Engineering a Self-Expandable Endovascular Embolization Device

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Background and Motivation

Clinical Problem. Embolizations are minimally invasive procedures performed to treat conditions such as aneurysms and hemorrhages. Metal coils are the most commonly used embolization device. Despite their accuracy and immediate action, their platinum makeup distorts radiographic images. They also allow recanalization of the target vessel. Metal coils are also expensive, require extensive training, and hospitals must stock very large inventories as different sized vessels require different sized coils. Other types of embolization devices like GelFoam are not entirely solid and can detach, increasing the chance of stroke. **(Fig. 1)**

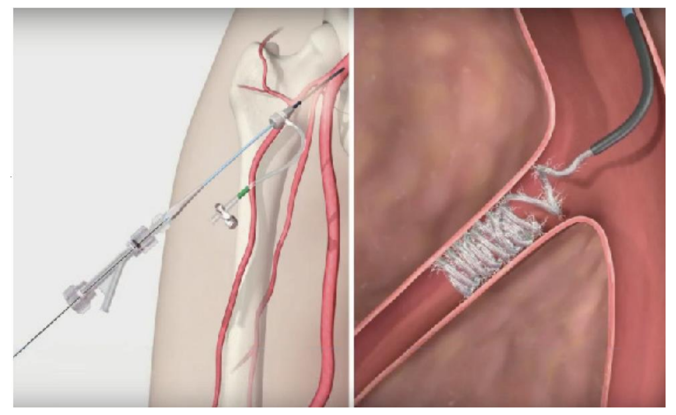


Figure 1. Standard trans-catheter embolization with metal coils.

Motivation. Transcatheter embolizations form a global market of over $2.69 billion. Given the wide variety of medical situations where embolizations are necessary, there is a pressing need to develop a more inexpensive, versatile alternative.

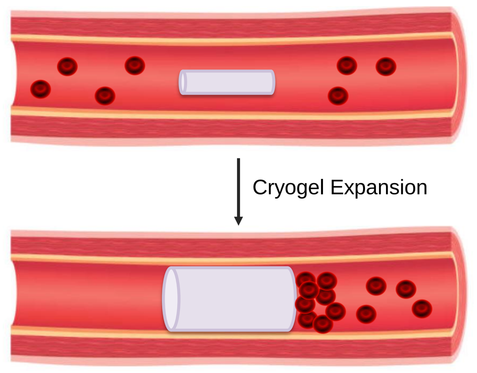


Figure 2. Schematic of our device effectively occluding a blood vessel.

Hypothesis. A macroporous alginate cryogel reinforced with polycaprolactone nanofibers and divalent crosslinks, fabricated and developed into a device with re-expansive and biocompatible properties, can effectively embolize a hemorrhage for a lower cost than current devices on the market. **(Fig. 2)**

Design Goals

Inexpensive: Improve affordability of embolization devices compared to metal coils.
Versatile: Expand the range of blood vessels a single device can occlude (every metal coil targets a specific blood vessel size)
Simple: Reduce the need for extensive training (different metal coils have different operating procedures)
Fast-Acting: Match the ability of metal coils to immediately embolize
Permanent: Match the ability of metal coils to form permanent blockages.

