. R. Real-time optical redox imaging of cartilage metabolic response to mechanical loading. Osteoarthritis and Cartilage 27, 1841–1850 (2019).

The Henak Lab has characterized the metabolic response to mechanical loading on short timescales.



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.*

Desired Forces Applied

1. ~20% strain or ~6 N of force
2. Control over amount of force applied
3. Triangular loading profile, 0.1–10 Hz frequency
4. Low-friction, biocompatible material compressing the cartilage

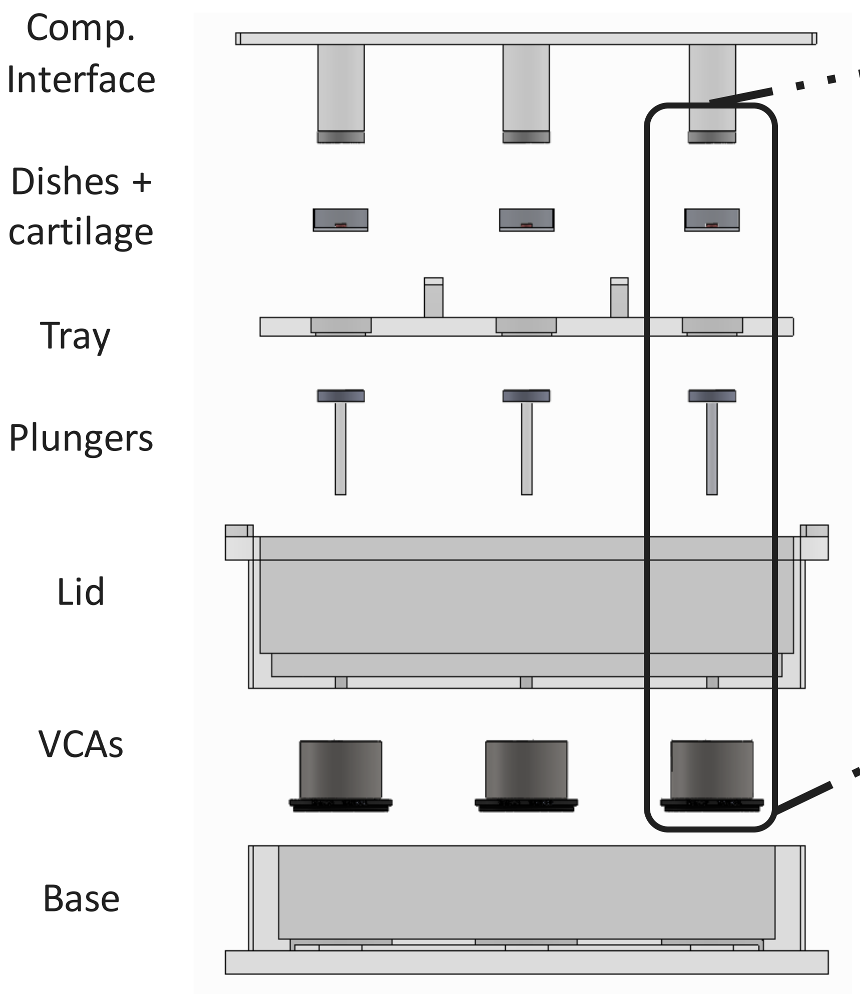
Incubator-Compatible

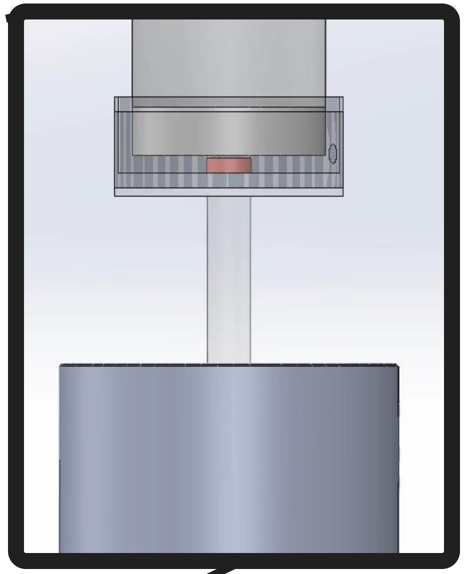
1. Fits in the incubator
2. Can withstand heat and humidity
3. Can withstand sanitation procedures

