TriFlow: A Programmable Flow System for Modeling Contrast Diffusion in Cartilage

STBL Soft Tissue Biomechanics Lab

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Background

- **Clinical motivation:** Detect early signs of osteoarthritic degradation before irreversible damage has occurred
- **How:** Enhance photon-counting computed tomography and biophysical modeling
- **Problem:** Current arthroscopic irrigation systems can only provide constant inflow/outflow fluid profiles
- **Prototype objective:** Develop irrigation system that delivers precise and varying concentration profiles of contrast agents in in porcine explants or stifles
- **Prototype purpose:** Device will allow exploration and simulation of range of boundary conditions that standardizes physiological joint injection control
- Experimentation with this prototype will enhance contrast diffusion analysis when boundary conditions may be unknown in eventual in-vivo human studies

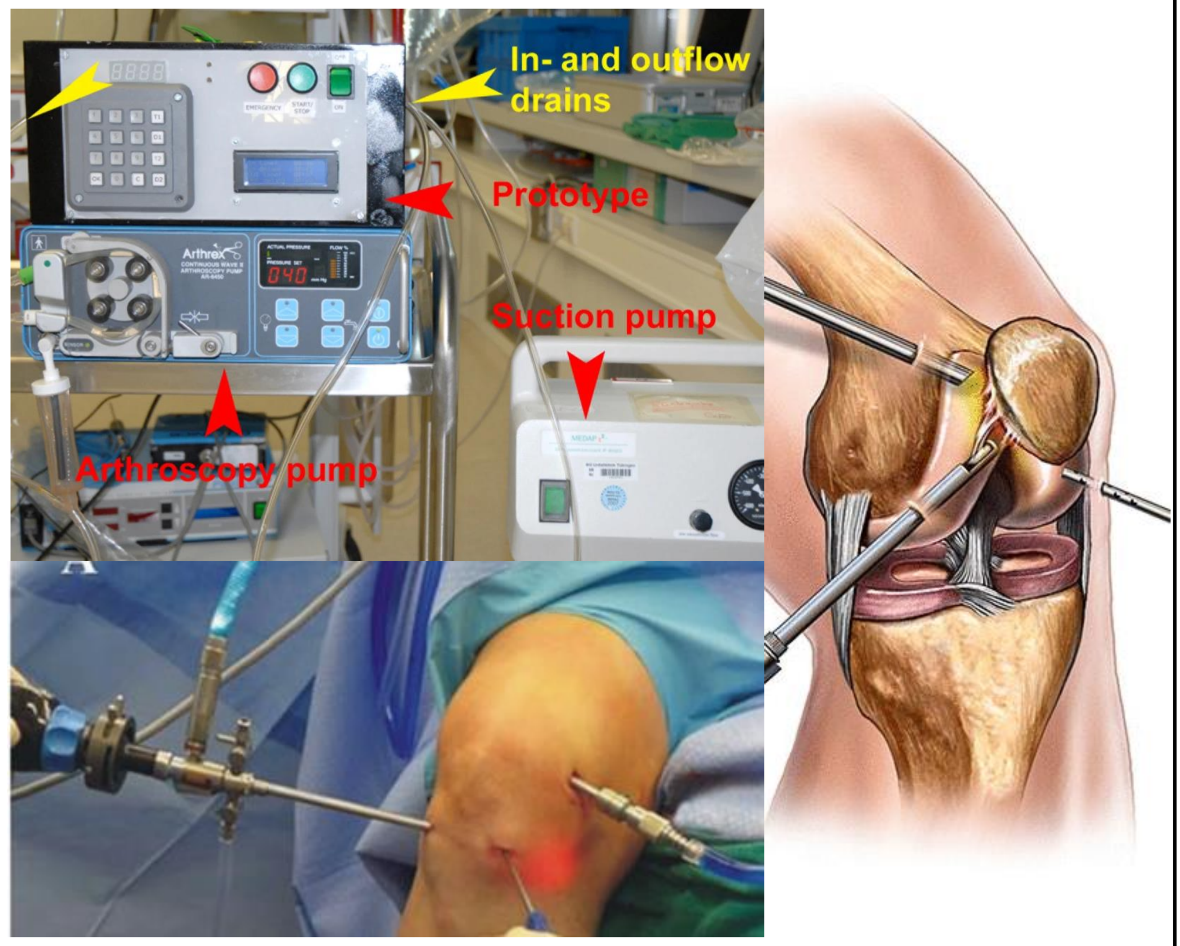

Figure 1. Constant flow arthroscopic irrigation system [1] [2] [3]

