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Microvascular channel bioprinter shutoff valve

Overview

- Problem Statement
- Background & Impact
- Competing Designs
- PDS & Client Requirements
- Overview of Designs
- Design Matrix
- Final Design
- Testing and Results
- Project Timeline and Future Plans



Background

- On any given day, over 100,000 people in the United States are waiting for a life saving organ donation [1],[2]
- **Bioprinting** is used to address gaps in organ availability, ex-vivo testing and other high risk surgery procedures [3]
 - Bioprinting is use of viable cells, biomaterials, or biomolecules in a 3D printer [3]

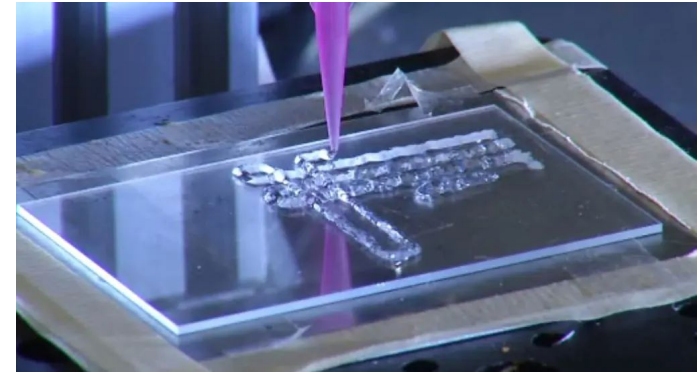


Figure 1: 3D printing a hydrogel [4]



Background: Impact

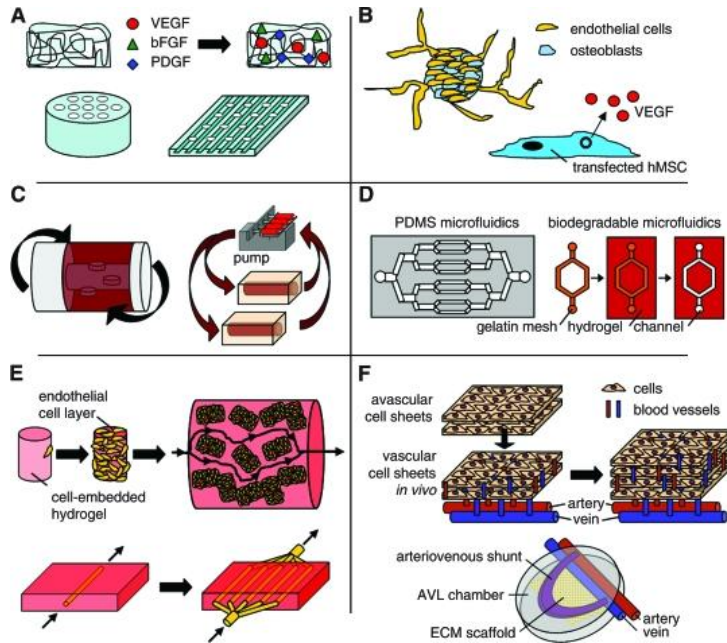


Figure 2: Schematic diagrams of different vascularization approaches [5]

- However, there are tissue engineering gaps when it comes to **vascularizing tissues**
 - Every cell must be within 50-70 μm for necessary perfusion [5]
 - Achieving capillary and arterial resolution remains a challenge
 - Smallest capillary: $\sim 10 \mu\text{m}$ diameter
 - Smallest artery: $\sim 150 \mu\text{m}$ diameter



