Evaluating Fabrication Methods for Implantable Microvalves in Hydrocephalus Treatment

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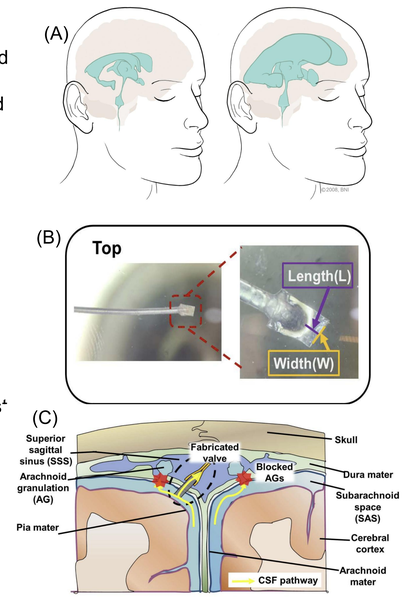
Introduction

Hydrocephalus is caused by excess cerebrospinal fluid, increasing brain pressure and risking damage if untreated [1], [2]. Shunts are the standard treatment but have high failure rates and often require revision surgeries [3], [4]. Micro implantable valves regulate flow through a set cracking pressure and preventing backflow. PDMS duckbill valves have shown promising benchtop results [5].

Material choice affects long term performance. PDMS may degrade over time, while alternative elastomers may improve durability and stiffness control [6]-[8]. However, fabrication is a major limitation for material evaluation, as most methods require cleanroom photolithography.

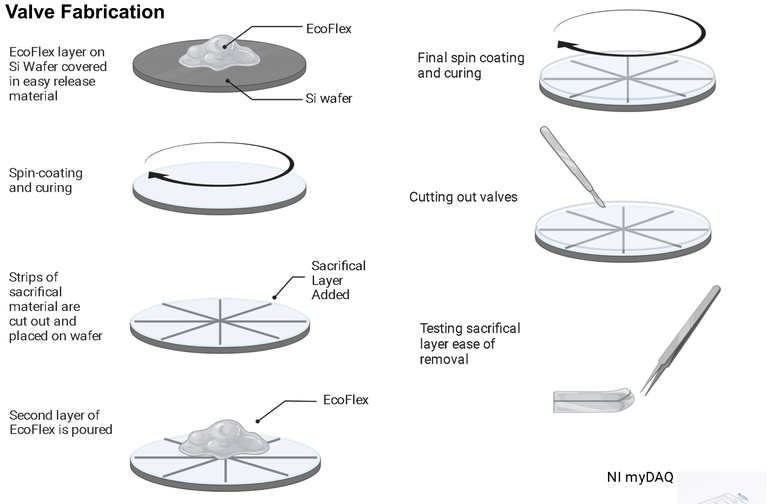
Objective:
Develop and evaluate non cleanroom fabrication methods and alternative elastomer materials for micro implantable duckbill valves.



Sources: (A) Barrow Neurological Institute [9]; (B-C) Jung et al. [5]

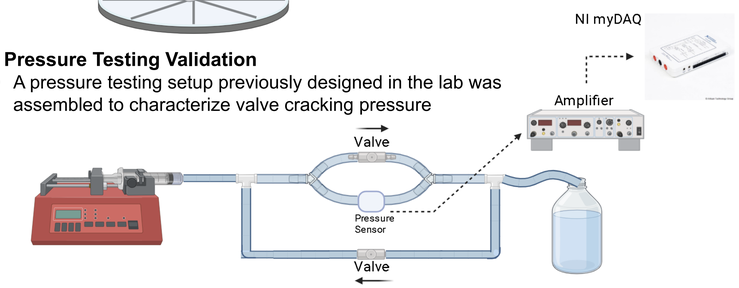
Methods

Valve Fabrication



Pressure Testing Validation

- A pressure testing setup previously designed in the lab was assembled to characterize valve cracking pressure



Results

Fabrication Outcomes
No fabrication method successfully produced a functional internal channel.
A wide range of materials and methods were tested, but all failed due to similar issues.

