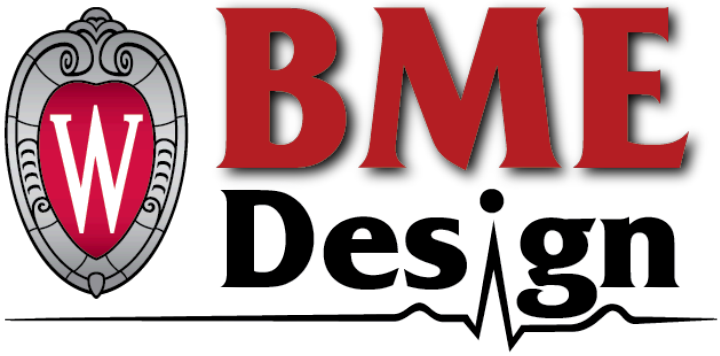

Microvascular channel bioprinter shutoff valve

Preliminary Report

BME 400 Design

October 14, 2025

Client: Professor David Dean

Advisor: Professor Paul Campagnola
University of Wisconsin Madison
Department of Biomedical Engineering

Team:
Leader: Dominique Gooden
Communicator: Steph Vigmond
BSAC: Mahathi Karthikeyan
BWIG: Sophie Speece
BPAG: Ana Toscano

ABSTRACT

Tissue engineering is a rapidly growing industry that grows and utilizes cells, tissues, and organs to address clinical and research needs [1]. However, one persistent problem in the field is vascularization of these tissues. One potential solution lies within chaotic bioprinting. Kenics Static Mixers (KSMs) create an alternating pattern of bio- and fugitive ink [2]. Continuously Extruded Variable Internal Channeling (CEVIC) technology, created by the Dean Lab, prints hydrogels in flat sheets rather than filaments [2]. The hydrogel outputs are intended to mimic vasculature from the artery level down to the capillary level. However, a difficulty arises in instantaneously switching between the different KSM outputs in order to have sequentially smaller hydrogel resolutions. Therefore, an automatic shutoff valve is needed. A solution was identified using clamps to cessate liquid coming into each of the KSMs, creating a vacuum to limit leakage and therefore seamlessly switch to another resolution. A second solution was also brainstormed, which utilizes a rotational element fitted within the CEVIC device that only allows output from one KSM at a time. These two designs will be fabricated and tested in order to resolve the hydrogel resolution and switching problem and allow vascularization and life-saving research to advance.

Table of Contents

1 INTRODUCTION

1.1 Motivation

On any given day, over 100,000 people in the United States are waiting for a life saving organ donation [3]. This statistic highlights a critical gap between the supply and demand of donor organs, a disparity that leads to mortality and underscores the limitations of the current donor-based system. Bioprinting has emerged as a disruptive technology with the potential to address this organ availability crisis by enabling the fabrication of functional tissues and organs [2]. The potential to create patient-specific organs on demand could one day eliminate transplant waiting lists and the complications associated with organ rejection. The applications of bioprinting extend into in-ex-vivo testing and support high-risk surgical procedures.

A critical barrier that still limits the clinical translation is vascularization. Over 90% of engineered tissue constructs fail to sustain long-term function because they lack a functional vascular network capable of delivering oxygen and nutrients [4]. This vascularization bottleneck severely limits the size and complexity of printable tissues. Current constructs rarely exceed 2 mm in thickness before central regions become hypoxic and necrotic [5]. The development of systems that can fabricate microchannels at physiological scales is essential to bridging the gap between laboratory prototypes and clinically viable tissues.

1.2 Existing Devices & Current Methods

Conventional Extrusion 3D Bioprinting serves as a foundational method in the field, characterized by its ability to utilize multi-material filaments to create complex tissue architectures while maintaining low leakage rates. However, this approach faces significant

limitations, including a typical resolution constraint of 100-200 µm and the risk of damaging sensitive cells during printing due to extrusion pressure [6].

A specific application of this printing technology is seen in 3D Printed Microfluidic Multiport Valves. These devices provide precise automated switching via stepper motor control, demonstrating no leakage in static tests and less than 0.5% leakage in dynamic use [7]. While effective in tested 800 µm channels, their performance at smaller scales, such as 10 µm, remains unverified.

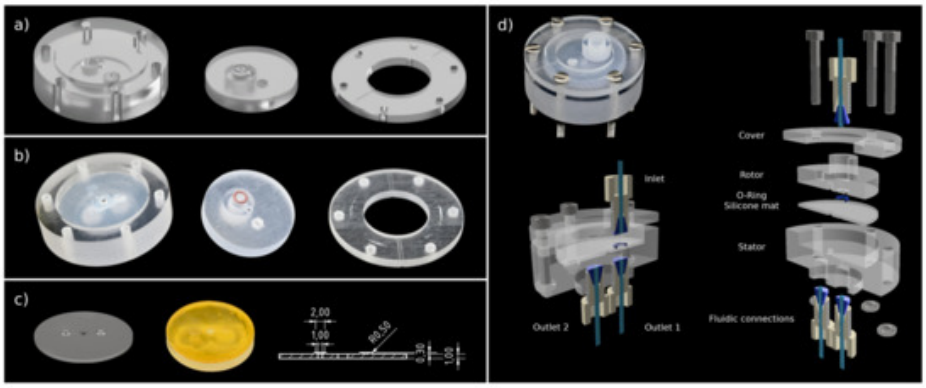

Figure 1: *Test valve CAD design for 3D-printed microfluidic multiport systems [7].*

In a separate technological approach, On-Chip Liquid-Metal Microvalves offer exceptional performance in fluid control. They achieve precise directional control with no leakage up to 320 mbar and a minimal leak rate of ≤0.043 µL/min at 330 mbar [8]. Their principal limitation is a lack of inherent sequential layering or branching capability, which necessitates design adaptation for complex systems.

