

Motivation

One main challenge of tissue engineering is vascularizing tissue engineered biomaterials to achieve the pattern and resolution of branching arteries and capillaries (down to 10 μm in diameter), as well as connecting to other vasculature and mimicking the circulatory system's functionality. Researchers in the Dean lab have identified a solution through chaotic printing. Kenics Static Mixers (KSMs) create an alternating pattern of bio- and fugitive ink, which is deposited through Continuously Extruded Variable Internal Channeling (CEVIC) technology. The CEVIC device connects all the KSMs to a nozzle that extrudes a flat hydrogel output, containing the vasculature from arteries down to capillary level (i.e., from largest to finest resolution). However, challenges remain with instantaneously switching between KSM outputs to achieve the appropriate output. Manual methods were unable to achieve timely switching. Additionally, the inclusion of a rotary valve to switch between KSM inputs did not fix leaking issues in the device. Therefore, the objective is **to create an automatic, programmable valve to seamlessly switch between KSM outputs**. In addition to automability, the client requires that the device maintain hydrogel patterning, integrate with the current lab setup, be biocompatible, and produce a 2-3 cm long hydrogel sheet with the resolution switching every $\sim 250 \mu\text{m}$.

Prior work

Many present devices utilize various bioprinting approaches to extrude hydrogels. Wang et. al. (2016) extruded hydrogels using a visible-light based stereolithography system. Additionally, Ceballos-Gonzales et al. (2023) evaluated other patent applications on closely related KSM-based technology. The competing vascularization bioprinting technologies are diverse, but none achieves the same hierarchical mid-extrusion resolution switching that CEVIC technology targets. Conventional extrusion bioprinting achieves resolutions only around 100 μm in addition to requiring physical repositioning, making continuous extrusions demanding.

Methods

The Integrated Rotary Element (IRE) was devised to address the challenge of seamless switching between microvascular channel resolutions. The IRE fits within the CEVIC device, blocks residual flow from all except the desired output channel, and rotates to cut off one channel/open the next. The apparatus includes the IRE itself complete with teeth to interface with a gear on a Servo motor which rotates the gear, a CEVIC device modified into two parts that interlock around the IRE, and a holder to keep the Servo and CEVIC connected. The IRE and two CEVIC halves were designed in SolidWorks and OnShape, and printed using biocompatible BioMed Clear Formlabs resin. The Gear and Holder were printed from Bambu Labs PLA. The Servo motor was programmed and powered by an Arduino. Testing was conducted using water, gelatin, and acellular hydrogels (3% GelMA and 0.8% HEC) at 1.5 mL/min and 0.5 bar to evaluate switching behavior, leakage, and backflow across multiple KSM cycles.

Conclusion

The IRE meets its most critical requirement of automated switching between KSM outputs, but leakage and backflow were observed during testing, so the device fails to meet the leakage requirements. The rotating element does not fully block inactive KSM ports, which undermines channel resolution and pattern integrity. However, the automated switching feature of the IRE allows researchers to program a hydrogel to print across multiple KSM resolutions.