Methods

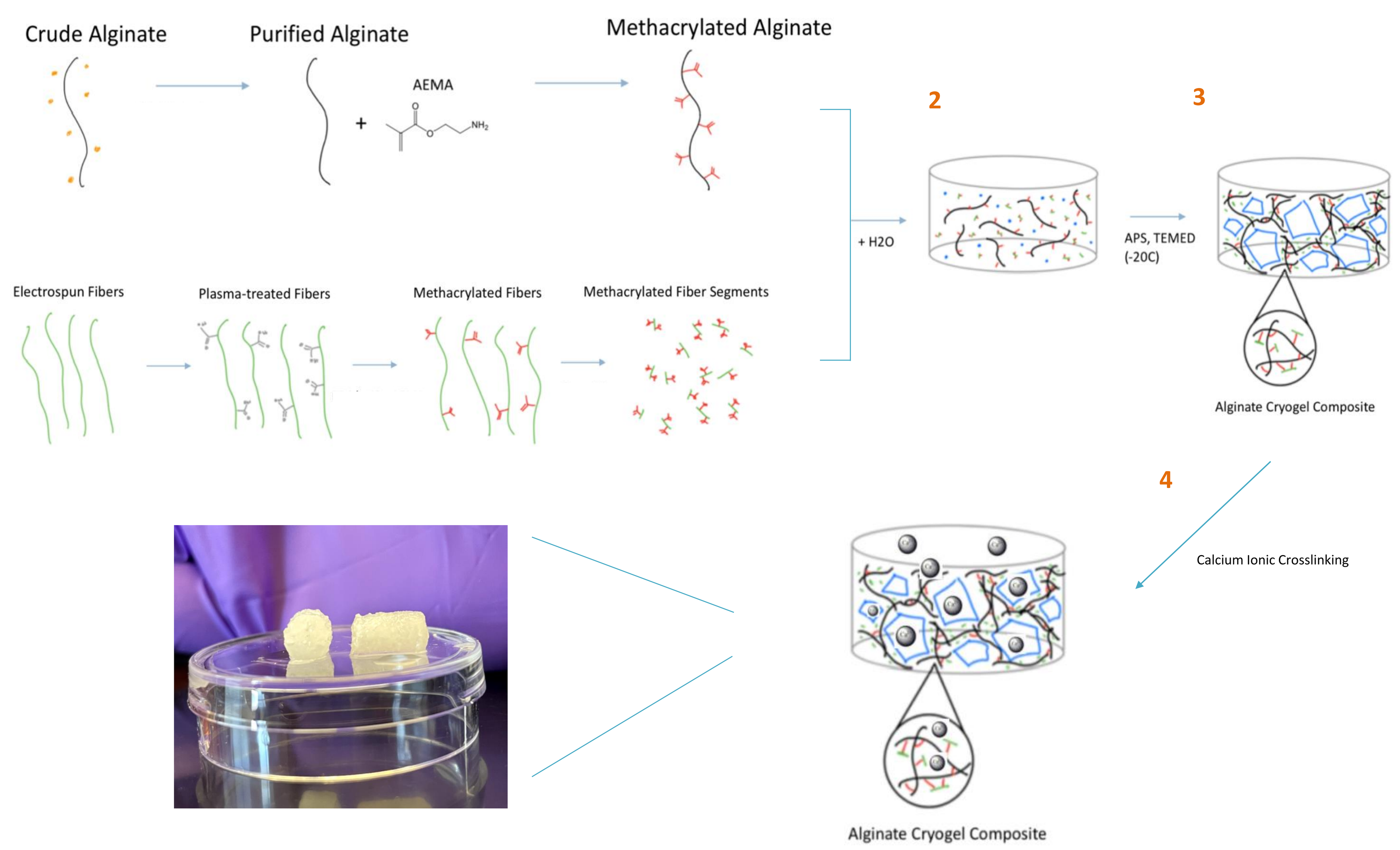


Figure 3. Basic steps of cryogel device synthesis. Crude alginate and electrospun PCL nanofibers are purified and functionalized before being crosslinked in a mold. Divalent calcium physical crosslinks are introduced as a final step.

Embolization Outcomes in a Swine Model

An immature female pig was used for the animal study. A cutdown procedure was used to access the right femoral artery **(Fig 4)**. Cryogel embolization devices were deployed using both angled and J-Tip catheters. Devices used ranged from 3mm to 5mm (diameter) x 8mm (length) in size and were soaked in glycerol prior to compression into catheter. A total of 17 devices were deployed in both the left and right renal arteries. A guidewire was used to push the devices through the length of the catheter. Iohexol was used as contrast agent.