Budget

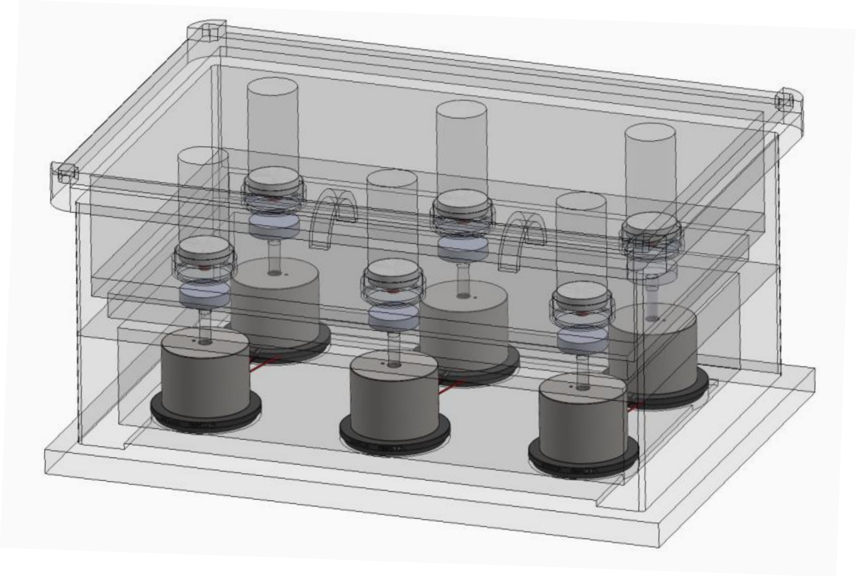
1. ≤ $5000

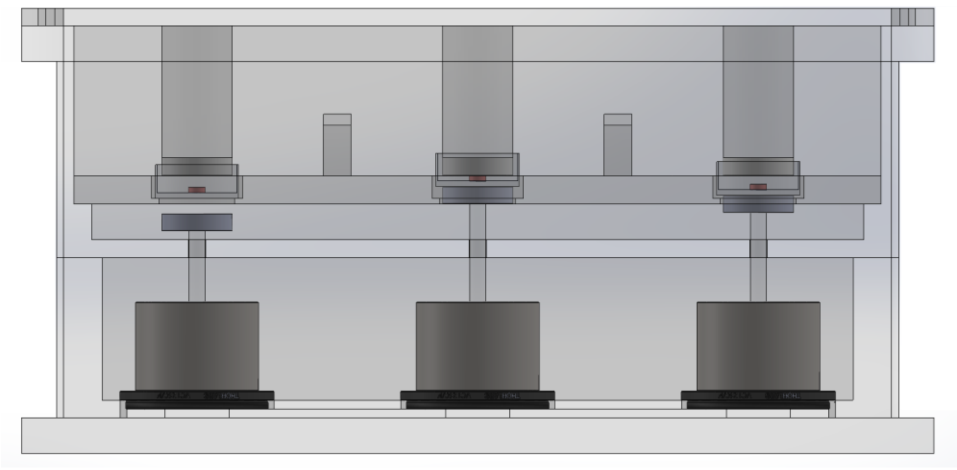
Midyear Progress





Housing is 3D-printed with biocompatible resin (BioMed Clear V1).





$$\sigma_z = \frac{F_{current}}{A_{ref}} = E\varepsilon$$

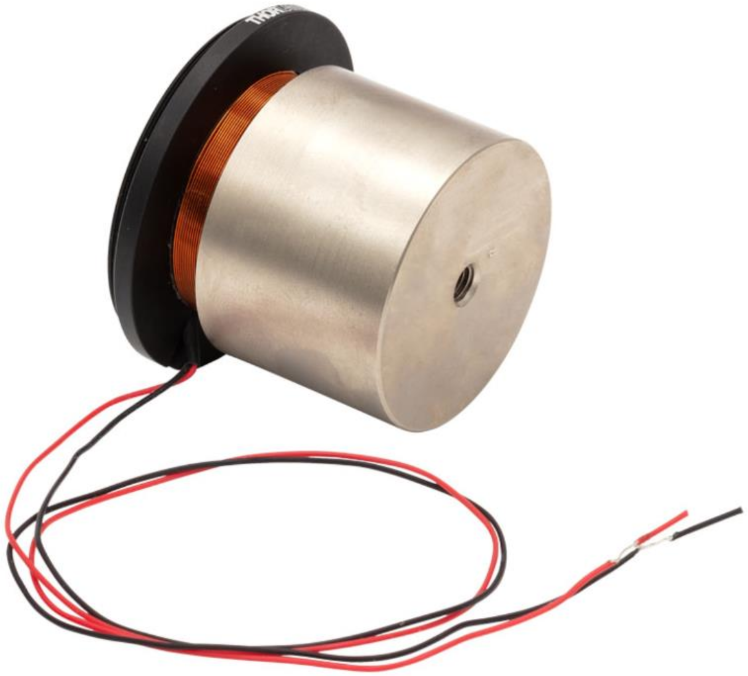
$$F \approx 6\ \mathrm{N}$$

$$E = 1\ [MPa]$$

$$\varepsilon = 0.2$$

$$A = \frac{\pi}{4}(6\ mm)^2$$

Cartilage approximated as linear elastic to estimate force order of magnitude.



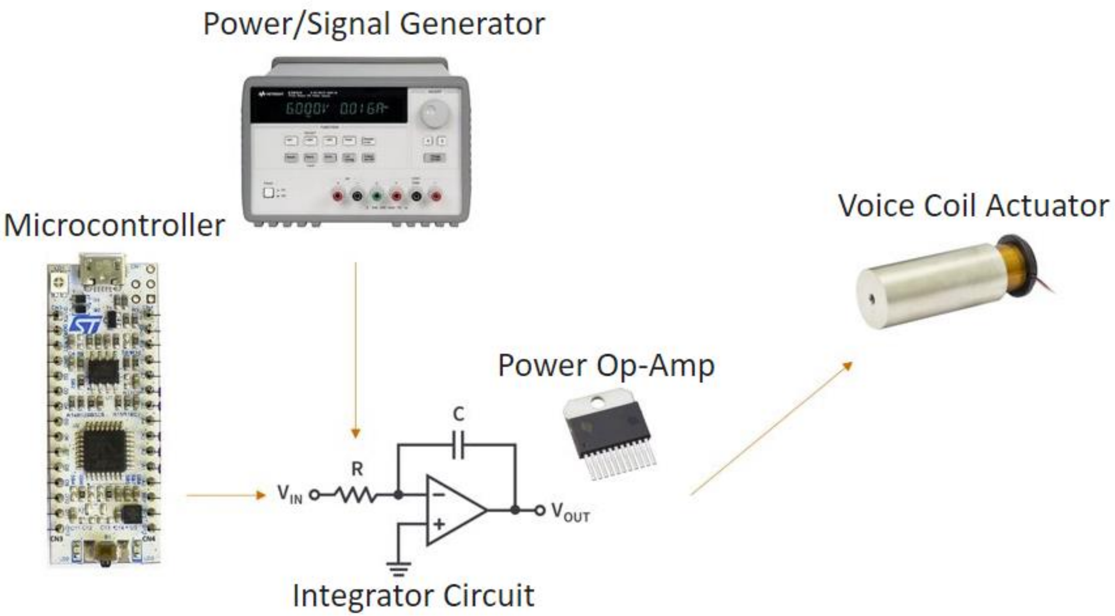
ThorLabs VC125C/M, the VCA to be used in the bioreactor [4].