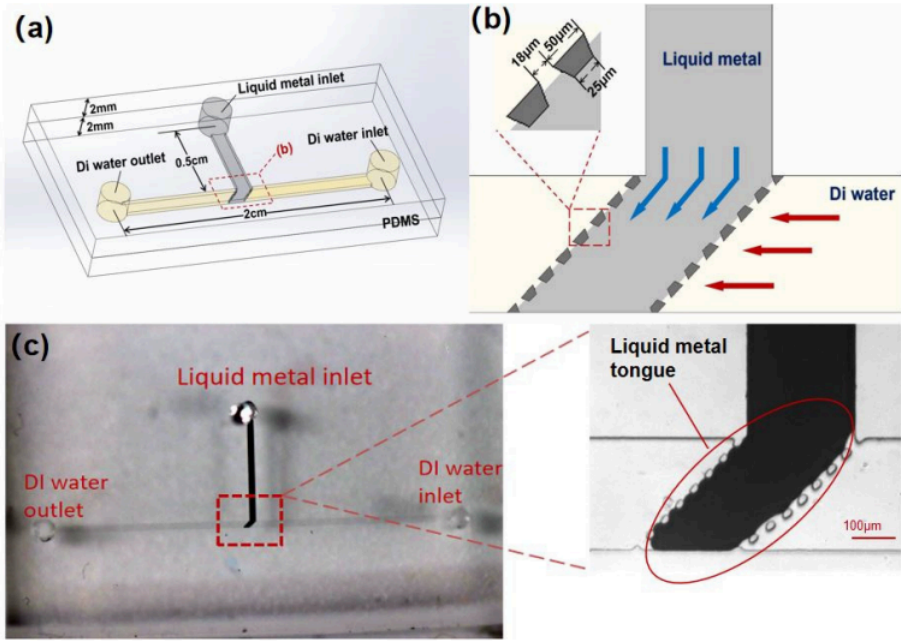

Figure 2: *Structural diagrams of the on-chip liquid-metal microvalve [8].*

1.3 Problem Statement

The task is to create an automatic valve to seamlessly shut off or switch between KSM outputs and multiple hydrogel resolutions, and for the design to be automated using software and programming.

2 BACKGROUND

2.1 Anatomy and Physiology

Current devices and methods have large gaps when it comes to vascularizing tissues. One reason this issue remains is that oxygen and nutrients for cells have to be within a certain physiological distance. Currently the vascularization methods include scaffolding, bioreactor designs which are mainly functional for in-vivo tissue, and microelectromechanical methods using PDMS material and biodegradable microfluidics [5]. However, one challenge with all the methods is that every cell must be within 50-70 micrometers for perfusion [5]. Additionally, achieving the necessary resolution of the complex vasculature still remains a challenge as a capillary is around 10 micrometers in diameter and an artery is around 150 micrometers in diameter.

To combat these challenges, researchers have come up with a way to bioprint the necessary resolutions: “chaotic printing” through KSMs. KSMs alternate channels of cell-seeded bio-ink and a fugitive ink to leave channels behind. This produces hydrogel sheets using a CEVIC device [2].

2.2 Client Information

Dr. David Dean is a professor at the University of Wisconsin-Madison in the Department of Biomedical Engineering, whose lab focuses on surgical reconstruction or regeneration of skeletal structures [9]. He acquired a PhD in 1993 from the City University of New York. His lab uses Computer Aided Design (CAD) to generate patient specific devices and implants, then 3D printing them. He focuses on the 3D printing of resorbable tissue engineered bone scaffolds. To

do this, the lab seeds cells, such as Mesenchymal Stem Cells (MSCs) or vascular progenitor cells onto 3D printed hydrogels, which is what this project pertains to. At the University of Wisconsin-Madison, he teaches several advanced Biomedical Engineering courses, has made ten publications in the last two years, and is the recipient of the 2024 CIRP BioM Best Paper Award [9].

2.3 Product Design Specification

The CEVIC device enables the fabrication of hierarchical, branching channels with continuous geometric and material gradients to mimic natural microvascular networks [2]. The system must operate with high precision, extruding 8 to 512 channels between 10 and 30 micrometers in diameter. The channel diameter is inversely proportional to the number of channels, increasing the number of channels requires smaller diameters. These specifications account for physiological dimensions where capillaries can be as small as 10 μm and must be within 50-70 μm of cells [2]. Key components include KSMs (around 12 cm height, 1 cm diameter) that mix GelMA and sodium alginate, and HEC fugitive ink, and rotary valves that direct flow at 1 mL/min and 0.5 bar [2]. Performance requires a less than 10% error between theoretical and measured channel widths, and transition lengths between channel regions are currently around 1 cm [2].