Background

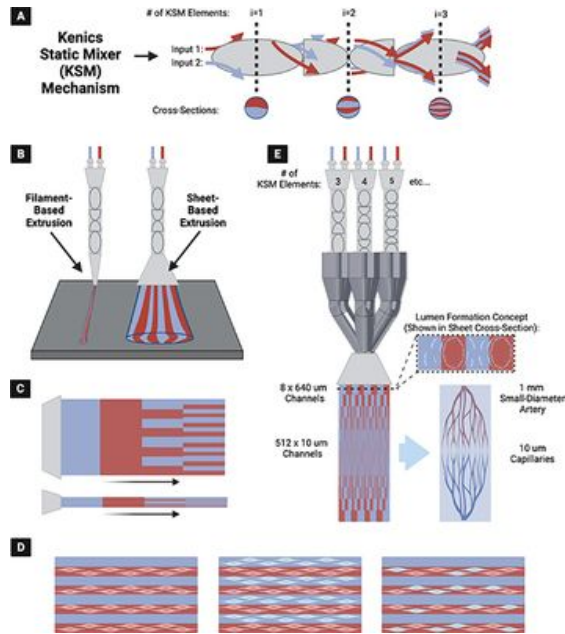


Figure 3: Cevic device that outputs a hydrogel sheet using KSM [3]

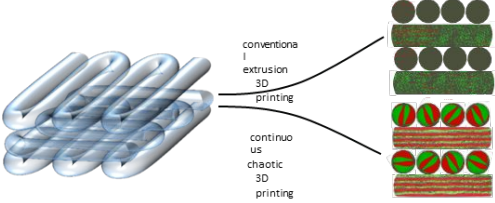
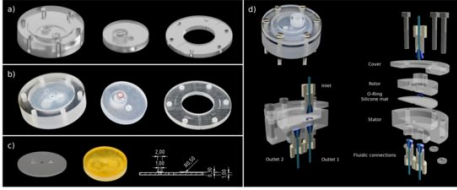
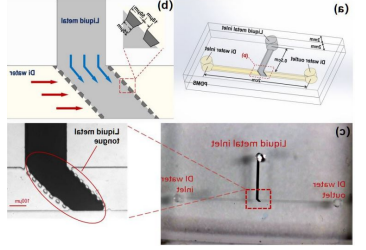
- Researchers have come up with a way to bioprint the necessary resolutions: “chaotic printing” via **Kenics Static Mixer (KSM)** [3]
 - Alternating channels of cell-seeded bio-ink and an evaporative gel to leave channels behind [3]
- Then print in a hydrogel sheet
 - Use a **Continuously Extruded Variable Internal Channeling device (CEVIC)** [3]
- **Problem:** Need to automatically switch between resolutions



Problem Statement

Create an automatic valve to seamlessly shut off or switch between KSM outputs, and therefore multiple hydrogel resolutions, ideally programmed so as to not need an operator.



Competing Designs	Conventional Extrusion 3D Bioprinting	3D Printed Microfluidic Multiport Valves	On-Chip Liquid-Metal Microvalve
Visual Representation	 Figure 4: Print results using conventional (top) and continuous chaotic (bottom) 3D printing methods [6].	 Figure 5: Test valve CAD design for 3D-printed microfluidic multiport systems [7].	 Figure 6: Structural diagrams of the on-chip liquid-metal microvalve [8].
Capabilities	Multi-material filaments Complex tissue architectures Low leakage rates	Precise automated switching No leakage (static tests) <0.5% leakage (dynamic use) Stepper motor control	Precise directional control No leak up to 320 mbar Leak rate $\leq 0.043 \mu\text{L}/\text{min}$ at 330 mbar
Limitations	Typically limited to 100-200 μm Extrusion pressure can damage sensitive cells during printing	Tested at 800 μm channels Performance uncertain at smaller sizes (10 μm)	No sequential layering/branching capability Requires adaptation



Client Requirements

Shut Off Valve Requirements:

1. Sterilizable via UV and autoclave (121°C, 15 psi, 100% humidity, 15 min)
2. Automated and seamless switching between KSM resolutions
3. Low shear stress on cells and minimize dead space in the tubing
4. Biocompatible materials

Vascular Networks Requirements:

5. Preserve alternating pattern
6. Maintain vascular network resolution: 10 μm – 1 mm
7. Must produce a continuous hydrogel sheet with channels that can branch within < 1 cm