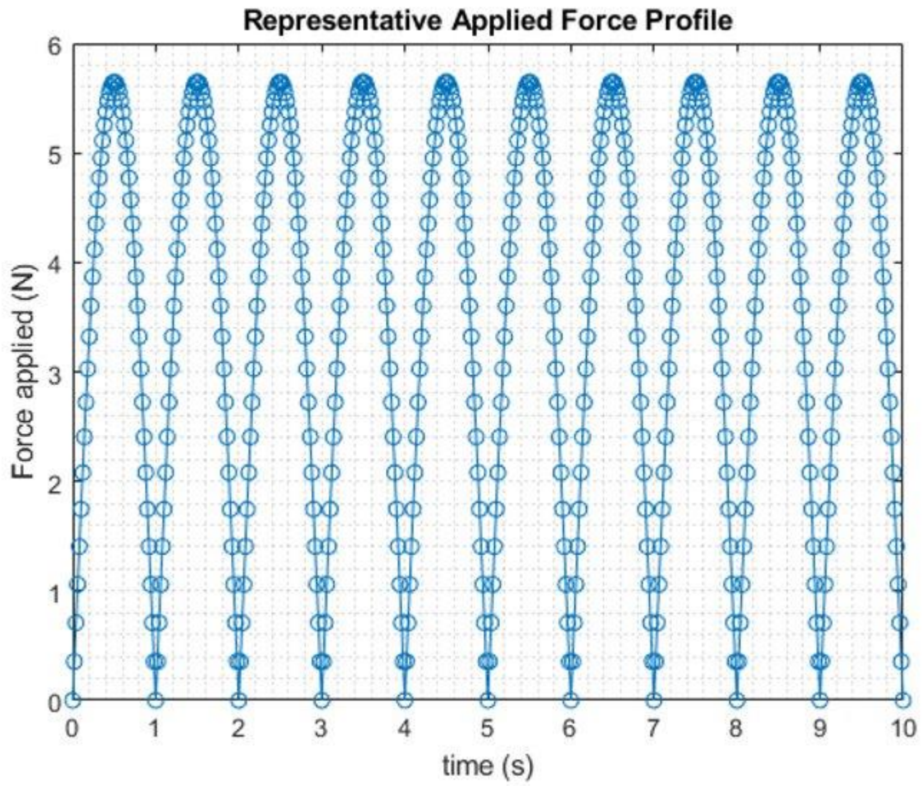
VCA force output is directly linked to current input (F = B x I)

Force Constant	12.4 N/A
Travel	12.7 mm
Req'd Duty Cycle	50%
Max Operating Temp	230F/110C

Relevant specifications for ThorLabs VC125C/M as they relate to product design specifications [4].

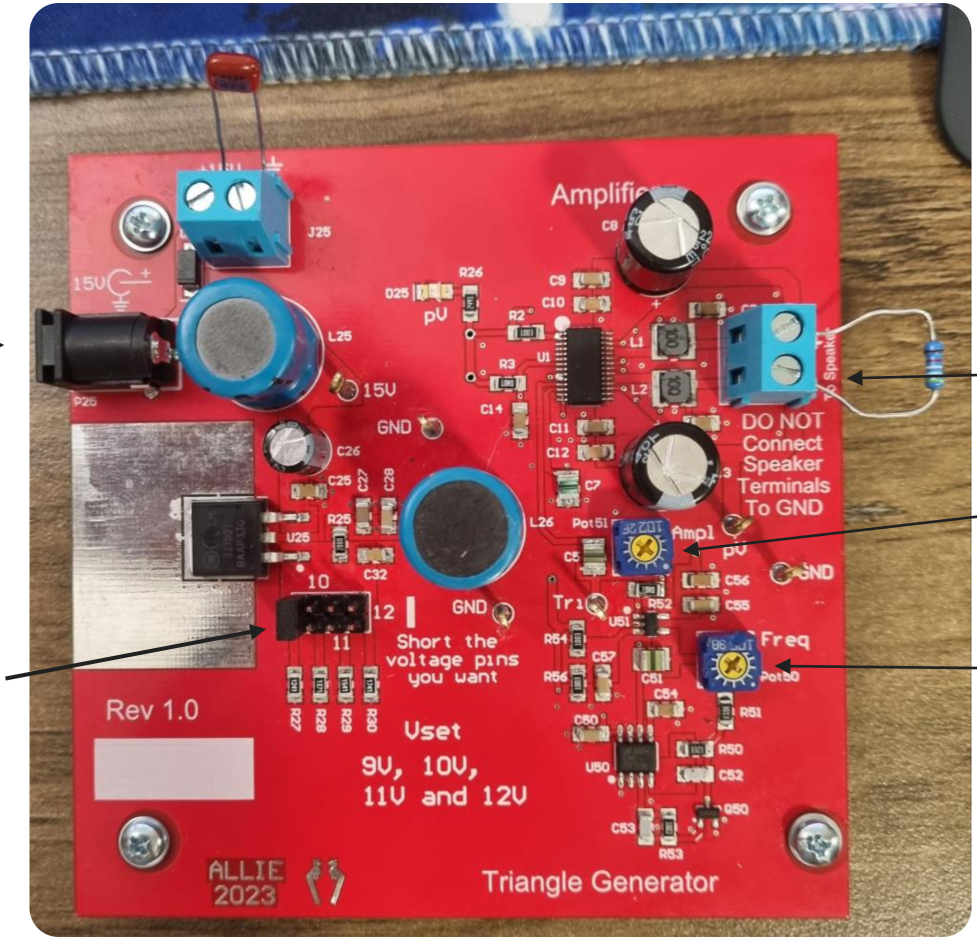
Use different components to generate the required signal