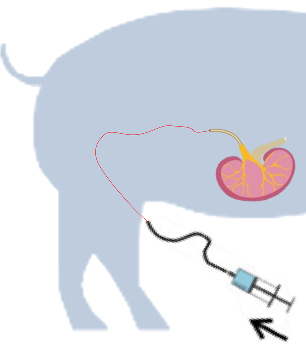


Figure 4. Graphic showing deployment route of cryogel devices through femoral artery to kidneys.

Left Kidney

Pre-embolization | Post-embolization

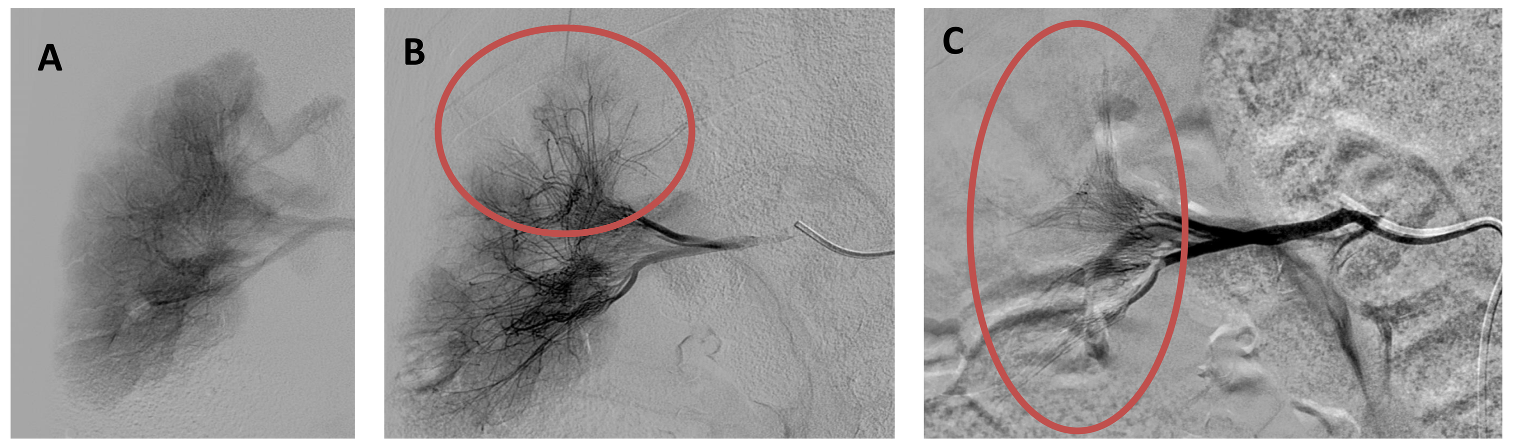


Figure 5. Left kidney before and after deployment of device. (A) Contrast can diffuse throughout cortex prior to device deployment. (B) Kidney after deployment of gel in upper renal artery. (C) Kidney after deployment in main renal artery, blocking all contrast.