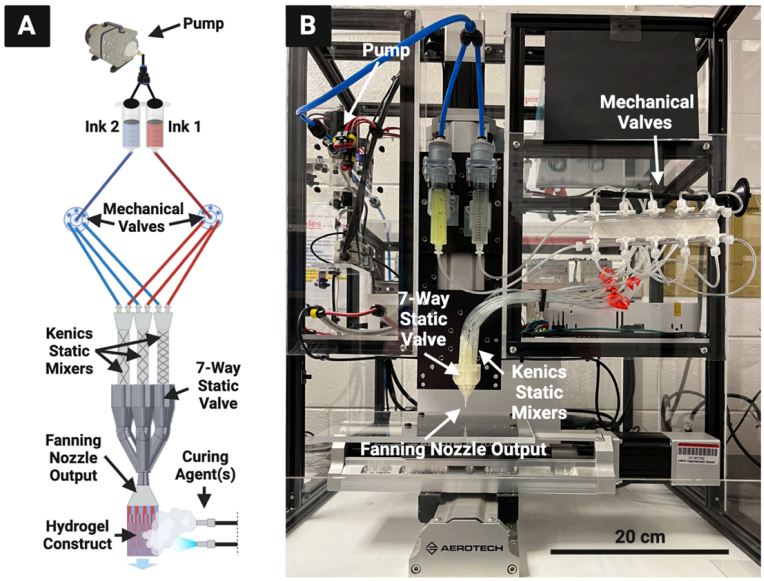

Figure 3: *Schematic of the hydrogel construct and system setup [2]*

The device supports automated operation controlled via LabVIEW, with pumps at 3.3 mm/s in a 20 ml syringe, and a manual mode using stopcocks [2]. For safety, valves must be removable for sterilization and withstand autoclave temperatures, with ergonomic design to minimize injury risk per ISO 14971 and 62366. All materials must be biocompatible per ISO 10993-1 and function in standard lab environments (20-25°C, 35-50% RH) while withstanding operational temperatures up to 70°C [10]. The shutoff valve must not exceed 10% of total system weight and have a shelf life of 5 years [11].

Production will involve 5 prototype units with a total budget of $500. Testing will follow ISO 9001 and ISO/IEC 17025, using calibrated instruments like the Druck DPI520 pressure controller and Sartorius scale. The device is expected to produce a hydrogel sheet in 5 minutes, enabling multiple prints per hour.

3 PRELIMINARY DESIGNS

3.1 Design 1 - Clamp Design

The Clamp design is an external feature intended to regulate fluid flow throughout the client's system. The clamps are designated to a certain KSM, and after the KSM is switched, the clamps on the tubing of the KSM that was previously operating is triggered to close, and the clamps on the tubing to the KSM that is now operating is opened. The design idea was inspired by Intravenous Clamps utilized in hospital settings to maintain fluid flow. The clamps would be placed directly on the tubing between the rotary valve and the KSMs. When necessary, the clamp will shut off to prevent wasted fluid output, as there is currently no mechanism to immediately stop fluid flow once the hydrogel printing is finished. The clamp design idea is strong in two areas:

a. It can maintain the hydrogel pattern resolution prior to printing.
b. It can be easily integrated into the client's framework without changing the printing process procedures.

The clamp design was the highest scoring design idea, however, the clamps may introduce mechanical tubing degradation due to continuous pressures exerted by the clamps. Therefore, the team intends to conduct further research on various automated clamps (such as roller, slide, and pinch clamps) and purchase one that integrates best with the client's setup (would likely require a further design matrix). One feature that would be important for consideration when selecting the clamp is its ability to be integrated into the client's framework, both electronically and mechanically.

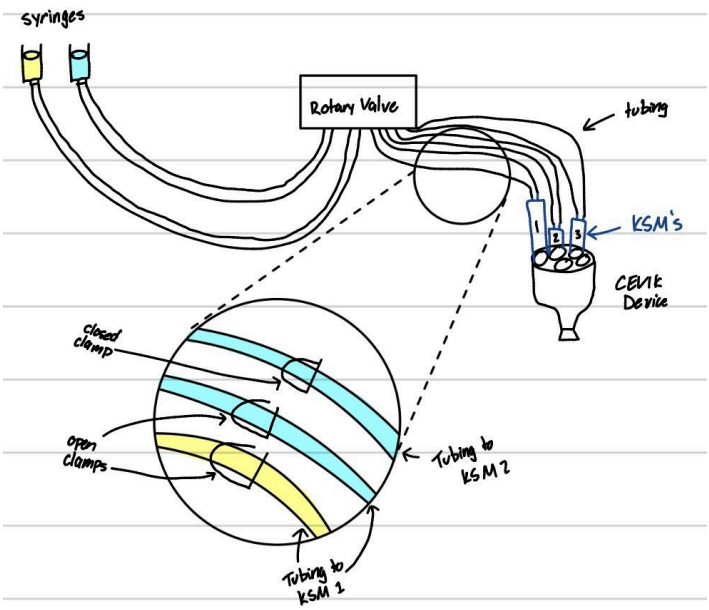

Figure 4: *Design 1 preliminary design sketch*

3.2 Design 2 - Integrated Rotary Element (IRE)

The IRE is a circular, uniform, disk of 25 mm. The IRE's purpose is to regulate which KSM deposits its output at a given time. One feature of this design is its ability to rotate itself to allow one KSM at a time to deposit its fluid output (as evidenced by the singular hole depicted in Figure 2). If fluid output is needed from another KSM, the IRE can rotate to that KSM. This design excels in automating which KSM deposits fluid, which could allow for the client to print unique vascular patterns.

The IRE design is also customized with toothed edges for utilization with a Servo Motor which can be programmed through an Arduino for automation. However, the continual rotation of the IRE within the CEVIC raises initial concerns about potential internal shear degradation to the CEVIC. Additionally, due to tight space restrictions in the CEVIC, the CEVIC might have to be redesigned to allow the IRE to fit and function properly with gears.