Triangle Wave Generator

Power Input



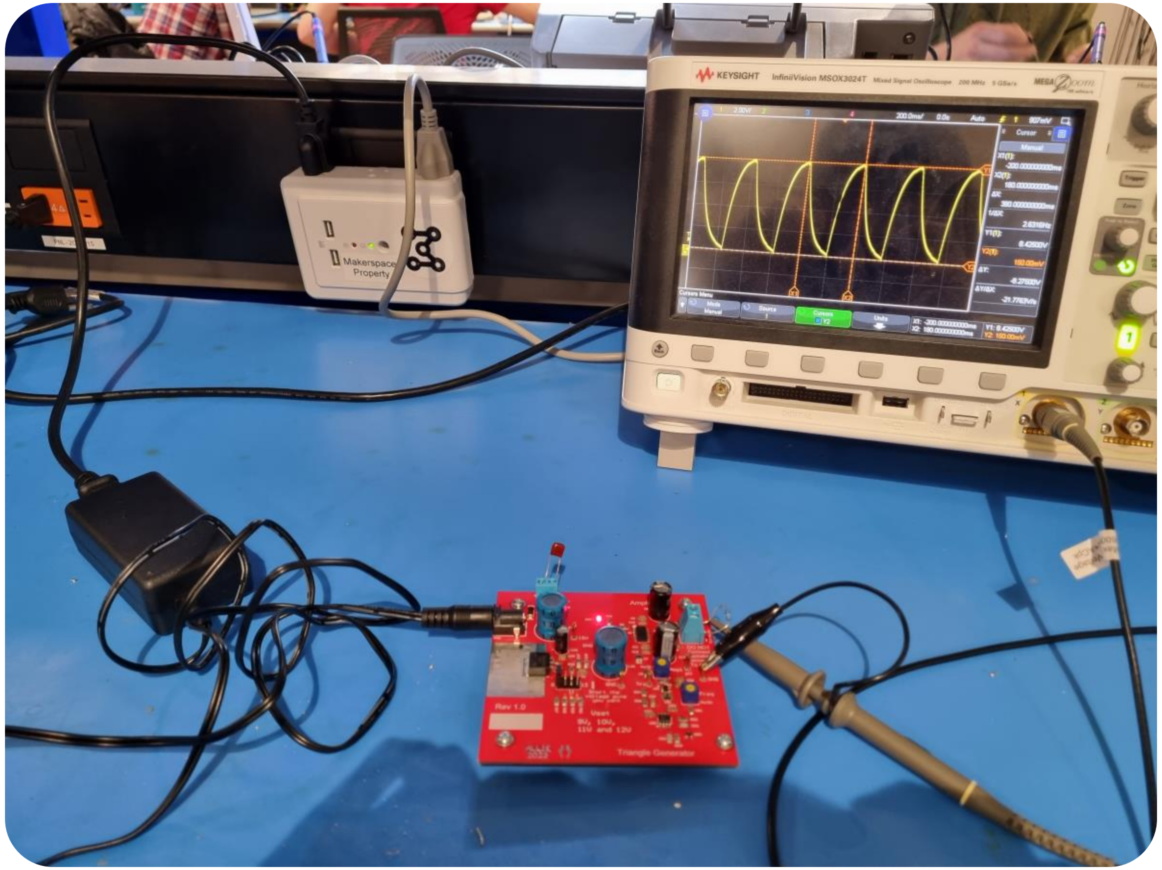
Output

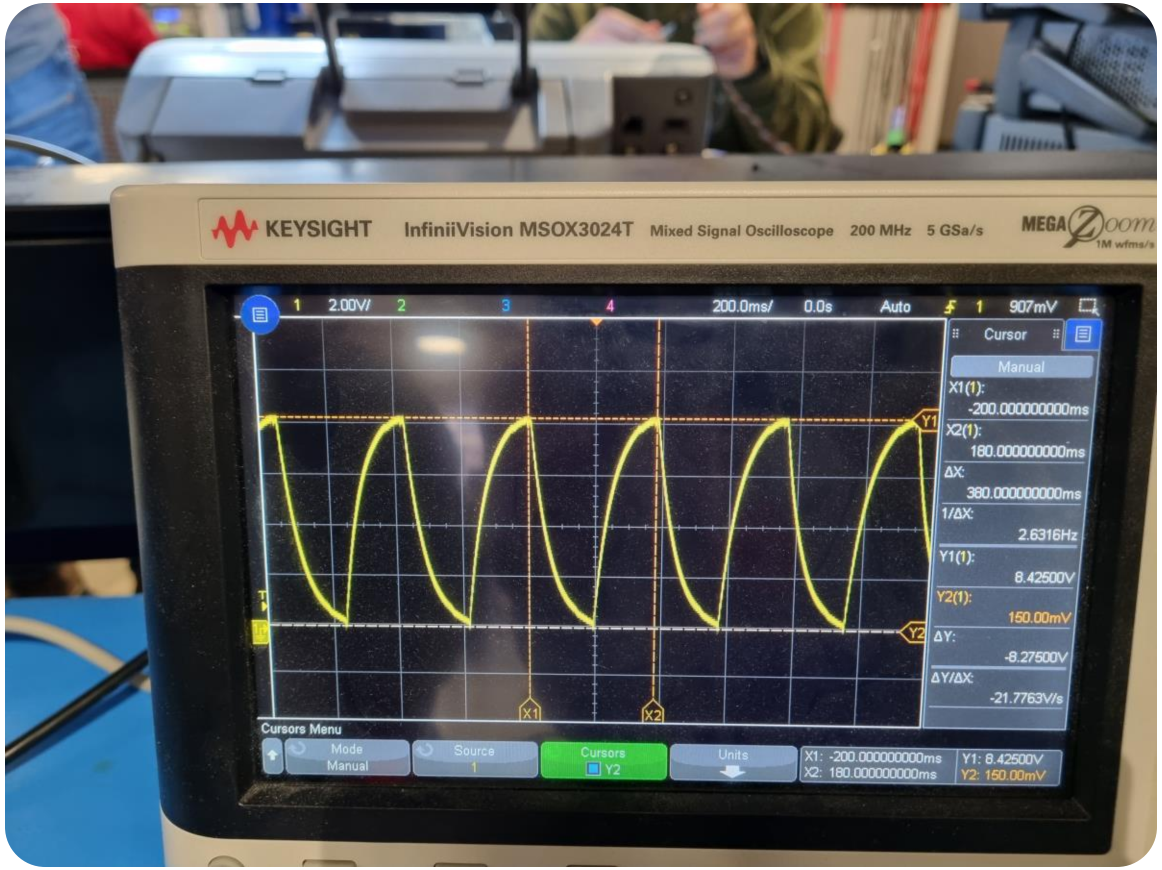
Amplitude Potentiometer

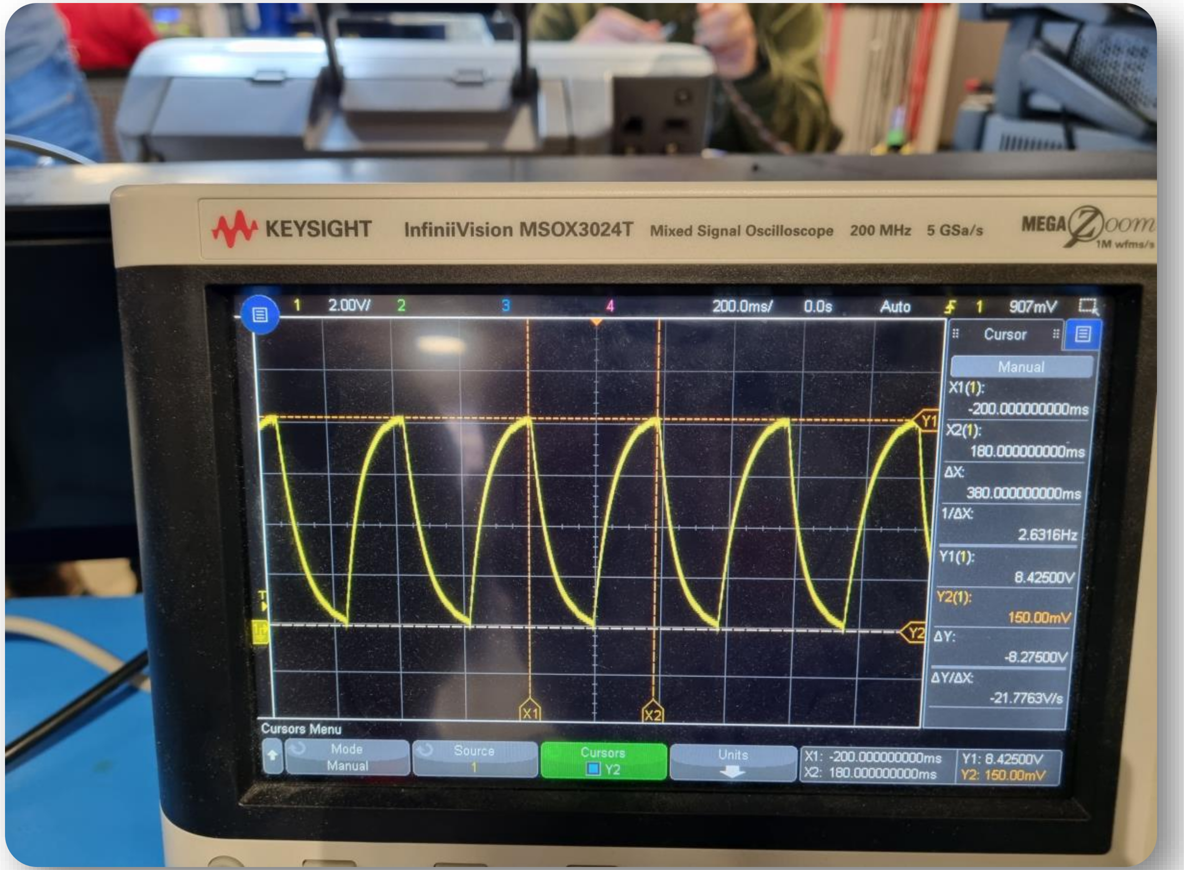
Frequency Potentiometer

Variable voltage 9V - 12V

[illegible]




KEYSIGHT
InfiniiVision MSOX3024T Mixed Signal Oscilloscope 200 MHz 5 GSa/s
1 2.00V/ 2 3 4 200.0ms/ 0.0s Auto 1 907mV
Cursor
Manual
X1(1): -200.000000000ms
X2(1): 180.000000000ms
ΔX: 380.000000000ms
1/ΔX: 2.6316Hz
Y1(1): 8.42500V
Y2(1): 150.00mV
ΔY: -8.27500V
ΔY/ΔX: -21.7763V/s
Cursors Menu
Mode Manual
Source 1
Cursors Y2
Units
X1: -200.000000000ms
X2: 180.000000000ms
Y1: 8.42500V
Y2: 150.00mV



