Microvascular Channel Bioprinting Shutoff Valve

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Motivation and Background

- **Over 100,000** people in the U.S. are waiting for a life-saving organ transplant [1]
- Tissue engineering, by way of 3D Bioprinting, allows for the fabrication of functional tissues and organs, but there remain gaps regarding **vascularization** [2], [3]
- Every cell must be **within 50-70 µm** for necessary perfusion [4]
- The smallest capillaries are ~10 µm in diameter, yet even advanced bioprinting methods achieve only ~20–100 µm resolution [5]

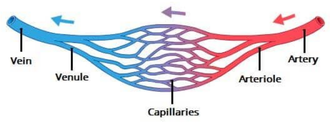


Figure 1: *Circulatory system hierarchy, from arteries to microvasculature (<150 µm), including arterioles and capillaries [6]*

- Dr. Dean's lab utilizes **Kenics Static Mixers (KSMs)** and a **Continuously Extruded Variable Internal Channeling Device (CEVIC)** to print alternating channels of GelMA/SA/LAP hydrogel and HEC fugitive ink (Figure 2) [3]

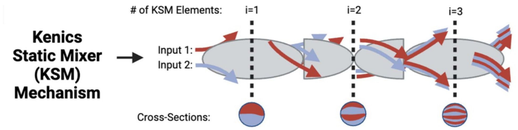


Figure 2*: Figure 2: KSMs enable high resolution microchanneling and hierarchical branching in bioprinted microvascular structures [3]*

- The CEVIC must **print resolutions sequentially** to **mimic the transformation of arteries to capillaries** in the body (Figure 1)
- The multi-scale resolution control enabled by KSMs makes **chaotic bioprinting** a candidate for **replicating hierarchical vascular structures**, such as those needed to perfuse **bone grafts** [3]

Problem Statement

To create an **automated, programmable valve** to seamlessly **shut off** or **switch** between **KSM outputs** and **multiple hydrogel resolutions.**

Design Specifications

1. **Automated** and **seamless** switching between KSM resolutions
2. **Low shear** stress on cells and minimize dead space in the tubing
3. Biocompatible materials
4. Preserve alternating pattern of HEC and GelMA
5. **Maintain vascular network resolution**: 10 µm – 1 mm [5]
6. Must produce a **continuous hydrogel sheet** of ~ 2 cm with **channels that can branch** ~ 250 µm
7. Must **integrate** with current Voron setup

Final Design - Integrated Rotary Element (IRE)

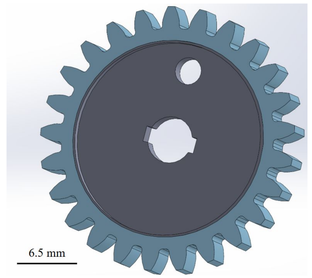


Figure 3: *Isolated 3D model of IRE. 3D printed with Clear Resin*

Figure 4: *3D model of assembled CEVIC, IRE, and Servo in holder*

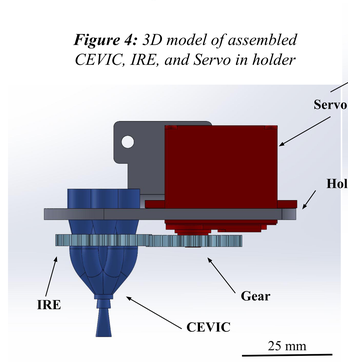
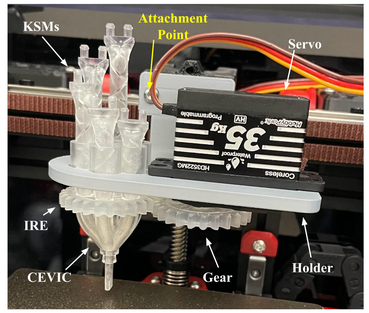


Figure 5: *Backside of the CEVIC, IRE and Servo assembled in holder*

Figure 6: *CEVIC- IRE, and Servo motor attached to the Voron via the holder*



Electronic	Mechanical	Integration
Testing		
- **Five trials**: push button to rotate **IRE +60** degrees **three times** from reference position (180 degrees total) - Goal was to measure whether the IRE returns to original position. - Motor powered by Arduino (5V)	Leak Testing with CEVIC and IRE Iterations (flexible & resin) - **Water** used for initial testing - Colored **gelatin** to observe channels - **GelMA & HEC** to test most updated IRE - Aligned IRE hole by hand	Fully assembled with syringe pump: - **10 trials** for leak testing - Measure **initial** and **final** volume in syringes - **Collected output** in graduated cylinder to quantify
Results		
- Total displacement: 207.8 degrees ± 6 - **p < 0.05 (Significant)** - **15.2%** average percent error returning to original position		- Mean %: **16.3, 3.1,** and **3.1**, respectively - **p = 0.1415** - Comparison tests performed with water

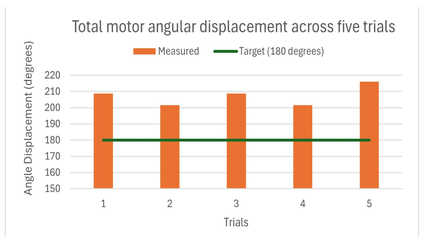


Figure 7: *IRE angular displacement induced by button press*

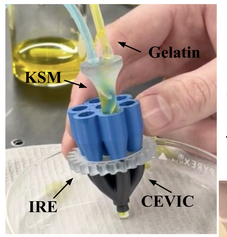


Figure 8: *Leak testing conducted with colored gelatin*

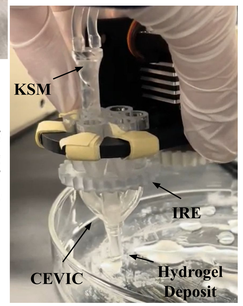


Figure 9: *Leak and Integration testing with GelMA and HEC hydrogels*

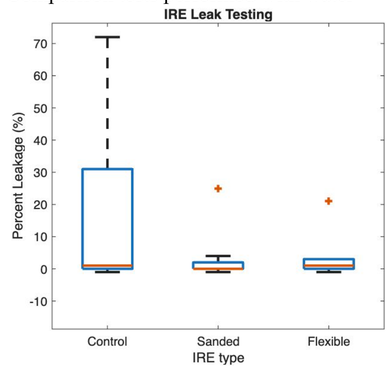


Figure 10: *Box-and-whisker plots of control, sanded, and flexible IREs for leak testing with water*

Conclusion

- IRE integrated with CEVIC through switching between KSM resolutions via button press **(Design Criterion 1)**.
- The design is fully integratable with client's bioprinting framework **(Design Criterion 7).**
- The alternating pattern of fluid was preserved throughout the device. Angular displacement errors could impact the final hydrogel resolution **(Design Criterion 6)**.
- All materials are fully biocompatible **(Design Criterion 3)**.

Future Work

- Integrating CEVIC, IRE, Arduino with Voron and rotary valve
- Further work with automation of switching between KSMs
- Implementation of negative pressure in device to reduce leakage while switching between KSMs
- 2:1 gear ratio on IRE to allow more efficient rotation
- Further testing is needed to validate that the channels are present in the correct dimensions.

Acknowledgements

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- Client Dr. David Dean, Josh Alexander
- Advisor Dr. Paul Campagnola

References

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