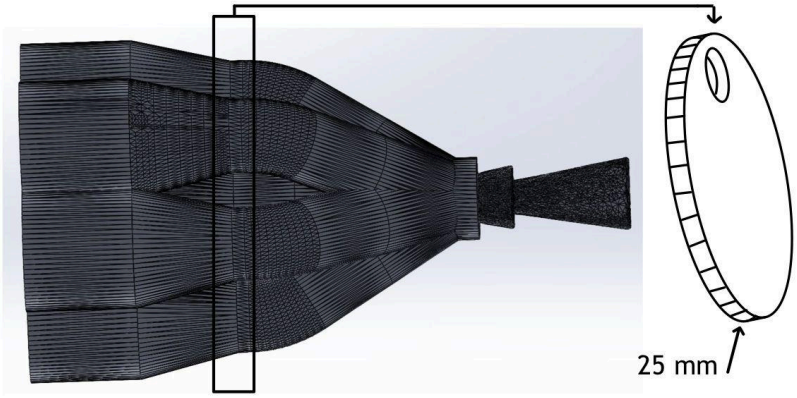

Figure 5: *Design 2: IRE CAD drawing*

3.3 Design 3 - Flow Diversion System

The Flow Diversion System is a systematic design idea that directs fluid flow throughout the system. The main feature of the FDS is the 3-way valve, which has 2 distinct positions:

1. Waste → directs fluid from syringe pumps & rotary valve to a waste vessel.
2. KSM → directs fluid from syringe pumps to appropriate KSMs to be printed.

These two positions enable the operator to direct the system to control how fluid is utilized. For example, if the fluid did not have an appropriate pattern or contains bubbles, the FDS can redirect that undesirable fluid to waste while preserving the remaining fluid. One benefit of this system is its ability to precisely control fluid direction. However, switching the valve consistently may lead to diminished quality of printed hydrogels due to disruptions in the fluid flow when fluid needs to be redirected. Additionally, fabricating the valve to work with small volumes might be challenging.

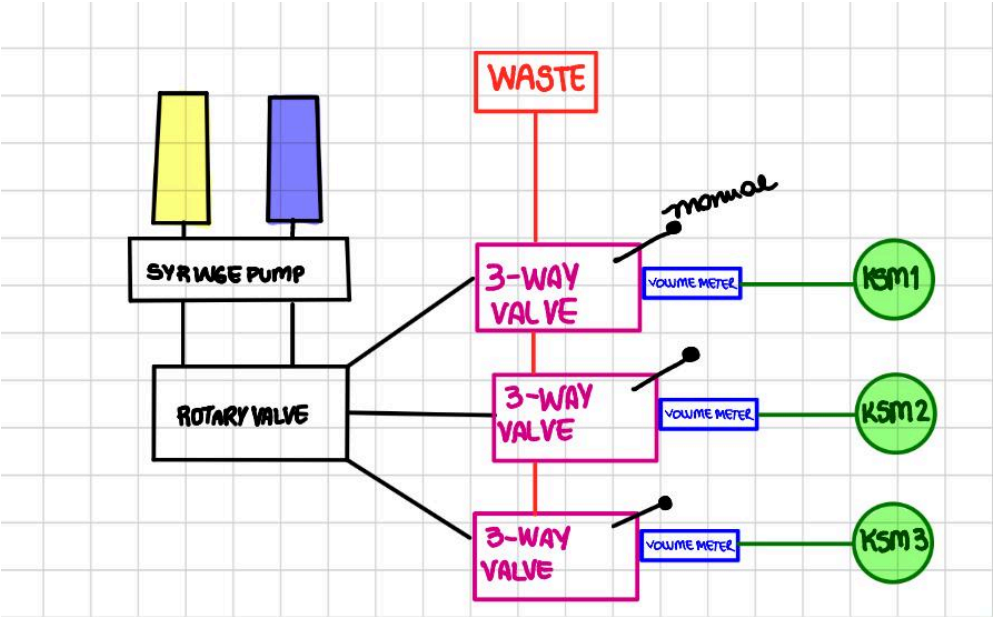

Figure 6: *Design 3 preliminary design sketch*

4 PRELIMINARY DESIGN EVALUATION

4.1 Design Matrix

Table 1: Design Matrix *- Compares all three design ideas scored across six categories with the weight of each determined by the client's need and team's values.*

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

Summary of Design Matrix

The three designs were assessed on seven criteria, with Maintenance of Pattern & Resolution, and Automation being weighted the highest. Maintaining Pattern & Resolution was defined as how well the device would print the hydrogel in the designated pattern. This ranked highly because achieving high resolution and structural integrity is integral for the project. This can also serve as a quality control check to evaluate the designs and minimize quality issues in the final hydrogel (i.e. presence of bubbles, fluid leakage or backward flow, disrupted

vasculature, etc.). The design being automatable is also very important because a client requirement is that the final design is automated. Automobility refers to how easy it is for the team to automate each design. Other criteria of importance include durability, ease of fabrication, and maintenance of workflow. Durability refers to how the CEVIC device and valve is affected over many uses. The design should not degrade rapidly with repeated use, especially since the client expects to frequently use the CEVIC device. Ease of fabrication assesses how feasible it is for the team to manufacture the design, and scored lower than Maintenance of Pattern & Resolution and Automation because the team can incorporate a new valve shutoff mechanism or change the design or process of the pre-existing CEVIC device in order to explore alternative ways to control flow. Maintenance of Workflow is defined as how seamless it is to integrate the team's design into the client's current framework. This provides easier integration of the design, however the client's workflow can be changed if necessary, so this was not weighted the highest. Finally, safety and cost are weighted the least because they are important to take into consideration, but the safety and cost of the team's designs are all similar.