Amplitude

8.275V

Wave Profile

Triangle-like
RC charging-discharging

Frequency

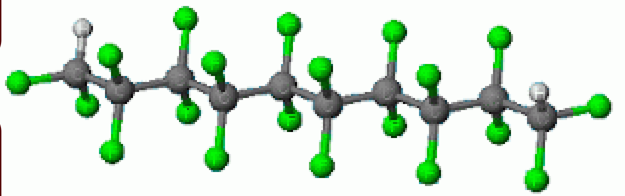
2.63Hz
Could not go lower

Chemically inert, nontoxic, and nonflammable substances

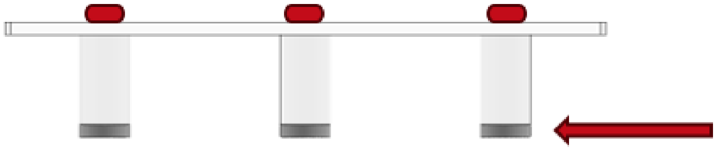
Low coefficient of friction ➔ less shear stress on the tissue

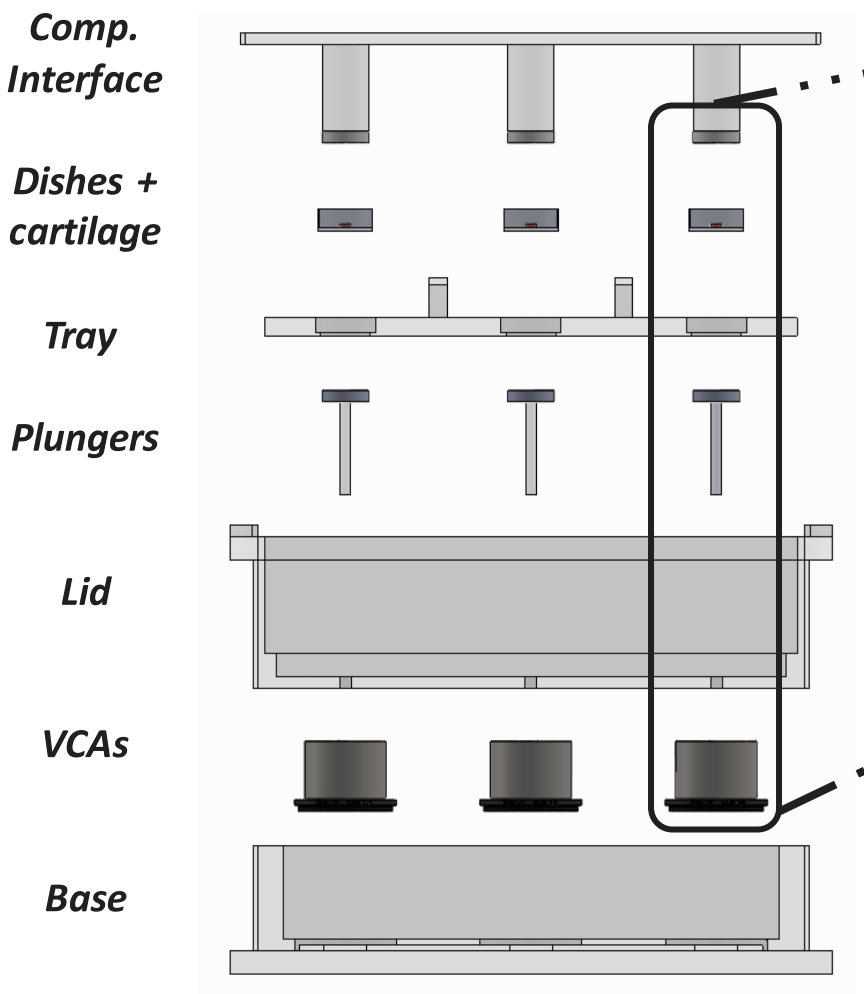
High-temperature resistance: M.T.: 635°F (335°C)
→ Sterilization method: Autoclave

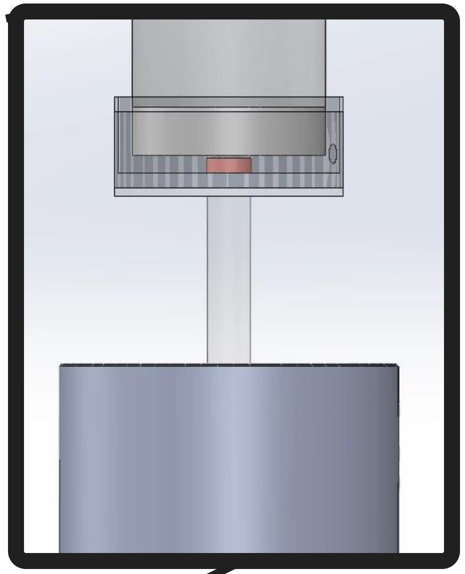
Fabrication method: (1) The plate and PTFE columns will be fastened
(2) Use button head socket cap screws along with flat washers