Right Kidney

Pre-embolization | Post-embolization

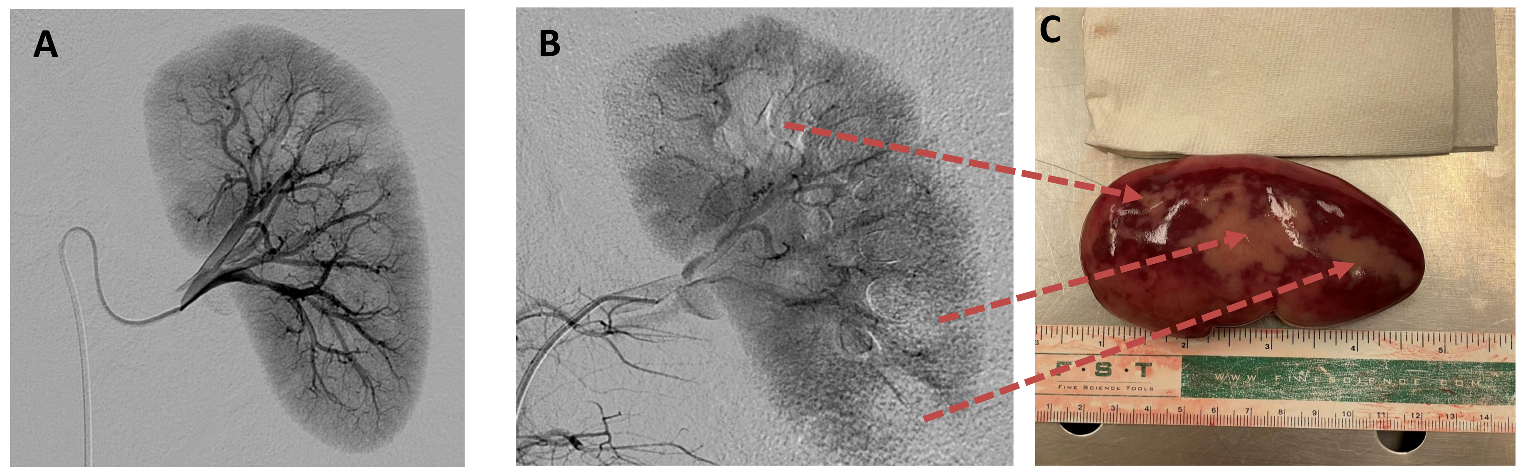
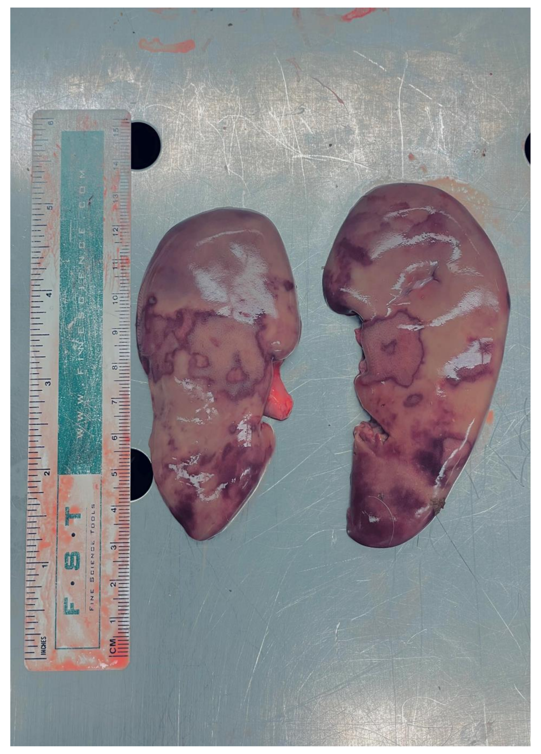


Figure 6. (A) Right kidney before and after deployment of device. (B) Kidney after deployment of devices to upper and lower renal artery. (C) Presence of discoloration consistent with acute infarction visible during gross pathology.



5 out of 5 deployments were successful in the left kidney, and 4 out of 12 deployments were successful in the right kidney. Major findings include:

- Cryogel is capable of embolization
- Device does not move once deployed (embolization is permanent)
- Cryogel is easy to deploy
- Cryogel is capable of swelling in blood

Gross pathology confirms the presence of discoloration consistent with acute infarction and significant blood clotting/pooling. **(Fig. 7)**

Figure 7. Gross pathology of left kidney. Mottled rings regions indicate infarction. Dark regions indicate blood pooling in kidney cortex.