The Clamp design scored the highest in Maintenance of Pattern & Resolution and Ease of Fabrication because there is no effect by the clamps on how the KSMs and CEVIC device operate, and not much modification needs to be done to the current set-up because the clamps go on the tubes between the rotary valve and the KSMs. Other designs would require more modification to the tubes or the CEVIC device itself, and this is a more complex fabrication procedure, and could affect the output hydrogel's pattern and resolution. The Internal Rotated Element scored highly in multiple categories, but is more complex when considering modifications to the client's current workflow. The Flow Diversion System scored the lowest of

all designs because it is more complex to fabricate and automate, and may affect the output hydrogel pattern and resolution more than other designs.

4.2 Proposed Final Design

The Clamp design scored the highest overall of all designs, and maintains the pattern & resolution of the hydrogel the best, is straightforward to fabricate, and maintains the client's workflow the most. This design beat the Internal Rotated Element by one point, and this design scores highly in automation, ease of fabrication, safety, and cost. Since each design has unique strengths and weaknesses, the team will prototype and test each design, and evaluate how they function.

The Clamp Design and Internal Rotated Element will be 3D printed using Formlabs Clear Resin. The designs will also incorporate other parts, including IV clamps, a programmable motor, tubing, and other necessary components.

5 DEVELOPMENT PROCESS

5.1 Materials

The following materials and components will be used to fabricate the shutoff valve: the KSMs, CEVIC devices, and Design 2: IRE will be printed from Formlabs BioMed Clear Resin available in the Grainger Engineering Design Innovation Lab [12]. Design 1: Clamps, will use the following: up to 12 small programmable pinch clamps, an Arduino Uno, a breadboard, wires, resistors, and other standard electrical components, either available through the UW Makerspace or leftover from bioinstrumentation classes [13]. Design 2: IRE, will use the following: a Servo motor, an Arduino Uno, a breadboard, wires, resistors, and other standard electrical components, either available through the UW Makerspace or leftover from bioinstrumentation classes [13].

For testing, the following materials will be used: two 20 mL syringes, a KD Scientific 200 Dual Syringe Pump [14], 1/16” OD silicone tubing to connect the syringes to the KSMs, GelMa 3%, sodium alginate 2%, LAP 0.1%, $CaCl_2$, Hydroxy ethyl cellulose (HEC), and DI water. All of these are available either through the Biomedical Engineering Teaching Lab or through the client.

5.2 Methods

The KSMs and CEVIC devices, in addition to Design 2: IRE, will first be designed/augmented in a 3D modelling program such as SolidWorks or AutoCAD. These 3D files will then be exported and printed on a Formlabs printer in the Makerspace with no internal supports to ensure that the interior geometry of the parts remains intact. The parts will undergo post processing such as removing supports and sanding rough edges before being assembled together.

The electronics required for each design will first be modelling using LTSpice or similar software, then built using a breadboard, wiring, and applicable electronics components to test functionality. Once a final design is confirmed, electronics will be soldered down and placed in an electronics box for containment and aesthetics.

Once 3D printing and electronics are complete, the designs will be assembled by hand and move on to testing. The following tests will be performed to evaluate the performance and safety of the product: Computational Fluid Dynamics (CFD) validation and performance testing, durability testing, cytotoxicity testing, and sterilizability testing. Note that electronics will be disconnected from the units for destructive testing. See the "testing" section below for more details about each test.

5.3 Testing

CFD validation will occur in tandem with prototype design and fabrication. It will confirm that flow through the KSMs, CEVIC, and shutoff valve is plausible and provide information on the type of flow within each component. It will also allow for optimization of flow velocities and pressures without physical testing.

Performance testing will evaluate the device to determine if it meets the following client requirements: The shutoff valve can seamlessly switch between KSM resolutions, the shutoff valve and switch between KSM fluid without human intervention, the resulting vascular networks must maintain their resolutions, the resulting vascular networks must maintain their alternation pattern, and the shutoff valve must limit dead space. Performance testing includes printing 5 hydrogel sheets as the researchers would, using two 20 mL syringes, a syringe pump, a CEVIC, the shutoff valve, and up to six KSMs. One syringe contains GelMa and alginate, and

the other syringe contains fugitive ink. For each of the five tests, the researcher will note any difficulties with automatic switching of the shutoff valve. The resulting hydrogel will be inspected using a microscope for alternating patterns and resolutions. These hydrogels will be compared to the client's hydrogels produced from the existing setup.

Durability testing will evaluate the device's ability to meet the following client and design requirements: The device must be able to operate for 5 minutes per hydrogel sheet, and print multiple hydrogel sheets per hour. Durability testing of 100 cycles (defined below) will be performed on 5 test units per design. Test evaluation will be performed by visual inspection and tensile/compressive testing following the durability test cycles. Additionally, 5 control units per batch will be evaluated using the same visual inspection and tensile/compressive testing. For Design 1: Clamp, a cycle is defined as a clamp opening and closing one time. The test unit is defined as one tube and one clamp. For Design 2: IRE, a cycle is defined as a full 360^{o} turn, and a test unit is defined as one CEVIC and IRE pair. In order for the units to pass the visual inspection, there should be no visible indications of wear and tear, such as scrapes, kinks, divots, or particulates. In order for the units to pass tensile/compressive testing, there must be no statistically significant difference in tensile strength between the control parts and the test parts.

Sterilizability testing will evaluate the device to determine if it meets the following client requirement: The shutoff valve must be sterilizable via UV. Sterilizability testing is not required for Design 1: Clamp, because no components of the design come into contact with the bio-ink. Sterilizability testing will test 5 units of Design 2: IRE through 5 cycles of UV sterilization. The units will be evaluated with visual inspection and their compressive strength will be evaluated against 5 control units. In order to pass visual inspection, the parts must not show any visible signs of stress or deformation, such as cracking or warping. In order to pass compressive testing,

the parts must have no statistically significant difference in compressive strength from the control parts.