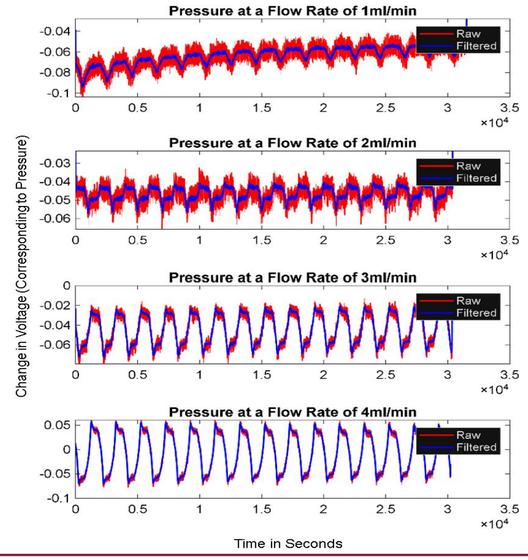
Summary of Fabrication Attempts and Outcomes

Elastomer Material	*Sacrificial Layer*	*Surface Treatment*	*Removal Method*	*Outcome*	*Observed Failure Mode*
Silicone elastomer (Ecoflex 00-30/00-50)	Low-density polyethylene (Saran Wrap)	None	Mechanical Removal, Acetone Dissolution	Failed	Could not extract material; structural damage
Ecoflex	Paraffin wax polyolefin film (Parafilm)	None	Mechanical Removal, Melting	Failed	Could not extract Parafilm; structural damage
Ecoflex	Polyvinyl acetate (PVA) adhesive (Elmer's glue)	None/Plasma	Water Dissolution	Failed	Beading of liquid; non-uniform layer; not used for channel
Ecoflex	Negative-tone photoresist (AZ nLOF 2020)	None/Plasma	Developer	Failed	Did not develop; no pattern formation
Ecoflex	Alcohol based dye ink (permanent marker ink)	None/Plasma	Acetone Dissolution	Failed	No channel formed; incomplete removal
Ecoflex	Aluminum Foil	None/Plasma/ Vaseline	Mechanical Removal	Failed	Could not extract foil; structural damage
Two-part silicone elastomer (silicone putty)	Alcohol based dye ink (permanent marker ink)	None/Plasma	Mechanical Removal	Failed	No channel formation; layers did not bond

Common Failure Modes:
- Irreversible bonding between elastomer layers, preventing channel formation
- Incomplete removal of sacrificial materials, blocking the intended flow path
- Structural damage during spacer extraction
- Poor wetting behavior of liquid sacrificial materials

PDMS Valve Pressure Testing Validation

Observed Behavior:
- Pressure increased before valve opening
- Sharp drop in pressure at opening (cracking pressure)
- Higher flow rate leads to higher pressure required
- Similar curve shape across all conditions
- Flow sensor did not give reliable readings
- Only pressure data used



Summary and Conclusions

- This project initially aimed to compare alternative materials for implantable duckbill microvalves
- During development, fabrication became the primary limitation, as non-cleanroom methods could not produce the microchannels required for valve function
- Multiple sacrificial layer and spacer strategies were tested, but none produced functional internal channels
- As a result, the project focus shifted from material testing to fabrication validation, identifying fabrication
- A benchtop pressure testing setup was also validated using PDMS reference valves, providing a platform for future valve evaluation once fabrication challenges are addressed

Future Directions

- Investigate alternative fabrication methods without requiring traditional cleanroom photolithography
- Test mold based soft lithography, laser micromachining, and high-resolution 3D printing
- Evaluate surface modification strategies to improve control of interlayer bonding
- Test material performance to compare alternative elastomers based on cracking pressure, durability, and reverse flow behavior
- Use the validated benchtop pressure testing system to assess newly fabricated valve designs and support development of scalable implantable microvalves for hydrocephalus treatment

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