Teflon, $-(CF_2CF_2)-$







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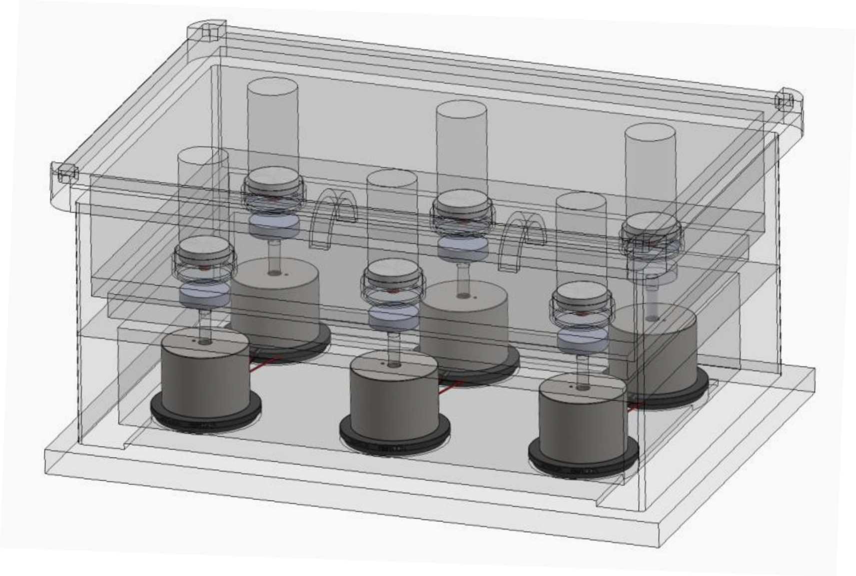
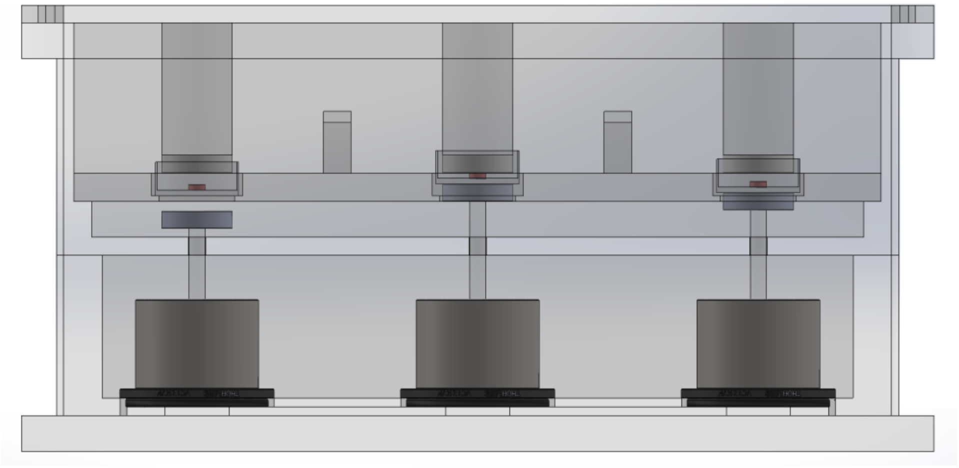




Incubator-Compatible

1. Fits in the incubator → **Housing dimensions in CAD** ✓
2. Can withstand heat and humidity → **Isolated electronics and good material selection** ✓
3. Can withstand sanitation procedures → **Isolated electronics and good material selection** ✓

Desired Forces Applied

1. ~20% strain or ~6 N of force → **Voice coil actuators** ✓
2. Control over amount of force applied → **Force validation** ✓
3. Sinusoidal/triangular loading profile, 0.1–10 Hz frequency → **Force validation** ✓
4. Low-friction, biocompatible material compressing the cartilage → **Teflon** ✓

Budget

1. ≤ $5000

Support and Conclusions

Scientific Literature

Industry Equivalents

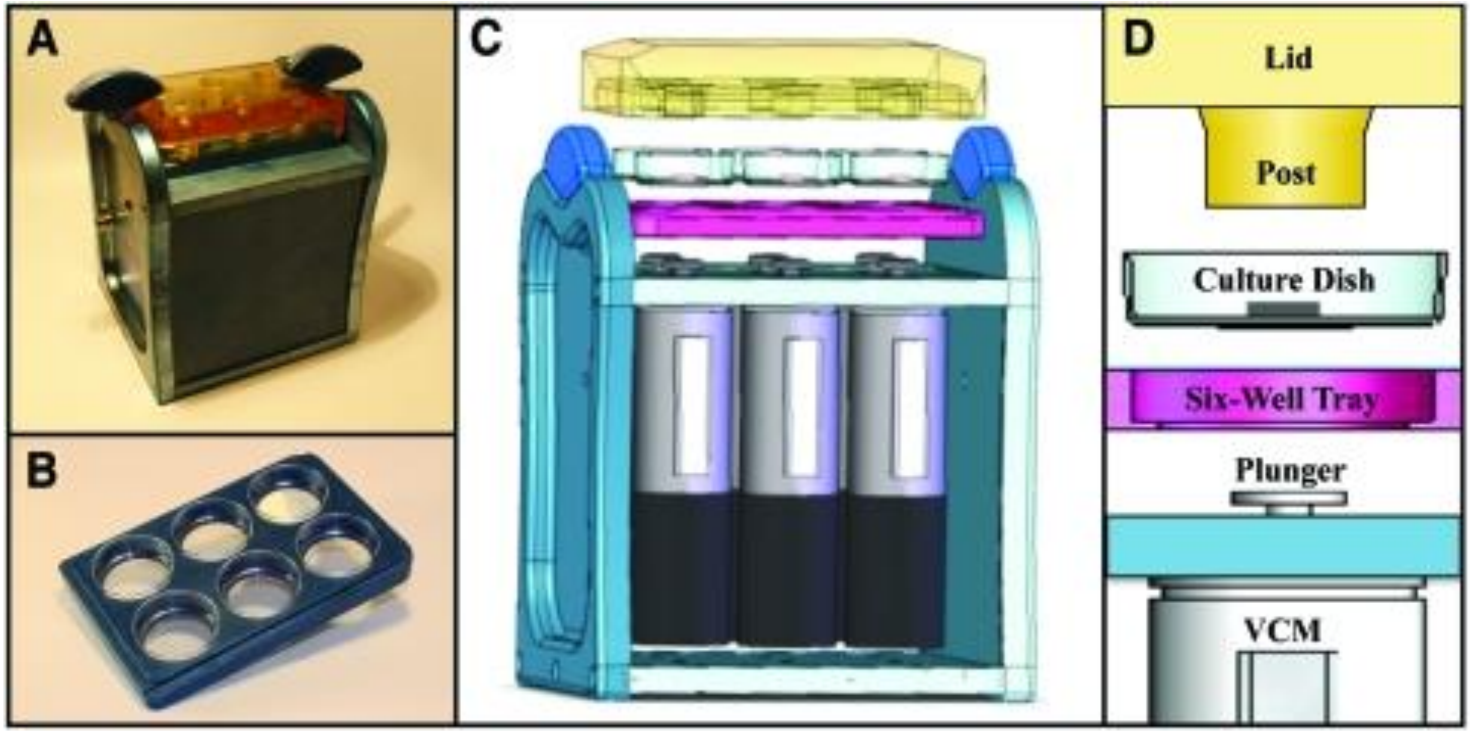
Review of Work and Future Aims

Lujan et al. provides design inspiration!