Prototype I Materials & Design

- **Design**: inflow, mixture, and outflow, fluid driven by two peristaltic pumps, steady state (inflow = outflow)
- Arduino Uno and L298N H Bridge motor driver control fluid flow rates
- Stir plate instantaneously mixes solution
- **Inflow**: water
- **Mixture**: beaker filled with mixture of water and dye (known initial dye concentration)
- **Outflow**: mixture of water and dye
- **Goal**: control concentration of mixture

Prototype I Design Validation

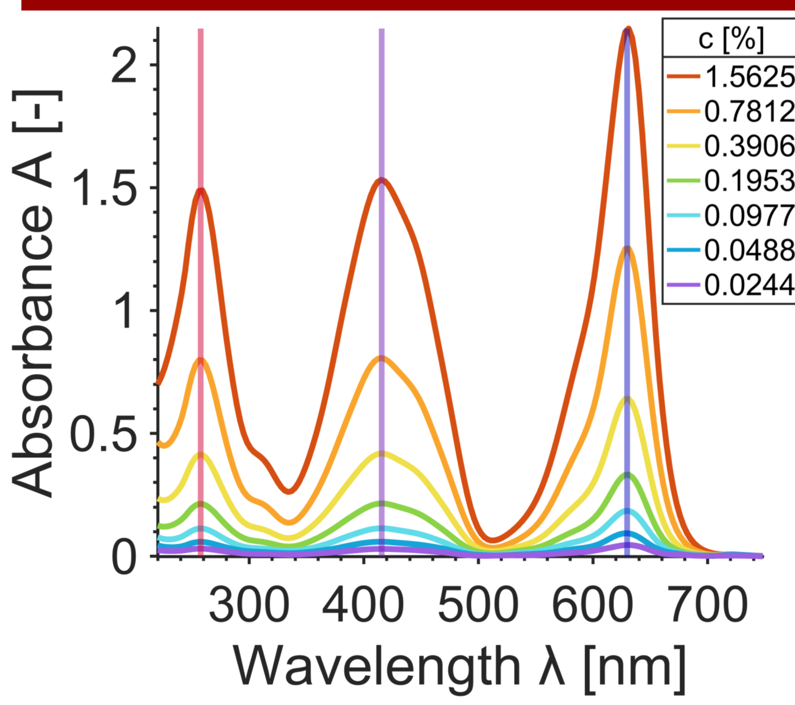

Figure 2. Absorbance spectrum graph (McCormick® Green Food Color)