6 CONCLUSION

In conclusion, tissue engineering is a growing field with broad potential. However, a universal problem is the need to vascularize engineered tissues for necessary perfusion. “Chaotic printing” of hydrogels using KSMs and a CEVIC device can print hydrogel sheets down to these resolutions, but a problem remains in switching between these resolutions while printing to imitate how arteries decrease in diameter to capillary size. For this reason, two designs were brainstormed, one consisting of clamps and the other of an internal rotary device, which will seamlessly shut off one valve and open another. Future work includes fabricating these designs and testing them to ensure they meet client requirements.

7 REFERENCES

[1] P. Chandra, S. Soker, and A. Atala, “Tissue Engineering: Current Status and Future Perspectives,” in *Principles of Tissue Engineering*, 2020.

[2] Ryan Hooper, Caleb Cummings, Anna Beck, Javier Vazquez-Armendariz, Ciro Rodriguez, and David Dean, “Sheet-based extrusion bioprinting: a new multi-material paradigm providing mid-extrusion micropatterning control for microvascular applications,” *Biofabrication*, vol. 16, no. 2, p. 025032, Mar. 2024, doi: https://doi.org/10.1088/1758-5090/ad30c8.

[3] “Organ Donation Statistics | organdonor.gov.” Accessed: Sep. 18, 2025. [Online]. Available: https://www.organdonor.gov/learn/organ-donation-statistics

[4] E. C. Novosel, C. Kleinhans, and P. J. Kluger, “Vascularization is the key challenge in tissue engineering,” *Adv. Drug Deliv. Rev.*, vol. 63, no. 4, pp. 300–311, Apr. 2011, doi: 10.1016/j.addr.2011.03.004.

[5] M. Lovett, K. Lee, A. Edwards, and D. L. Kaplan, “Vascularization strategies for tissue engineering,” *Tissue Eng. Part B Rev.*, vol. 15, no. 3, pp. 353–370, Sep. 2009, doi: 10.1089/ten.TEB.2009.0085.

[6] S. V. Murphy and A. Atala, “3D bioprinting of tissues and organs,” *Nat. Biotechnol.*, vol. 32, no. 8, pp. 773–785, Aug. 2014, doi: 10.1038/nbt.2958.

[7] J. Diehm, V. Hackert, and M. Franzreb, “Configurable 3D Printed Microfluidic Multiport Valves with Axial Compression,” *Micromachines*, vol. 12, no. 10, p. 1247, Oct. 2021, doi: 10.3390/mi12101247.

[8] J. Gong, Q. Wang, B. Liu, H. Zhang, and L. Gui, “A Novel On-Chip Liquid-Metal-Enabled Microvalve,” *Micromachines*, vol. 12, no. 9, p. 1051, Sep. 2021, doi: 10.3390/mi12091051.

[9] J. D. Graham, “David Dean,” College of Engineering - University of Wisconsin-Madison. Accessed: Oct. 14, 2025. [Online]. Available: https://engineering.wisc.edu/directory/profile/david-dean/

[10] “Laboratory Temperature and Humidity Requirements & Compliance | Primex,” OneVue Sense. Accessed: Sep. 18, 2025. [Online]. Available: https://onevuesense.primexinc.com/blogs/onevue-sense-blog/laboratory-temperature-humidity-requirements

[11] “Oxygen Shutoff Valve, w/ Locking Handle,” Jorgensen Laboratories. Accessed: Sep. 18, 2025. [Online]. Available: https://jorvet.com/product/oxygen-shutoff-valve-w-locking-handle/

[12] “3D Printers,” Grainger Engineering Design Innovation Lab. Accessed: Oct. 14, 2025. [Online]. Available: https://making.engr.wisc.edu/equipment/3d-printers/

[13] “Materials for Sale,” Grainger Engineering Design Innovation Lab. Accessed: Oct. 14, 2025. [Online]. Available: https://making.engr.wisc.edu/minimarts/

[14] “KD Scientific 200 Dual Syringe Pump,” The Lab World Group. Accessed: Oct. 14, 2025. [Online]. Available: https://www.thelabworldgroup.com/product/kd-scientific-200-dual-syringe-pump/

8 APPENDIX

8.1 Product Design Specifications

Function

On any given day, over 100,000 people in the United States are waiting for a life saving organ donation [1], [2]. The need for organs far exceeds the amount of organs donated per year. Because of this, many researchers are looking towards tissue engineering to fill the demand for transplants, as well as tailor them to a patient's specific needs. One of these methods is known as "bioprinting," which is the use of viable cells, biomaterials, or biomolecules in a 3D printer [3].

Within bioprinting there exist several methods, one such is "chaotic printing." Chaotic printing is a bioprinting strategy utilizing a kenics static mixer (KSM) to produce alternating channels of high resolution filament (less than 10 μm in width). These KSMs can be combined with a Continuously Extruded Variable Internal Channeling, or CEVIC, device to extrude these high resolution hydrogels into sheets while maintaining the alternating channel structure of chaotic printing. It should be noted that both the KSM and CEVIC devices are patent-pending [3].

Currently, the CEVIC devices can autonomously print hydrogel sheets of one resolution. If multiple resolutions from multiple KSMs are needed, the inputs must be manually changed. This takes time for the researcher and does not allow for a seamless transition between hydrogel channel resolutions. Therefore, the purpose of this project and the function of the device is to be an automatic valve to seamlessly shut off or switch between KSM outputs, and therefore hydrogel resolutions, ideally programmed so as to not need an operator.