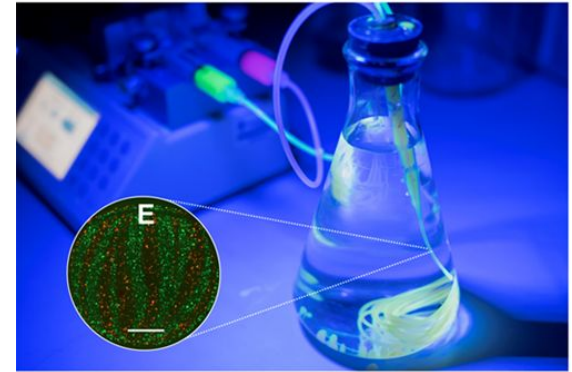


Figure 7: System setup and schematic of the hydrogel construct [6].



Product Design Specifications

Performance:

- Flow rate: 1 mL/min at 0.5 bar
- Transition length: ~1 cm (branching)
- Extrusion: 8-512 channels
- Automated pump: 3.3 mm/s

Key Parameters & Accuracy

- Weight: $\leq 10\%$ of total system
- Operation time: 5 min/hydrogel sheet
- Withstand fluid temperatures of $\sim 70^\circ\text{C}$

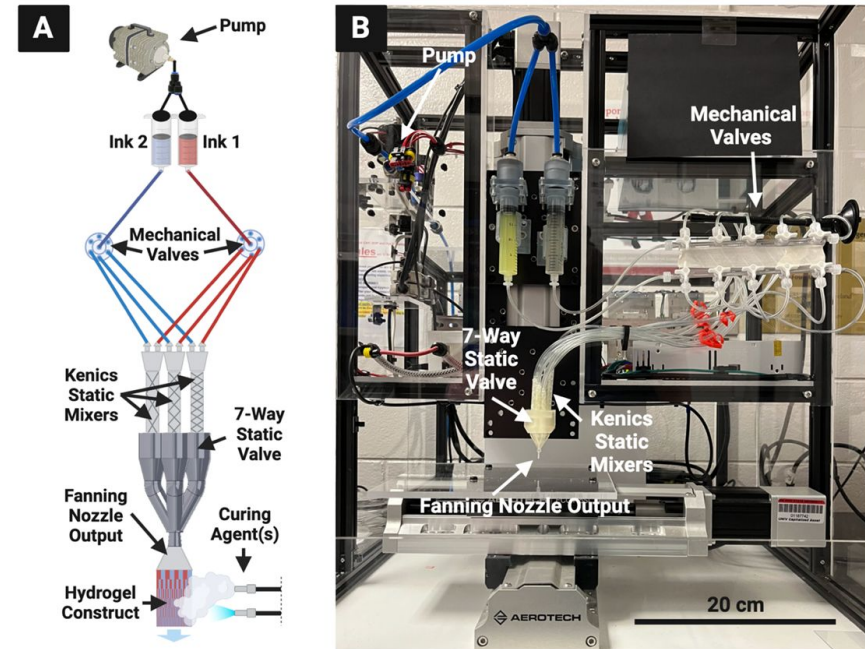


Figure 8: Schematic of the hydrogel construct and system setup [3],[6].



