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Design and Implementation of a Cerebral Aneurysm Rupture Phantom

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INTRODUCTION

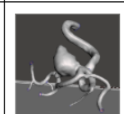
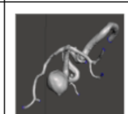
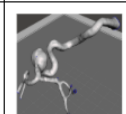
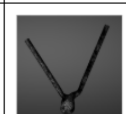
When a cerebral aneurysm ruptures and bleeds into the brain or surrounding area, hemorrhagic stroke occurs. This life-threatening event has a 50% mortality rate, resulting in half a million deaths worldwide each year [1]. Unfortunately, 66% of the patients who survive a ruptured cerebral aneurysm still suffer permanent neurological deficits [1]. There is a lack of physical models (laboratory phantoms) that can realistically mimic the biomechanical behavior of aneurysms during rupture. To better understand the aneurysm rupture mechanics, this study focuses on the design and implementation of a cost-effective and easy-to-fabricate phantom using a 3D printing technique. To facilitate a predictable rupture event in the phantom, we utilized a computational model to find the weak spots and adjusted the wall thickness, mimicking wall thinning phenomena [2]. This phantom model can also be used to validate computational models, test stent and coil devices, and provide surgical training.

METHODS

Geometry Identification. Aneurysm models from the Aneurisk dataset repository were employed—specifically, Cases 36, 39, and 42. MeshMixer was used to simplify the geometry file. A 3.175 mm diameter cylinder was created to simplify the inlet and outlet for easy fabrication and position. The geometry was then hollowed, and the vessel wall was thickened to 0.55 mm. These models were then meshed in Ansys Mechanical to be prepped for Computational Fluid Dynamics (CFD) analysis.

CFD analysis was then performed on the models to find several essential properties contributing to aneurysm rupture, such as mean velocity, wall shear stress (WSS), and average pressure. The analysis aimed to identify areas of flow diversion to manually weaken the vessel's walls at overlapping points of higher pressure and wall shear stress. The program chosen for analysis was Ansys Fluent; the vessel's walls were treated as no-slip rigid walls. The blood flow within the models was treated as a transient pulsatile flow of a non-Newtonian fluid with a density (ϱ) of 1060 kg/cm^3 and a Carreau viscosity model (μ) of 0.0035 Pa·s. At the identified points, the models were weakened by creating 4 mm spherical imprints in the inner vessel wall at distances of 0.4 mm, 0.45 mm, and 0.5 mm. The resulting thickness at these weak spots is 0.15 mm, 0.1 mm, and 0.05 mm.

Table 1: Aneurysm Models

	Patient 36	Patient 39	Patient 42
Raw Image			
Analytical Model			
Mesh Grid			

Aneurysm Material Selection. Stratasys Elastico Clear was chosen for its human artery-like properties and was verified using four different rheometer tests and six total samples, as shown in Figure 1.

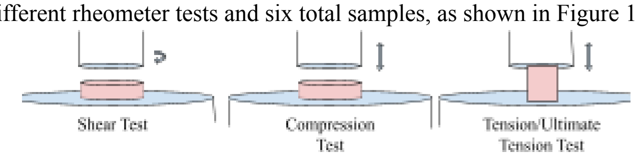


Figure 1: Rheometer Tests [3]

Two material shapes were tested: a puck with a thickness of 4 mm and a diameter of 8 mm and a rectangle with dimensions of 20x5x1 mm. The four tests included subjecting the disc sample to an oscillating shear force–where the discs experienced 1% strain, constant compression force, and subjecting the rectangular shape to a constant tension force, and an ultimate tensile test. Each test was conducted six times, with the ultimate tensile test conducted three times, at two temperatures (20°C and 37°C) totaling 42 tests.

Brain Matter Material Selection. A concentration of 0.6% wt of agarose gel was chosen as the material to mimic brain tissue. The selection criteria were based on several factors: the material needed to be clear, maintain a solid state at 37°C, and exhibit mechanical properties comparable to brain tissue. Specifically, the material was required to retain its shape under applied stress and exhibit low stiffness. At a 0.6% wt concentration, agarose gel has a Young modulus value of 600-700 Pa, while the brain has a value closer to 1 kPa [4]. Additionally, the density of the brain is 1.04 g/ml, while agarose gel at the aforementioned concentration has a density of 1.005 g/ml. The last similarity is Poisson's ratio, which is approximately 0.5 for agarose gel and 0.48 for the brain.