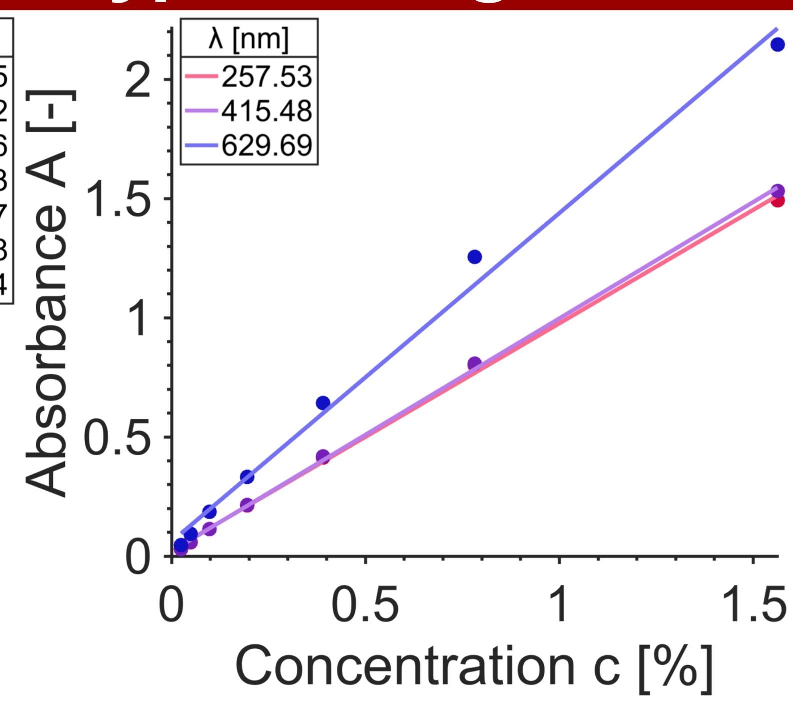

Figure 3. Concentration calibration curve

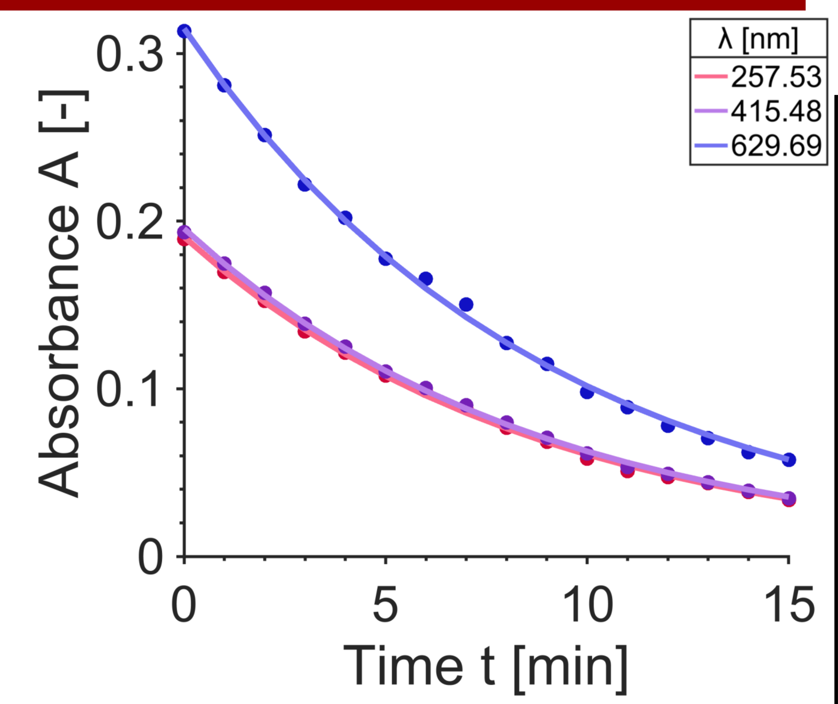

Figure 4. Prototype I Design Validation: Steady State Dilution Test (Absorbance)

