Mechanical Characterization Testing for Creating an In-Vitro Vessel Model with Properties and Anatomical Structure Similar to Human Neurovascular

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Abstract

The objective: To create a Circle of Willis model with mechanical properties comparable to human vascular. Eight mechanical property tests are to be conducted on a selected polymer.

The ratio of polymer layering replicates the intima and media of the vascular with reference geometries and mechanical testing of human common carotid arteries from donors. Final polymer results determine the ratio of material used for both layers and a SolidWorks CAD of the Circle of Willis has been created for printing. The system will support monitoring equipment and tubing attached to the inlets and outlets under static and dynamic loads that replicate physiological conditions.

Introduction

Endovascular devices are becoming more widely accepted ischemic stroke treatment options in patient healthcare. Current devices must be innovated to quantify the intricate anatomy of the human vascular system. *In vivo* models are limited by local vessel structure and may lack neurovascular anatomy mechanical properties. Standard aneurysm models replicate the structure of the Circle of Willis (figure 1). Previous vessel models are often made from silicone and glass, which do not accurately represent the properties of human tissue. This study focuses on a UV-cured polymer mesh (Agilus and Vero-clear).

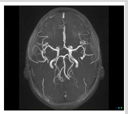

Figure 1: MRI Image of the Circle of Willis [1].

Requirements

This study focuses on a novel UV-cured polymer mesh (Agilus and Vero-clear) and compares them to the human tissue characteristics by quantifying the mechanical properties using eight different mechanical tests:

Table 1: Mechanical Property Tests.

Tests Conducted		
Shear	Radial Force	Poisson's Ratio
Compression	Tension	Lubricity
Hardness	Compliance	

Based on the analysis of these tests, in comparison to data provided on human vascular mechanical properties, create a Circle of Willis model that most closely replicates the human vascular mechanical properties.

Methods

Two polymer shores are selected with rigid material as the intima, 20% of the sample, and the softer material as the media, 80% of the sample. The samples are 1.2mm thick with layers of 0.96mm and 0.24mm for the 80 and 20% layers, respectively. Combinations 30a/50a and 40a/60a are characterized with a HR-2 Rheometer (TA Instruments) and a C-Arm fluoroscope. All samples were soaked in phosphate-buffered saline (PBS) and are tested under similar conditions to the human body response.

- Test 1: Shear- Sample in tension from 0.1 to 3.0 Hz. (**Fig 1**)
- Test 2: Compression – Dynamic modulus from 0.1 to 3.0 Hz. (**Fig 1**)
- Test 3: Hardness – Applied force until deformation. (**Fig 2**)
- Test 4: Radial Force – Response up to 50% compression of inner diameter. (**Fig 3**)

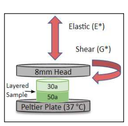

Figure 1 (left): Compressive and shear sample set up.

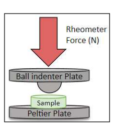

Figure 2 (Middle): Hardness test setup.

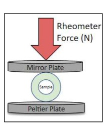

Figure 3 (Right): Radial force test setup.

Methods Continued

- Test 5: Tension – Pulled dynamic axial response within 0.1 to 3.0 Hz. (**Fig 4**)
- Test 6: Compliance – Radial and axial volume change with pressure. (**Fig 5-6**)

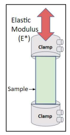

Figure 4: **Left**- The sample clamps into the Rheometer and force is applied vertically.

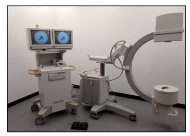

Figure 5: **Middle**- Compliance, fluoroscope (C-Arm) device.

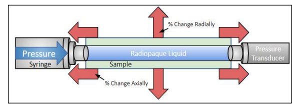

Figure 6: Right- Compliance setup. Syringe of 30cc Conray is used to pressurize the sample.

- Test 7: Poisson's Ratio – Radial response to compression. (**Fig 7**)
- Test 8: Lubricity – Catheter friction test at 500 um/s for 5 cm. (**Fig 8**)

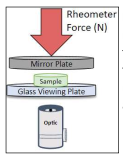

Figure 7: **Left** Poisson's ratio uses the Rheometer to provide downwards force (N) and the axial response is recorded for analysis.

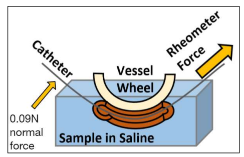

Figure 8: **Right**- The Lubricity setup uses a smooth catheter attached to the Rheometer and a CAD wheel model to apply force against the sample. A baseline test provides frictional forces [2].

Results

Examples of tests 1, 2, 6, & 8 as representative data. The full report includes all 8 testing data analyses.