Both use voice coil motors/actuators

Both compress sample upwards

Both six culture dishes



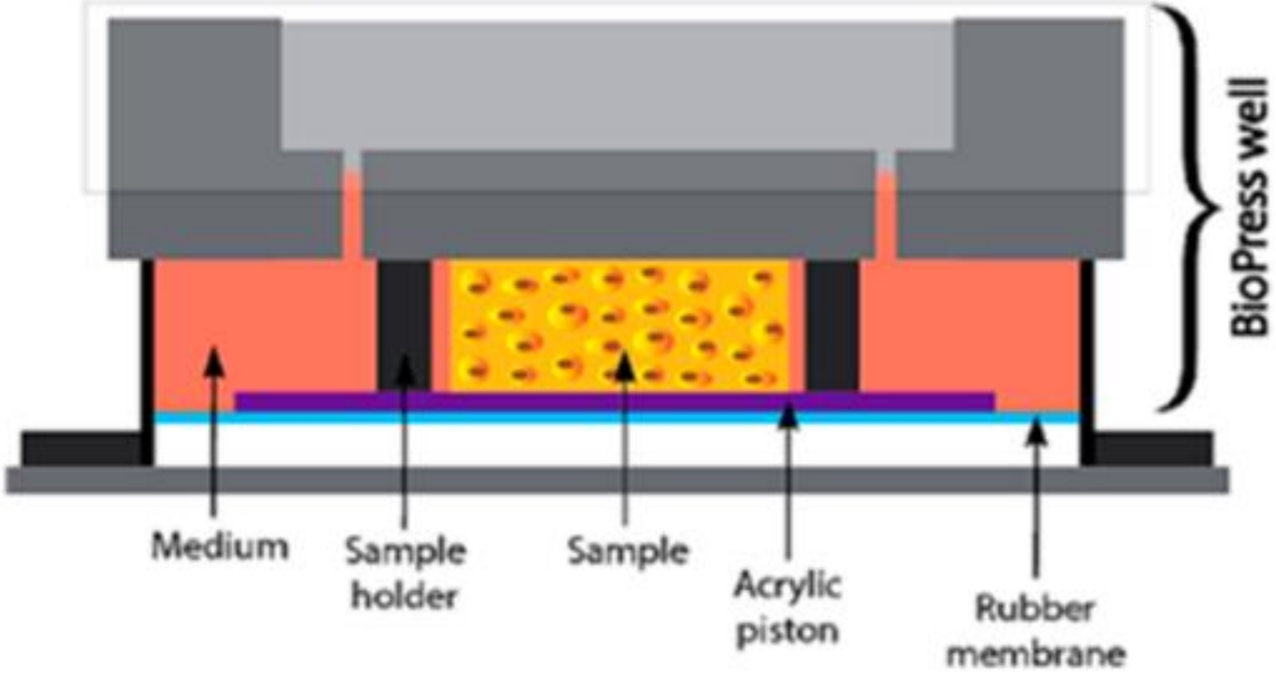
Lujan, T. J. et al. A novel bioreactor for the dynamic stimulation and mechanical evaluation of multiple tissue-engineered constructs. Tissue Eng Part C Methods ***17****, 367–374 (2011).*

[5]

Industry equivalents fail to meet all requirements!

Missing uniform uniaxial compressive strain application

Flexcell FX-5000 system



Uzieliene, I. et al. Chondroitin Sulfate-Tyramine-Based Hydrogels for Cartilage Tissue Repair. International Journal of Molecular Sciences ***24****, 3451 (2023).*

[6]

Finalize circuitry and validate VCA force output with custom input using Henak Lab load cell(s)

Finalize and 3D print housing schematics

Machine PTFE compressive interface and configure within housing

Our current design allows for closed-loop force control and meets all given design criteria while remaining under $5000.

Acknowledgements

Our ME faculty advisor & client, Dr. Corinne Henak

Our BME faculty advisor, Dr. Paul Campagnola

Our TA, Patrick Dills

Professor Mark Allie for PCB Design

Thank you!
Questions are now welcome.

1) [1] Yao, Q. et al. Osteoarthritis: pathogenic signaling pathways and therapeutic targets. Sig Transduct Target Ther 8, 1–31 (2023).
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).
3) Walsh, S. K., Skala, M. C. & Henak, C. R. Real-time optical redox imaging of cartilage metabolic response to mechanical loading. Osteoarthritis and Cartilage 27, 1841–1850 (2019).
4) “Thorlabs - VC125C/M Voice Coil Actuator, 12.7 mm Travel, SM2 External Thread, Metric,” www.thorlabs.com.
5) Lujan, T. J. *et al.* A novel bioreactor for the dynamic stimulation and mechanical evaluation of multiple tissue-engineered constructs. *Tissue Eng Part C Methods* **17**, 367–374 (2011).
6) Uzieliene, I. *et al.* Chondroitin Sulfate-Tyramine-Based Hydrogels for Cartilage Tissue Repair. *International Journal of Molecular Sciences* **24**, 3451 (2023).