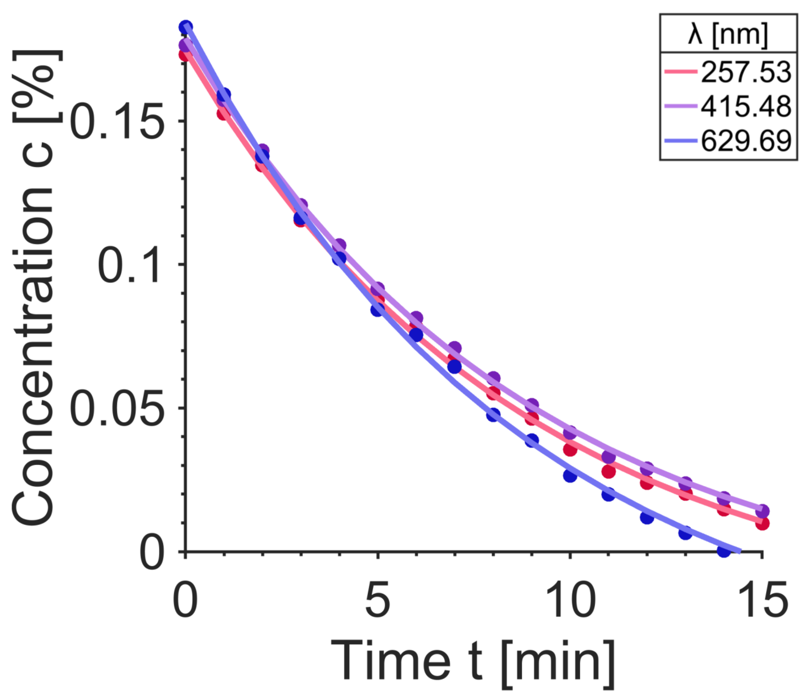

Figure 5. Prototype I Design Validation: Steady State Dilution Test (Concentration %)

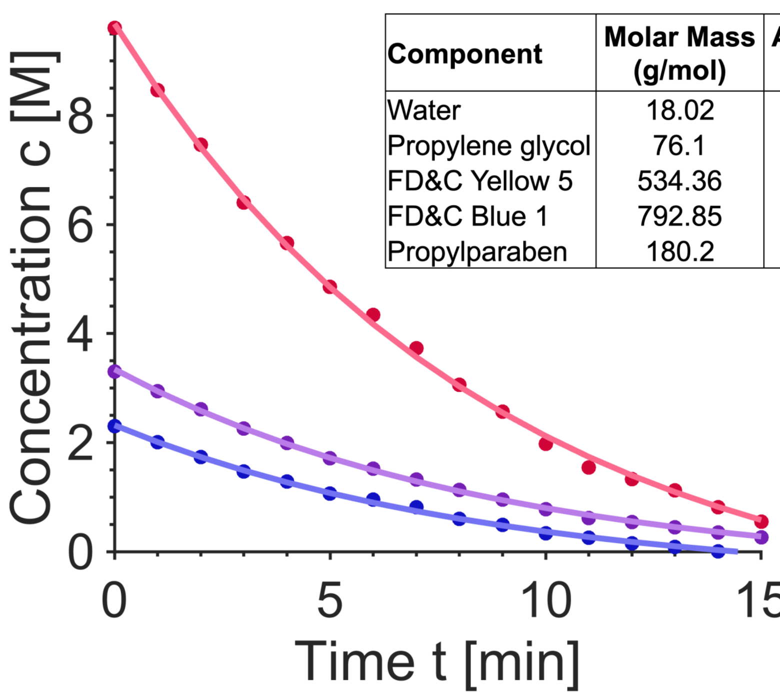

Figure 6. Prototype I Design Validation: Steady State Dilution Test (Molarity)

Component	Molar Mass (g/mol)	Absorbance λmax (nm)
Water	18.02	N/A
Propylene glycol	76.1	~200-230
FD&C Yellow 5	534.36	~425-428
FD&C Blue 1	792.85	~628-630
Propylparaben	180.2	~257-258