Design 1 - Clamp

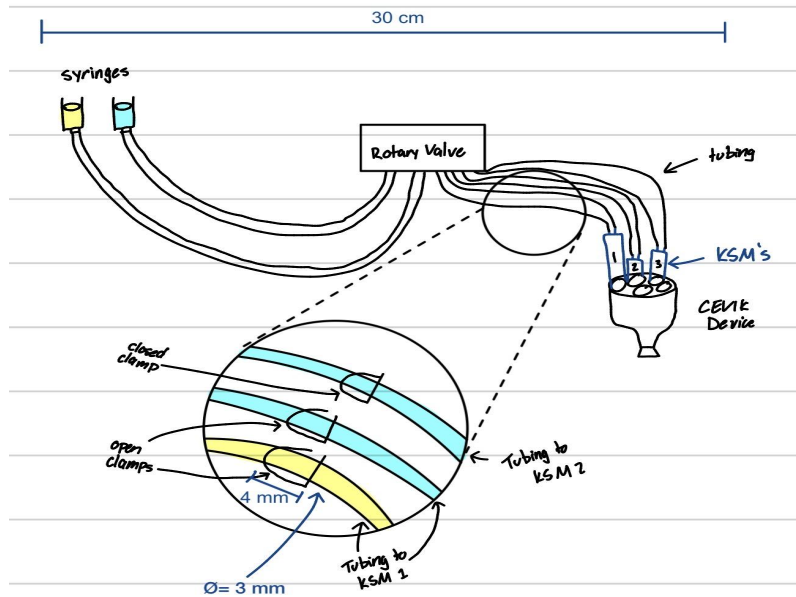


Figure 9: Schematic of clamps attached to tubing in open and closed positions

Automated clamps placed on tubing between rotary valve and KSMs.

Clamp opens after the appropriate KSM has been selected and activated.

Design Strength:

- Maintains pattern and resolution of hydrogel

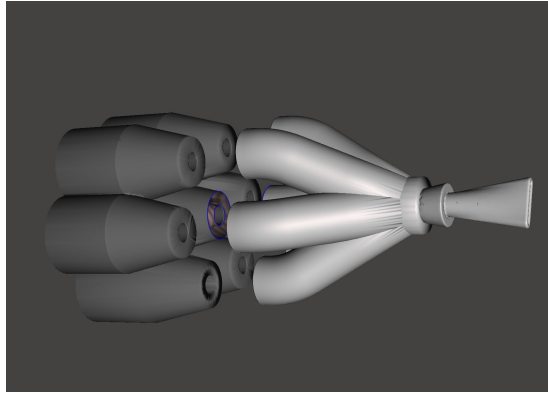
Design Weakness:

- Possible tubing degradation due to continuous pinching of clamps



Design 2 - Integrated Rotary Element (IRE)

Figure 10: CEVIC
3D model split
into two parts



Augments the existing CEVIC device to have a rotating valve within it

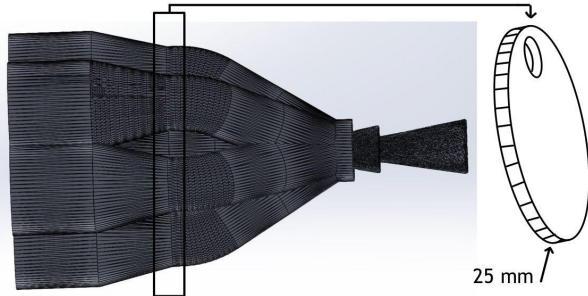
Design Strengths:

- Allows for immediate cessation of liquid from one KSM and beginning of another
- Can interface with a Servo Motor and be easily programmed with an Arduino

Design Weaknesses

- Requires tight tolerances
- Degradation between the pieces over time

Figure 11:
Schematic
showing where
rotary element
will be inserted



Design 3 - Flow Diversion System

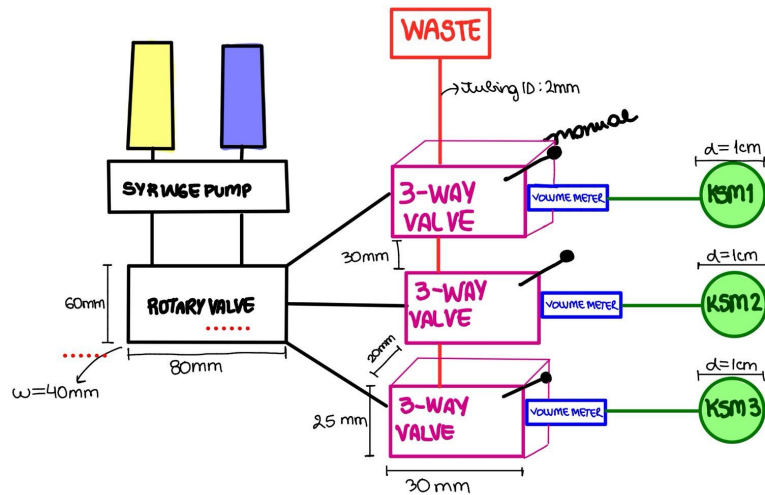


Figure 12: Diagram outlining fluid inputs and outputs from 3-way valve

Manual 3- way valve between rotary and KSM.