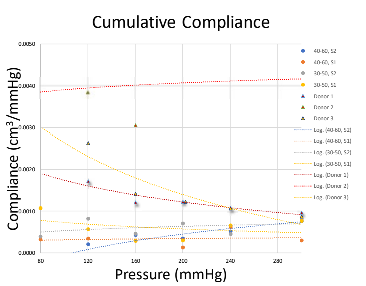

Figure 8: Direct compliance comparison between samples and donors (p-value <0.001). Test 6.

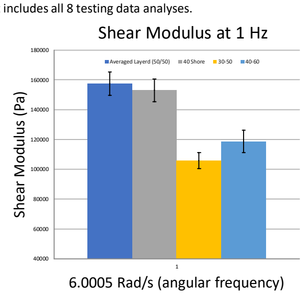

Figure 9: Proof of concept validation that ratio and layering control can improve performance without averaging shore hardness. Test 1.

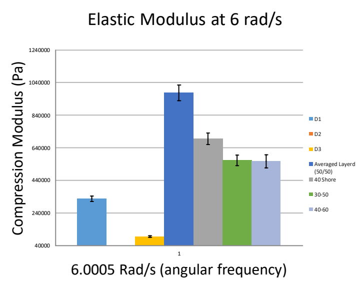

Figure 10: Elastic modulus decreases compared to pure and 50% layered samples through controlled layer ratios and thickness. Test 2.

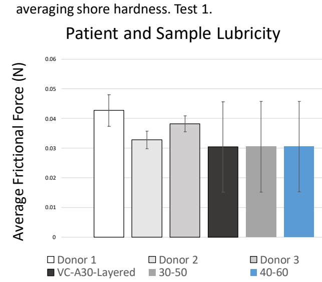

Figure 11: Lubricity comparison between sample and donors displays a similar friction force to human vascular. Standard deviation/2 errors display similarity along the positive error axis. Test 8.

Results Continued

Table 2: Statistical Comparison between the 80-20% layered samples, donor samples, and the 50% layering previously tested. All 8 mechanical test statistics are included in final report.

Statistical Comparisons Between Donors & Samples						
Donor	30-50: 80/20% % diff.	30-50: 80/20% p value	40-60: 80/20% % diff.	40-60: 80/20% p value	50% Layered % diff.	50% Layered p value
Compressive moduli						
Donor 1	-22.30	<.001	-23.59	<.001	-20.5	<.001
Donor 2	-76.71	<.001	-77.10	<.001	-328	<.001
Donor 3	-82.82	<.001	-83.10	<.001	-303	0.005
Poisson's Ratio						
Donor 1	-31.51	.016	-28.88	.024	-13	.146
Donor 2	-50.52	<.001	-48.62	<.001	18.4	.007
Donor 3	-38.21	.013	-35.84	.002	-1.92	.847
Lubricity						
Donor 1	27.33	<.001	27.39	<.001	28.6	<.001
Donor 2	33.39	<.001	33.45	<.001	7.05	<.001
Donor 3	31.33	<.001	31.39	<.001	20.2	<.001
Compliance						
Donor 1	55.76	<.001	70.03	<.001	-202	<.001
Donor 2	90.18	<.001	93.35	<.001	27.3	.070
Donor 3	70.32	<.001	79.89	<.001	-102	.002

Discussion

- Using controlled, anatomically similar layering and shore hardness resulted in lower percent difference between the polymer samples and human vascular donor mechanical properties.
- Results display improvement from previous Bioengineering Devices Lab (BDL) research.
- Expectedly, some tests, such as tension, shear, and compression, resulted that the polymer performed with higher moduli than human vascular.

Future Studies – Further Shore Analysis

Future work may include adding an adventitia layer to the samples, however, another set of donor testing would need to be conducted due to the removal of adventitia in the first study. Additional work may also include using ratios of 30-40 and 40-50 shore hardness with the same 80-20% layering method. Once completed, a new model could be designed to be more anatomically correct physically and mechanically.

References

[1] C. Settanni, "In Vitro Neurovascular Model Development for Liquid Embolic Implant Simulation," *Google*. [Online]. Available: https://docs.google.com/presentation/d/14mdgqx2XWuA98fz6Ufh07s_CHWN_O8-w/edit#slide=id.p9. [Accessed: 10-Oct-2021].

[2] N. G. Norris, W. C. Merritt, and T. A. Becker, "Application of nondestructive mechanical characterization testing for creating in vitro vessel models with material properties similar to human neurovascular," *Journal of biomedical materials research. Part A*, 17-Sep-2021. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/34617389/.

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