Client requirements

The client has the following requirements:

- The shutoff valve can seamlessly switch between KSM resolutions.
- The shutoff valve can switch the KSM fluid without human intervention.
- The resulting vascular networks must maintain their resolutions (from 10 micrometers at the smallest to 1 millimeter at the largest).
- The resulting vascular networks must maintain their alternating pattern.
- The shutoff valve must limit dead space.
- The shutoff valve must be low shear on the cells passing through.
- The shutoff valve must be sterilizable via UV and autoclave and must withstand the following for 15 minutes:
    - 121°C [4]
    - 15 psi [4]
    - 100% humidity [4]
- The shutoff valve material must be biocompatible.

Design requirements

1. **Physical and Operational Characteristics**
    a. **Performance requirements:** The CEVIC device enables the fabrication of hierarchical, branching channels with continuous gradients in geometry and materials, effectively mimicking natural microvascular networks. Its main advantage is precise structural control, but the microvalve's slow opening (around 9.2 seconds for a 30 degree valve) due to pressure drop and oxide buildup limits rapid, dynamic switching in bioprinting [3]. The syringes must operate at a rate of 1 milliliter per minute and 0.5 bar. The kenics static mixers should be able to mix GelMA and HEC fugitive ink to ultimately form a consistent, cohesive striated composition pattern that can be printed. The KSMs should also be able to maintain a watertight seal when attached to the valve rotary. The valves near the KSMs should be able to shut on/off to allow the appropriate mixture compositions to be printed. The final fluid mixture is then transported to the nozzle output and should be able to extrude between 8 to 512 channels between 10 and 30 micrometers.

    Printing can occur via an automated or manual process. In the automated version, pumps operate at a rate of 3.3 millimeters per second. In this setup, LabVIEW controls 2 rotary valves that switch between KSMs to control printing time and overall fluid composition. The automated electric rotary valve should be able to direct fluid to its appropriate KSM. In the manual process, the user must manually operate a stopcock on the valves to maintain hydrogel flow between KSMs without interruption.

    b. **Safety:** The valve should be removable for sterilization purposes after each use. The manually operated valves should prioritize ergonomic design to ensure safe clamping and minimize potential injury risks during use. To reduce risk, the design should minimize direct contact with device components. A programmed pause feature can also be incorporated, allowing the user to safely adjust the equipment without concern of automated parts moving. The components should also be able to withstand autoclave temperatures. Proper precautions should be implemented to minimize safety risks in accordance with ISO 14971, 62366.

    c. **Accuracy and Reliability:** The system should be able to operate with a high degree of precision and accuracy, given that capillary sizes are small (μm range) the morphology of the printed biomaterial is directly correlated to its function. The hydrogels undergo a sodium alginate and $CaCl_2$ reaction to cure the hydrogel, ensuring its structural integrity and durability.

    A 10 percent error between measured and theoretical channel widths, which stresses the importance of incorporating valve shutoff mechanisms to avoid depositing too much/little bioprint fluid. Additionally, it is critical to expose the hydrogel to $CaCl_2$ while it prints to help improve thickness uniformity and minimize disruptive channel flows.

    Finally, transition lengths between varying channel number regions were around 1 centimeter [3]. However, decreasing the fluid output rate and automating the valve switch could help achieve reduced transition lengths which would enhance the reliability of the hydrogel.

d. **Life in Service:** The device must be able to operate for 5 minutes for each hydrogel sheet. Over time the device should be able to print multiple hydrogels per hour.

e. **Shelf Life:** The shutoff valve is expected to maintain reliable performance for approximately 5 years.

f. **Operating Environment:** Materials must be biocompatible in accordance with ISO 10993 and capable of withstanding operating temperatures up to 70 degrees celcius. Standard laboratory conditions will apply during use, with ambient temperatures maintained between 20 and 25 degrees celsius and relative humidity in the range of 35–50 percent relative humidity, as recommended for controlled laboratory environments [5].

g. **Ergonomics:** Valves should be designed to minimize shear stress on the materials passing through and must allow intuitive manual operation with a controllable flow rate as low as 1 milliliters per minute [3]. The motors controlling the valves should be able to be neatly and compactly integrated within the device to prevent interference with biological samples and to isolate electrical components from user contact.

h. **Size:** The KSMs are about 12 centimeters in height and 1 centimeter in diameter, with channel flow rates ranging from 1 to 1.5 milliliters per minute. It is important to account for physiological dimensions, including artery and capillary diameters, as well as the distance between capillaries and cells in the body. The smallest arteries measure roughly 150 microns in diameter, while the smallest capillaries are approximately 10 microns [3]. A capillary must be within 50 to 70 microns of every cell in the body in order for the cell to have sufficient blood flow. Accordingly, the CEVIK device must be able to print within these dimensional constraints. The current manual valve to select the channel the bioink flows through is 16 centimeters in width and the current automatic valve to select the KSM is 5 centimeters in diameter [3].

i. **Weight:** The shutoff valve, positioned around either the manual or automatic rotary valve, should not exceed 10% of the total system weight. This restriction ensures that the valve remains sufficiently lightweight to operate effectively without compromising the performance of the mechanical components [6].

j. **Materials:** The CEVIK device and KSM are fabricated using clear biocompatible resin. The material selected for the shutoff valve must be chemically compatible with this resin, ensuring that it does not cause degradation or alter its properties. A solution of 3 percent GelMA and 2 percent sodium alginate is usually heated to allow it to flow through the KSMs [3].

k. **Aesthetics, Appearance, and Finish:** The shutoff valve should integrate seamlessly with CEVIK machine and any relevant connected components without causing excessive wear or interfering with functionality.