Each valve has 2 positions, directing fluid from input to:

1. Waste
2. KSM

Transparent tubing enables visual monitoring of hydrogel fluid



Design 3 - Flow Diversion System

INTERNAL BALL MECHANISM CROSS SECTION

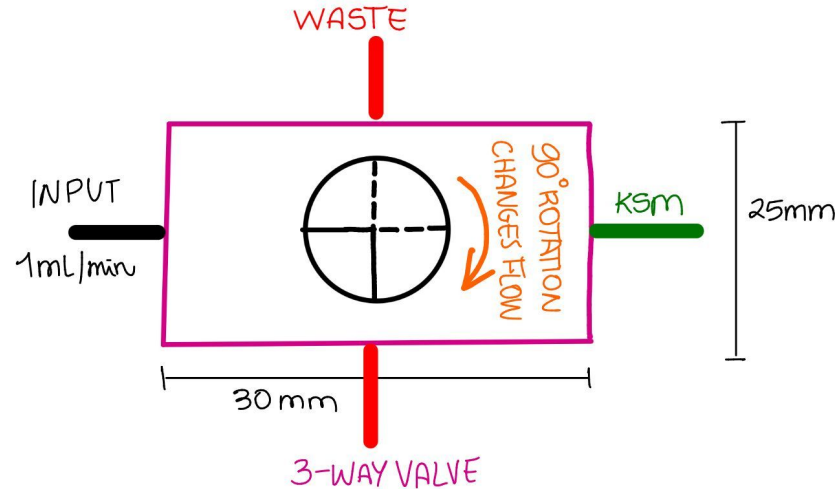


Figure 13: Close up of three-way valve

Design Strengths:

- Enhanced precision with volume based automation

Design Weaknesses:

- Difficult fabrication
- Durability concerns given the valves directly interact with fluids



Design Matrix

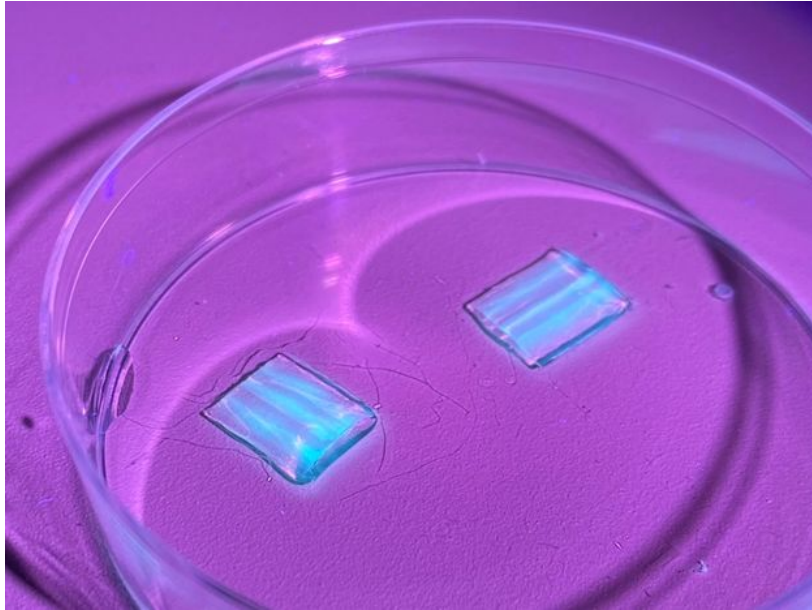


Figure 14: Depicting pattern [6]