Mechanical Properties

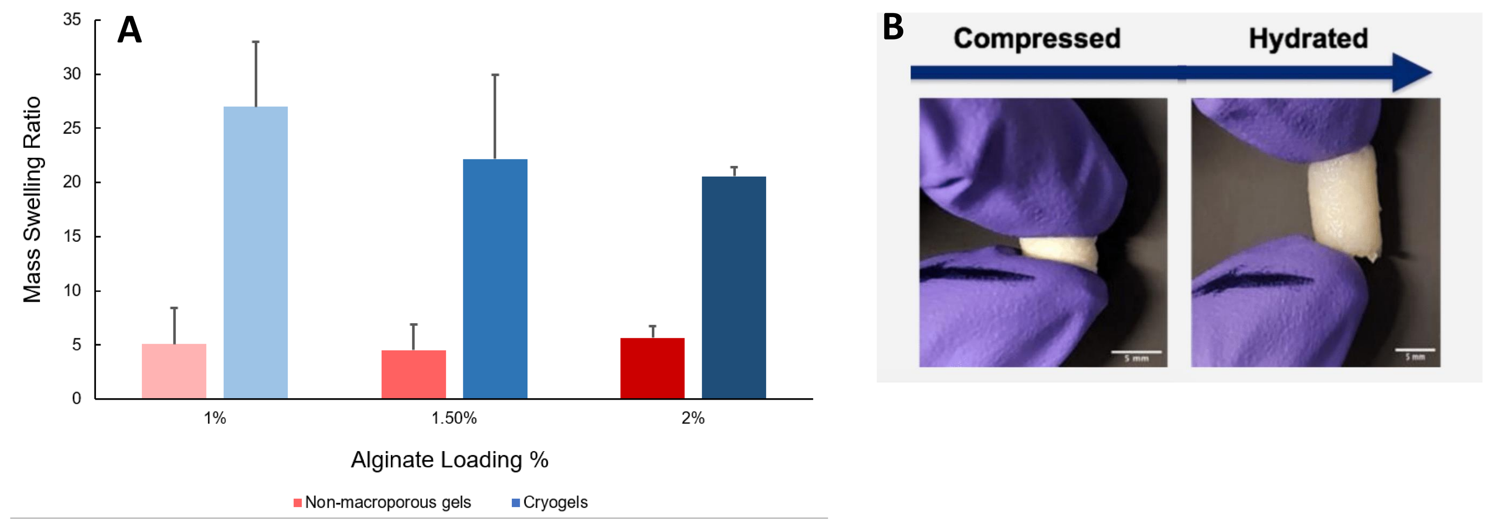


Figure 8. (A) Macroporous gel structure is necessary to achieve necessary swelling capabilities. (B) Demonstration of swelling capabilities of macroporous alginate cryogel.