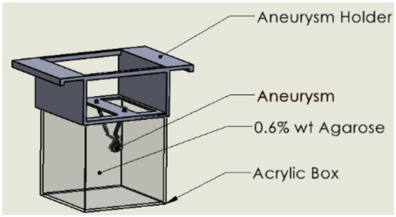


Figure 2: Labeled Aneurysm Setup

Phantom Design and System Integration. Boxes with the dimensions of 3 ¾ x 3 ¾ x 3 ¾" were used as a container for the phantom. The 3D-printed aneurysm model was suspended inside the box within the agarose to simulate brain tissue forces. Figure 2 shows a SolidWorks design of the aneurysm rupture phantom setup.

As shown in Figure 3, the aneurysm rupture phantom setup was submerged inside a water bath and connected to a pulsatile pump using silicone tubes to emulate the cardiovascular system. The aneurysm rupture phantom and reservoir were kept at 37°C with the circulating water bath to mimic human body temperature. A blood mimic composed of 54.1% glycerol and 45.9% water by weight was pumped through the system. A high-speed camera was pointed at the aneurysm to record the behavior of the aneurysm movement and rupture.

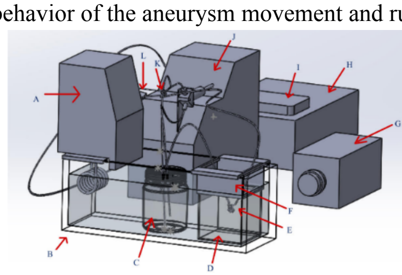


Figure 3: System Setup

The arrows in Figure 3 indicate the instruments critical to the system setup: a) LAUDA ECO ET 6G circulating water bath heating element, b) water bath container, c) jar with blood mimic, d) 100% clear polystyrene box with brain mimic, e) aneurysm model, f) aneurysm holder, g) high-speed camera, h) Transonic Systems Inc. HT110 bypass flowmeter, I) National Instruments DAQ, J) 1405 Harvard Apparatus Co. Pulsatile blood pump, K) Transonic Systems Inc flow sensor, L) Pressure sensor.

RESULTS

Material Properties. We obtained the shear and compression modulus, tensile, and ultimate tensile test results. Figure 4 presents the shear and compression modulus for Stratasys Elastico Clear at both 20°C and 37°C. All material testing results will be present in the full submission. Comparing these results to the properties of human vessels, the findings in Sodawalla's work [5], and considering the variance of tissue mechanics from patient to patient, Elastico Clear is a sufficient material for aneurysm modeling.

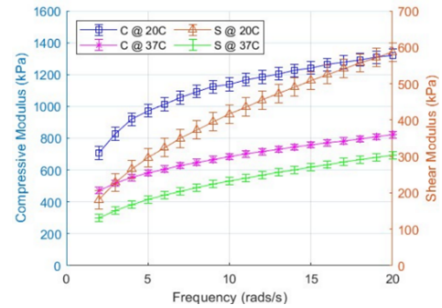
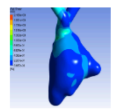
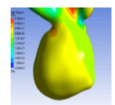
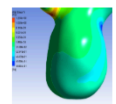
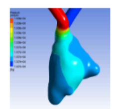
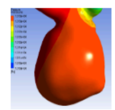
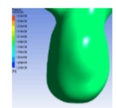
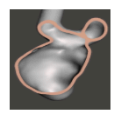
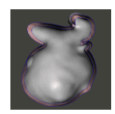
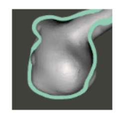


Figure 4: Average Shear and Compression Modulus

CFD. Table 2 shows WSS and pressure distribution on the three geometries. The spots where the pressure peak exists were trimmed to a thinner layer to trigger the rupture, as shown below.

Table 2: CFD Analysis

	Patient 36	Patient 39	Patient 42
Wall Shear Stress Contour			
Pressure Contour			
Weakened Spot			

Rupture Results. Table 3 will document the rupture behavior for each aneurysm type with varying thicknesses.

Table 3: Rupture Results

	Pressure 1	Pressure 2	Pressure 3
0.15 mm	t = time in seconds	t	t
0.10 mm	t	t	t
0.05 mm	t	t	t

DISCUSSION

Understanding the behavior of aneurysm rupture is a key step to understanding the damage caused to the brain from the rupture. This study strives to develop an economical and practical phantom to recreate rupture behavior in a well-controlled laboratory condition. We are in the final step of fabricating these phantoms and conducting the data collection. This will be updated based on the upcoming results.

ACKNOWLEDGEMENTS

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REFERENCES

[1] "Statistics and Facts" Brain Aneurysm Foundation.
[2] Diab et al. *The British J. of Radiology* 96.1141 (2023): 20220686.
[3] Norris et al., *J. of bio. materials research*, 110(3), 612-622.
[4] Sridharan et al., *J. of neural engineering*, 10(6), 066001.
[5] Sodawalla et al., *J. of bio. materials research*, 112.8 (2024):e35465