Table 1: Shutoff Valve Design Matrix

Criteria (weight)	Concept A: Clamp		Concept B: Internal Rotated Element		Concept C: Flow Diversion System	
Maintain Pattern & Resolution (25)	5/5	25	4/5	20	4/5	20
Automatable (20)	3.5/5	14	5/5	20	4/5	16
Durability (15)	3/5	9	3/5	9	3/5	9
Ease of Fabrication (15)	4/5	12	4/5	12	3/5	9
Workflow Maintenance (15)	4.5/5	13.5	3/5	9	4.5/5	13.5
Safety (5)	4.5/5	4.5	5/5	5	4.5/5	4.5
Cost (5)	4/5	4	5/5	5	5/5	5
Total (100)	Sum	82	Sum	81	Sum	77



Final Design

- Scored the highest of the 3 designs, but all 3 have unique advantages

Figure 15:
Clamp Design

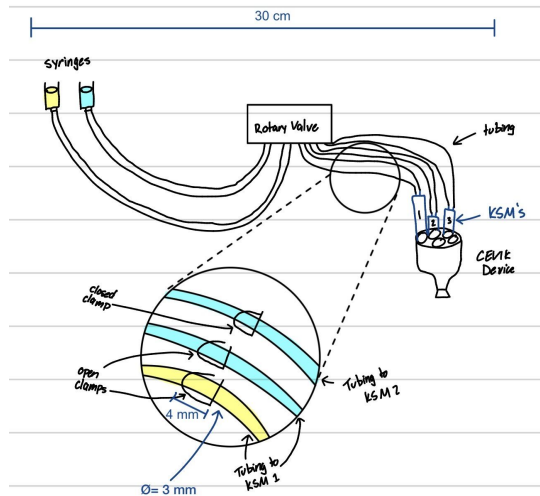
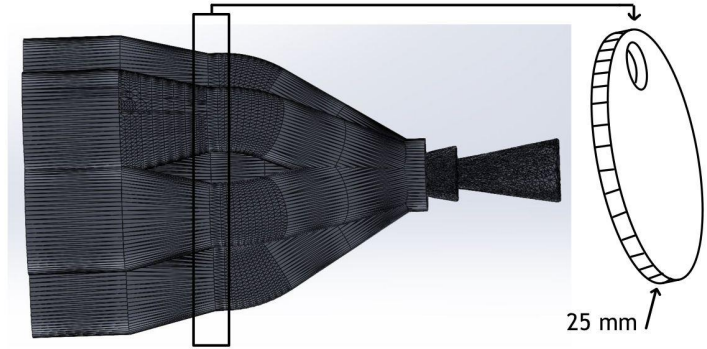


Figure 16: Integrated Rotary Element



- Since it is a year-long project, hope to test all the designs, particularly Clamp & Internal Rotated Element



Testing and Future Work

Future Work

- The team will split into two groups:
 - Design and Fabrication
 - Computational Fluid Dynamics (CFD)
- Given the two semester timeline, the groups will model and build both the Clamp Design and the IRE Design

Testing

- Validate designs using CFD
 - Evaluate different P and v
- Verify resolution and pattern using research methods developed by client
- Verify material biocompatibility using cytotoxicity testing
- Durability testing



Project Timeline

Task	Aug	September				October					November				Dec	
	26	4	11	18	25	2	9	16	23	30	6	13	20	27	4	11
Project R&D																
Empathize																
Background...					X											
Prototyping					X											
Testings																
Deliverables																
Progress Reports		X	X	X	X	X										
Prelim presentation						X										
Final Poster																
Meetings																
Client			X	X	X											
Advisor		X	X	X	X											
Website																
Update		X	X	X	X											

Table 2: Gantt chart for project timeline



Acknowledgements

Professor Campagnola - Advisor

Professor David Dean - Client

Mr. Joshua Alexander - Client



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Questions?



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