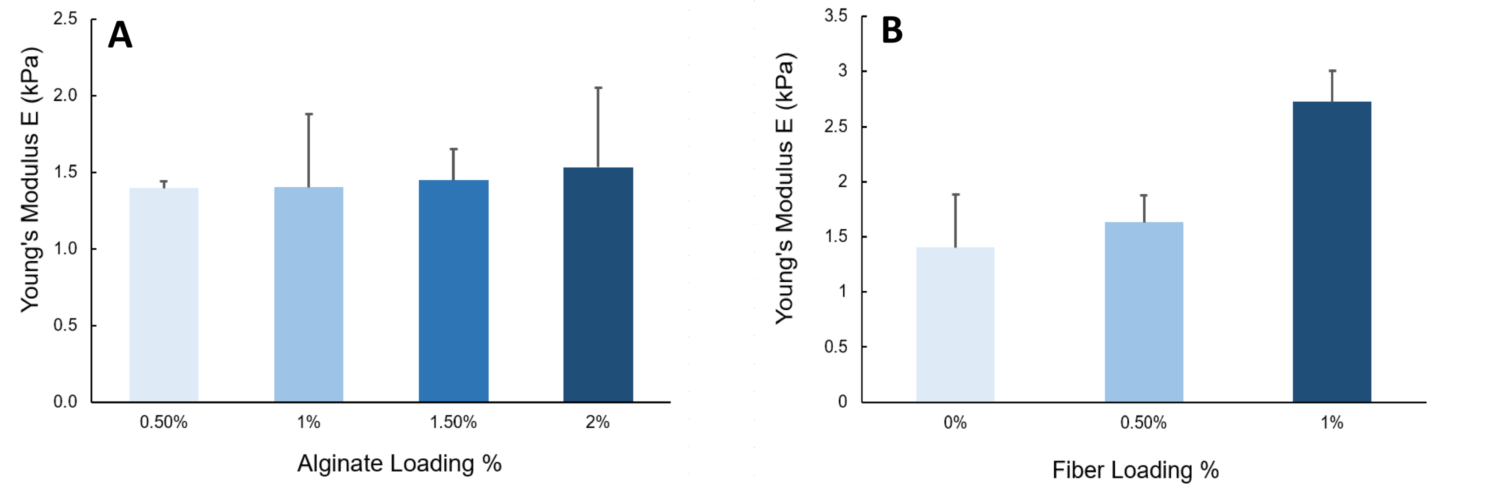


Figure 9. (A) Increased fiber loading does not increase Young's Modulus. (B) Increased PCL nanofiber loading does increase Young's Modulus.

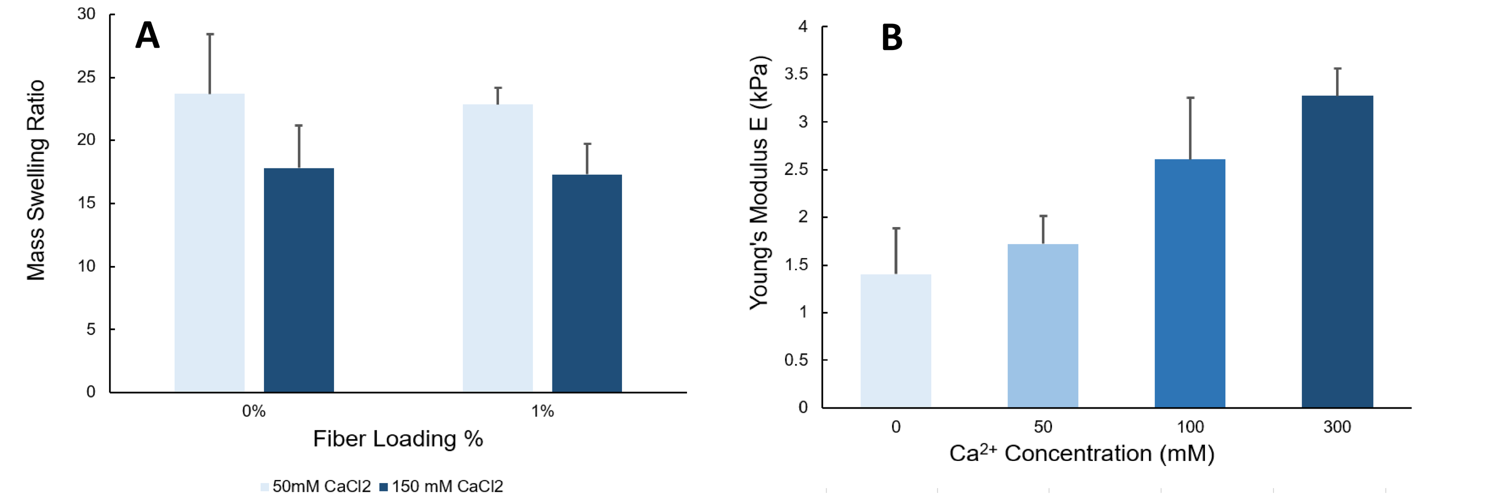


Figure 10. (A) Addition of divalent calcium cation crosslinking increases Young's Modulus. (B) Increased ionic crosslinking decreases swelling ration whereas fiber loading does not.

Conclusions and Future Directions

Conclusions:

We have successfully developed a device capable of endovascular embolization. The device is inexpensive to manufacture, versatile, swells quickly, and utilizes a simple deployment procedure. Results strongly suggest blood vessel occlusion is permanent.

Future Directions:

Additional mechanical strength would be beneficial, so modifying alginate reinforcement mechanisms should be explored. Additionally, potential uses as a drug delivery platform and topical hemostat can be explored by evaluating drug release properties and physical shape.

References and Acknowledgments

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