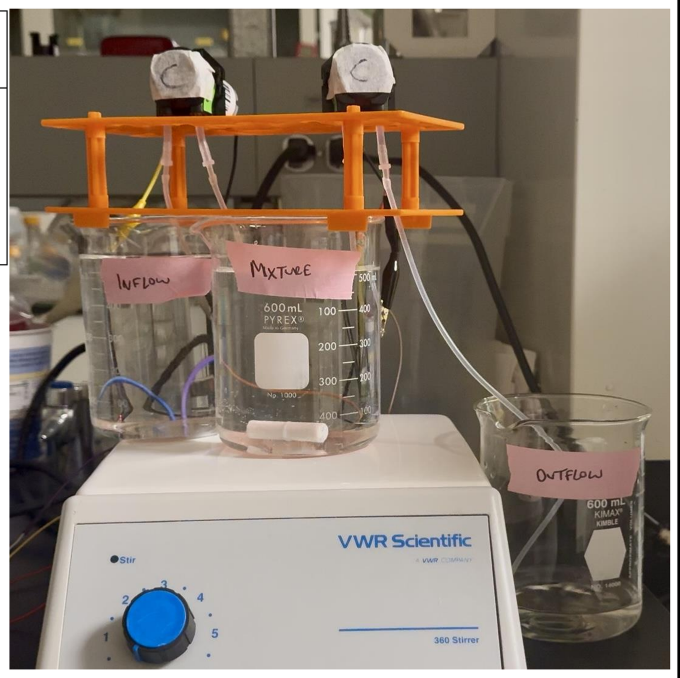

Figure 7. Prototype I Design

Prototype I Testing Results

- **Control:** Successfully demonstrated programmable control of flow rates within ±5 mL of target across calibration runs
- **Concentration:** Baseline absorbance curve enabled conversion of sample absorbance to concentration (molarity)
- **Dilution test:** Concentration followed exponential decay function after 15 min: confirmed reliable mixing and steady state

Prototype I Limitations

- Flow rates only consistent within 5 mL in test runs, limited precision for low-volumes
- Max flow rate 55 mL/min (300 mL/min aim)
- Voltage-based motor control drifted
- Could only dilute or concentrate mixture: unable to create sinusoidal or similarly varying concentration profile
- No physiologically competing pressure or cartilage/tissue interface to validate device

Prototype II Materials & Design

- 3 NEMA 23 stepper motors interfaced with a 3D-printed peristaltic pump adapter and controlled by 3 TB6600 stepper motor drivers systematically create tunable dilution curve profiles
- Two pumps are dedicated to inflow of solution while the other pump solely handles outflow. Separate inflow pumps allows for independent control of liquids, which facilitates precise adjustment of dilution ratio

