Innovative Modeling of Diseased Vessels

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Abstract

This project's purpose is to design and construct a reusable and anatomically accurate *in vitro* model for testing biomaterials that treat cerebral aneurysms. Unruptured brain aneurysms have various forms of treatments available. Common remedies for aneurysms, delivered via catheter, include clipping, embolization (clogging of the aneurysm), and flow diversion. In the past 20 years, endovascular embolization has become the preferred method of treatment. Northern Arizona University's Bioengineering Devices Laboratory (BDL) has focused its research on the use of biocompatible liquid-to-solid embolics. To continue advancement in this research process, it is necessary to test and validate this novel treatment with an *in vitro* model. In contrast to prior models, this model will strive to be anatomically correct. Therefore, the team will use custom synthetic vasculature, in place of glass or a two-part mold, to construct a more compliant model with properties that better mimic various types of vessels. The casting for the vasculature will incorporate a 3D printed inner core and a milled outer mold. The material used for the model is a polyacrylamide alginate composite, created in the BDL, with tunable mechanical properties. Along with the novel modeling method and material, the *in vitro* model will include a pulsatile flow, non-Newtonian fluid, and a flowmeter. With this more realistic testing regime, the biomaterial aneurysm treatment will quickly progress in the FDA approval process to produce a commercially available treatment to patients.

Project Requirements

Table 1: *Engineering Requirements*

Engineering Requirements	Target and Tolerance
Accuracy of Anatomical Measurements	±.05mm between measurements
Compliance of Vessel Material	0.4±0.2% change in diameter
Physiological Accuracy of Flows	2.5±0.5 mL/s
Physiological Accuracy of Fluid	3.5±0.5cP, 37±.2℃, Non-Newtonian (shear thinning)
Transparency of Vessel Material	Opacity of 15% or less
Accuracy of Data Acquisition	Pressure ±0.2%, Temperature ±.25%
Accuracy of Manufacturing Processes	±0.1mm from design
Size	36"x36"x24"(LxWxH)
Weight	75lbs≥

Engineering Design

Background Information

This project requires the design of a completely new *in vitro* model. This model will utilize a polyacrylamide alginate composite that can be optimized to better mimic the human body. There was no original system when this project began. The *in vitro* model will be tested following the system setup in Figure 1. A thermocouple (TC) measures the fluid's temperature, a pressure transducer (PT) measures the pressures, and a flow meter (FM) measures the flowrate going into the model. The system establishes pulsatile flow using a peristaltic pump and a set rate of bypass occlusion. The main element that changes in the system is the aneurysm vessel model.

Methods - Design Components

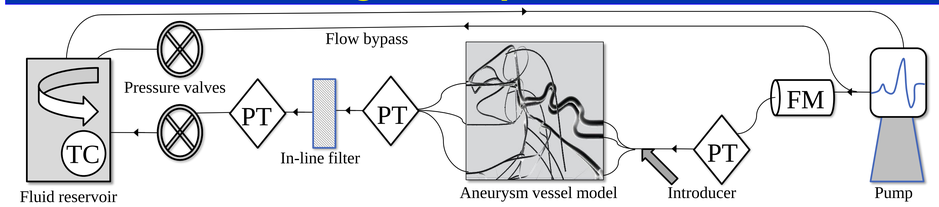

Figure 1: *In-Vitro model configuration. Model can be run in the lab or under C-arm fluoroscopy.*

This project includes an interchangeable parts design allowing for different components to be switched without interfering with the other elements. The model is the main focus of this project.

Methods - Casting

Typical methods for creating in-vitro models include glass blowing, two part mold with lost wax, and silicone tubing. This model was created using a PLA 3-D printed core, wax CNC cast, and a polyacrylamide alginate composite polymer (BAM) for the mold. The 3-D CAD and physical models of the casting assembly are provided in Figures 2 and 3, respectively, and Figure 4 shows the casting

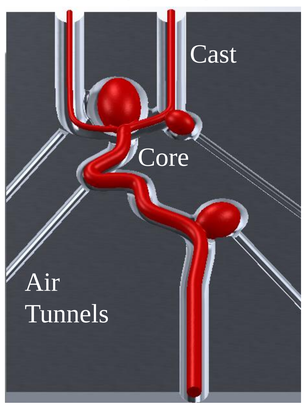

Figure 2: *3-D CAD model of casting assembly*

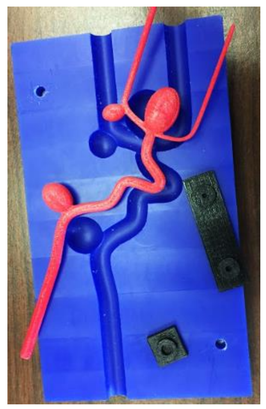

Figure 3: *Casting assembly parts*

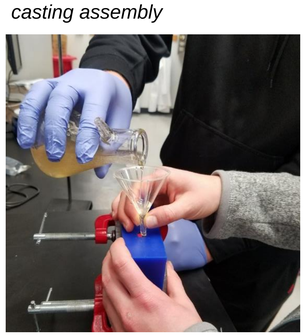

Figure 4: *Pouring polymer into casting apparatus*

Casting Procedure:

- Mix polymer
- Insert core into cast
- Insert bottom stabilizers
- Close cast around core
- Pour in polymer
- Insert top stabilizer
- Allow material to cure
- Take apart apparatus
- Remove/dissolve core
- Connect model to system

Data Acquisition

The signal amplification (SA) box, Figure 6 (with schematic), makes signals readable by the computer. The received signals are processed in LabView, then displayed, as shown in Figure 5. Common human values from the PT's, TC and FM were created.

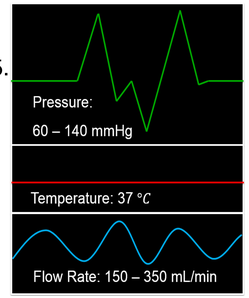

Figure 5: *Data Collected*

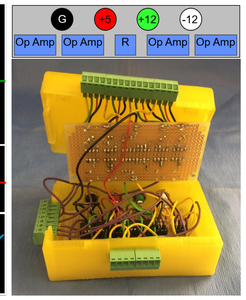

Figure 6: *Inside of SA Box*

Model Fluid

Currently DI water is the industry standard fluid for modeling blood through a vessel. CMC was used to more accurately model the properties of blood [1]. The Rheometer HR-2 was used to test the viscosity and shear rate of the samples. Figure 7 displays the comparison with Di water, blood, and different CMC compositions.

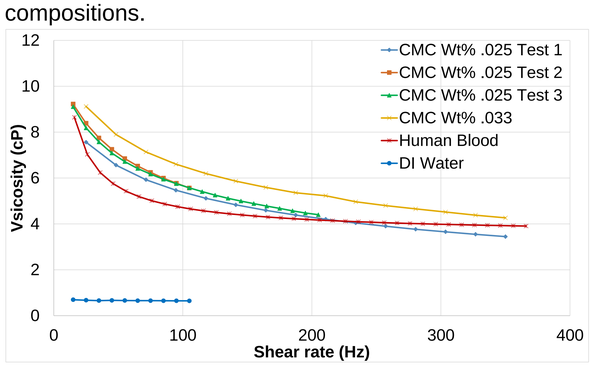

Figure 7: *Viscosity vs. shear rate*

Results - Casting

After numerous attempts, casting with BAM material was unsuccessful. Further work requires continued casting trials with the BAM material. Casting with ClearFlex 50 in a two-part and casted model did work but the model is not physiologically accurate. This model will be used until a more accurate model is casted.

Figure 8: *Data Collected.*

Discussion

This is a functional model that can be used for the intended purpose of aneurysm blocking device testing. The model includes three aneurysms that are of various sizes that are comparable to typical human aneurysms. They are also located in common locations along the vessel that are common with patients. This allows for the doctor testing their devices to experience finding and treating the aneurysm in an atomically/physiologically correct environment without biometrics.

Conclusions

The material used for casting includes more minor alterations in order for it to be suitable for the use in this design. Future research on this project will heavily rely on improving the model. Originally the cast was made of the PLA and CNC milled. In order to heat the material after pouring a metal cast was the best option. Stainless steel is the best choice but aluminum was used in this case to elevate the cast. Next the removal of the core was improved. In the beginning we broke the small arms of the core off and pulled it out. Then we tried dissolving the core which allowed it to become pliable and easily slide out of our model but severely dehydrated the model. Submerging in water rehydrated the model and returned it to its original state.

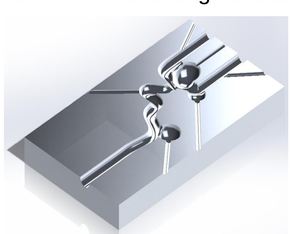

Figure 9: *Metal block*

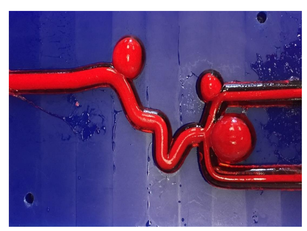

Figure 10: *Casted vessel*

References

[1] Vimmr, Jan, and Alena Jonasova. "Non-Newtonian Effects Of Blood Flow In Complete Coronary And Femoral Bypasses". *Research Gate*. N.p., 2009. Web. 14 Apr. 2017

Acknowledgments

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