2. **Production Characteristics**

a. **Quantity:** The client requires only 1 to 2 units. For testing purposes, 5 units will be produced to support the testing requirements. The testing protocol will involve repeating experiments with the same prototype across multiple runs to ensure reliable and statistically meaningful results.

b. **Target Product Costs:** The total budget is $500, with a target cost of $15 per unit. Most expenses are expected to arise from 3D printing materials, with some additional electronic components purchased separately. The actual production cost for 5 units, estimated at $75, is projected to remain well below the allocated budget.

3. **Miscellaneous**

a. **Standards and Specifications:** Production and testing will follow established standards to ensure accuracy, safety, and regulatory compliance. The protocols and reference materials described below define the requirements for fabrication, measurement, and validation of the prototypes. Fluidic resistance measurements follow standard protocols using pressure steps (5 and 10 milibar) with controlled flow intervals (30 seconds), employing ISO-calibrated instrumentation such as the Druck DPI520 pressure controller and Sartorius MC1 LP620P scale, ensuring traceability and compliance with ISO 9001 and ISO/IEC 17025. EN-ISO 10993-1:2009/AC:2010 (Class I Biocompatibility) is referenced for guaranteeing biocompatibility and safety for direct or indirect biological contact, which is critical for cell culture applications and potential medical device use.

b. **Customer:** The client prefers that the valve be programmable to run for different combinations KSM, thereby reducing operator time and effort.

c. **Patient-related concerns:** This device is not patient contacting, therefore there are no patient-related concerns. This device does not store any patient data. However, this device may come into contact with a cell-seeded bioink. Therefore, the material and finish of the device should be biocompatible, non-toxic and low-shear to prevent unnecessary cell death and cell rupture.

d. **Competition:** There are numerous bioprinting valve techniques that have demonstrated low leakage rates and adaptability for systems operating at resolutions as fine as 10 micrometers. The Continuous Chaotic Bioprinting of Skeletal Muscle-like Constructs produces multi-layered, multi-material filaments with microvascular channels at resolutions down to 10 micrometers, demonstrating strong potential for complex tissue architectures [7]. The chosen material, alginate hydrogels, presents a challenge as it may not be optimal for clinical translation [7]. Configurable 3D Printed Microfluidic Multiport Valves with Axial Compression use stepper motor control for precise, automated switching, with no leakage in static tests and less than 0.5 percent in dynamic use [8]. The testing configuration used 800 micrometers channels, which are relatively large, raising uncertainty about performance at the smaller sizes needed [8]. The novel on-chip liquid-metal microvalve enables precise directional control of fluid flow, with no leak detected at pressures up to 320 millibar and a leak rate of less than or equal to 0.043 microliters per minutes at 330 millibar [9]. The method does not address sequential layering or branching between K mixers, requiring adaptation for applications involving complex fluid routing [9].

Bibliography

[1] “Organ Donation Statistics | organdonor.gov.” Accessed: Sep. 18, 2025. [Online]. Available: https://www.organdonor.gov/learn/organ-donation-statistics

[2] CDC, “About Transplant Safety,” Transplant Safety. Accessed: Sep. 18, 2025. [Online]. Available: https://www.cdc.gov/transplant-safety/about/index.html

[3] Ryan Hooper, Caleb Cummings, Anna Beck, Javier Vazquez-Armendariz, Ciro Rodriguez, and David Dean, “Sheet-based extrusion bioprinting: a new multi-material paradigm providing mid-extrusion micropatterning control for microvascular applications,” *Biofabrication*, vol. 16, no. 2, p. 025032, Mar. 2024, doi: https://doi.org/10.1088/1758-5090/ad30c8.

[4] CDC, “Steam Sterilization,” Infection Control. Accessed: Sep. 18, 2025. [Online]. Available: https://www.cdc.gov/infection-control/hcp/disinfection-sterilization/steam-sterilization.html

[5] “Laboratory Temperature and Humidity Requirements & Compliance | Primex,” OneVue Sense. Accessed: Sep. 18, 2025. [Online]. Available: https://onevuesense.primexinc.com/blogs/onevue-sense-blog/laboratory-temperature-humidity-requirements

[6] “Oxygen Shutoff Valve, w/ Locking Handle,” Jorgensen Laboratories. Accessed: Sep. 18, 2025. [Online]. Available: https://jorvet.com/product/oxygen-shutoff-valve-w-locking-handle/

[7] E. J. Bolívar-Monsalve *et al.*, “Continuous chaotic bioprinting of skeletal muscle-like constructs,” *Bioprinting*, vol. 21, p. e00125, Mar. 2021, doi: 10.1016/j.bprint.2020.e00125.

[8] “Configurable 3D Printed Microfluidic Multiport Valves with Axial Compression.” Accessed: Sep. 18, 2025. [Online]. Available: https://www.mdpi.com/2072-666X/12/10/1247

[9] J. Gong, Q. Wang, B. Liu, H. Zhang, and L. Gui, “A Novel On-Chip Liquid-Metal-Enabled Microvalve,” *Micromachines*, vol. 12, no. 9, p. 1051, Sep. 2021, doi: 10.3390/mi12091051.

8.2 Expense Report

Item	Description	Manufac-turer	Mft Pt#	Vendor	Vendor Cat#	Date	#	Cost Each	Total	Link
Category 1										
	3D Printed CEVIK & 5 KSMs	N/A (3D Printed)	N/A	N/A	N/A	09/19	1		$3.48	
									$0.00	
Category 2										
									$0.00	
									$0.00	
								TOTAL:	**$3.48**	