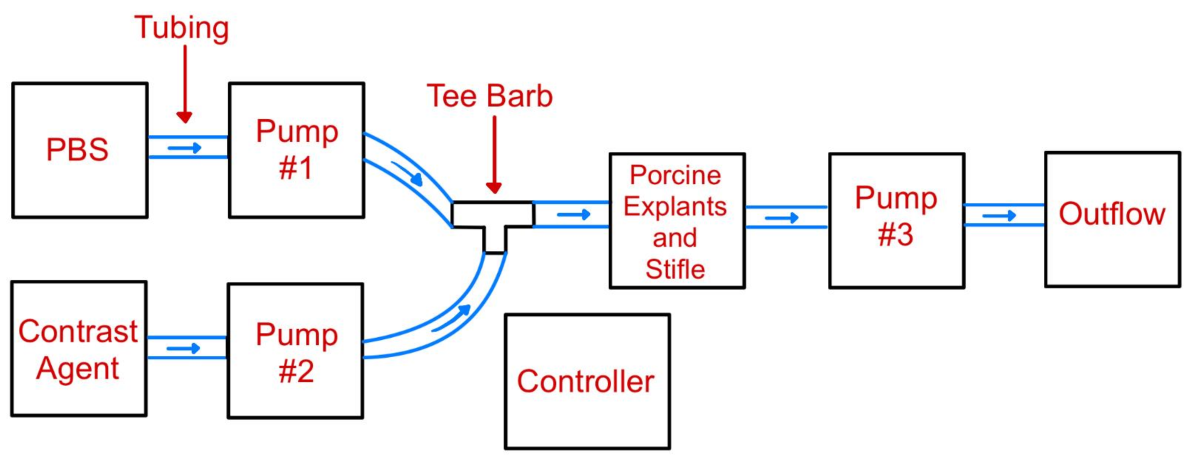

Figure 8. Schematic of prototype II design

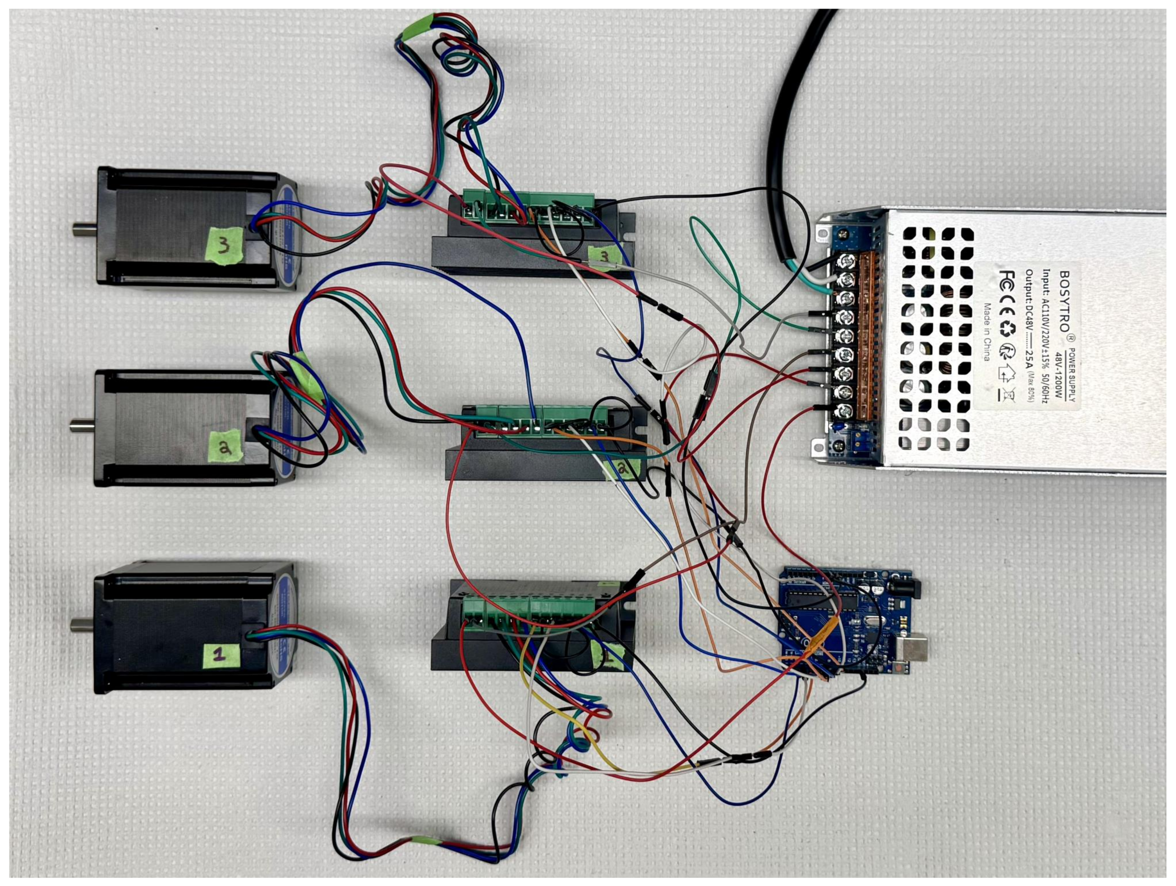

Figure 9. Motor, motor driver, power supply, and Arduino set-up

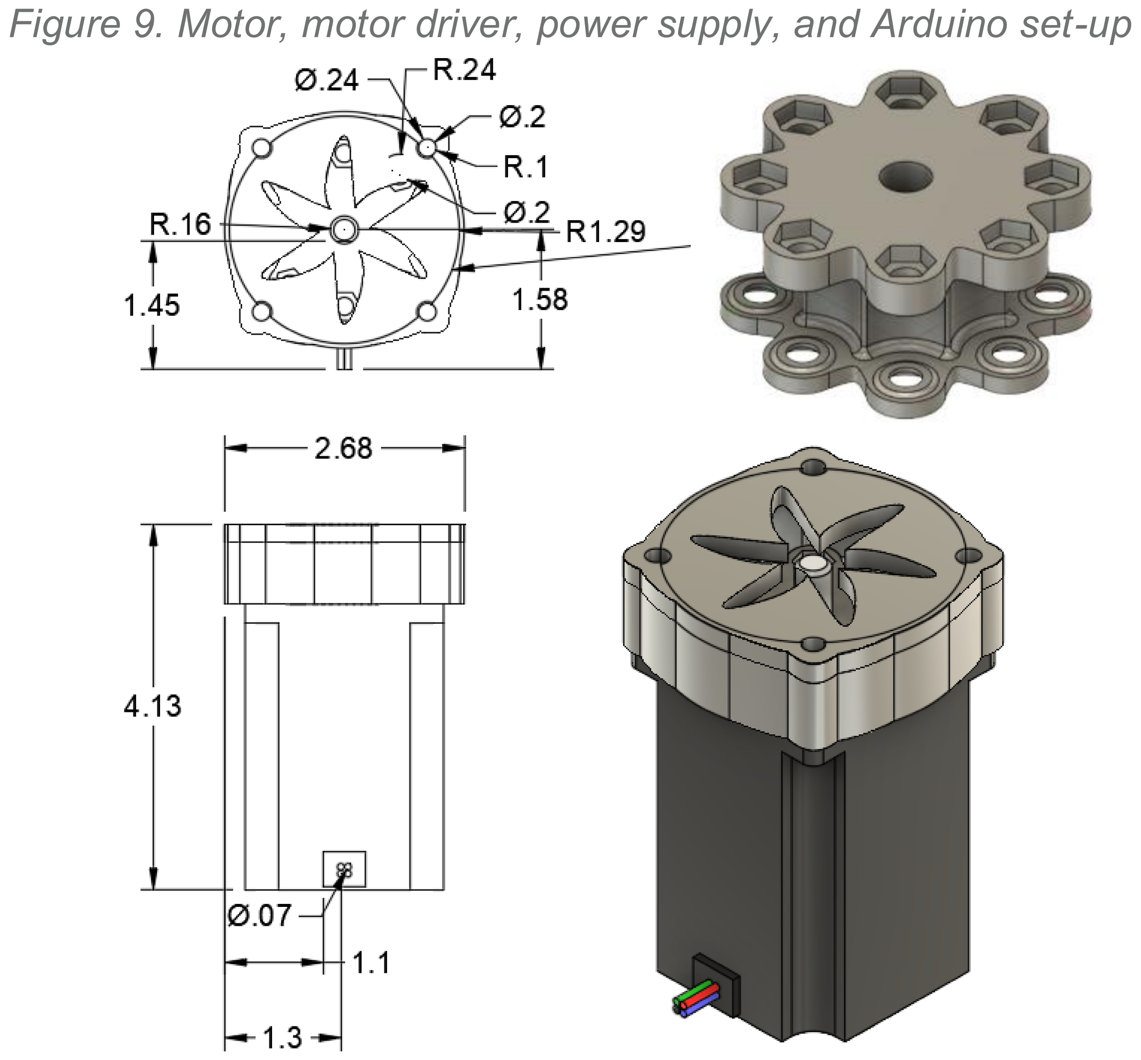

Figure 10. CAD design of peristaltic pump

Future Steps

- Test and improve peristaltic pump design
- Calibrate flow rates of prototype II
- Fine-tune motor control program
- Validate function of prototype II
- Experiment with new concentration profiles
- Utilize contrast agent instead of dye
- Incorporate biologically relevant testing conditions (tissue-mimicking hydrogel, in-vivo porcine stifle models)

References

[1] Ateschrang, A., Albrecht, D., Schröter, S., *et al.* Septic arthritis of the knee: Presentation of a novel irrigation-suction system tested in a cadaver study. *BMC Musculoskelet Disorders* 12, 180 (2011).

[2] *Knee Arthroscopy*. Health Jade. (n.d.). https://healthjade.com/knee-arthroscopy/

[3] *Arthroscopy*. healthdirect. (n.d.). https://www.healthdirect.gov.au/arthroscopy

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