



# Product Demo & Testing Results (Final)

PROJECT MANAGER: ISAAC SMITH

WEB/DATA MANAGER: LUKE NELSON

BUDGET LIAISON: KATHRYN NELSON

TESTING MANAGER: ADITYA PONUGUPATY

# Original Client Demands

1. Develop, justify, and characterize the following attributes (recommended but not limited to):

- Virtual design of vessel model using innovative biomaterials
- 3D-print of virtual design for measuring:
  - Biaxial vascular tension of materials
  - Blood vessel compliance
  - Lubricity of model interior
  - Compressive and Shear Modulus
  - Compatibility with an *in vitro* pressure (and flow) measurement system --- (*on hold*)

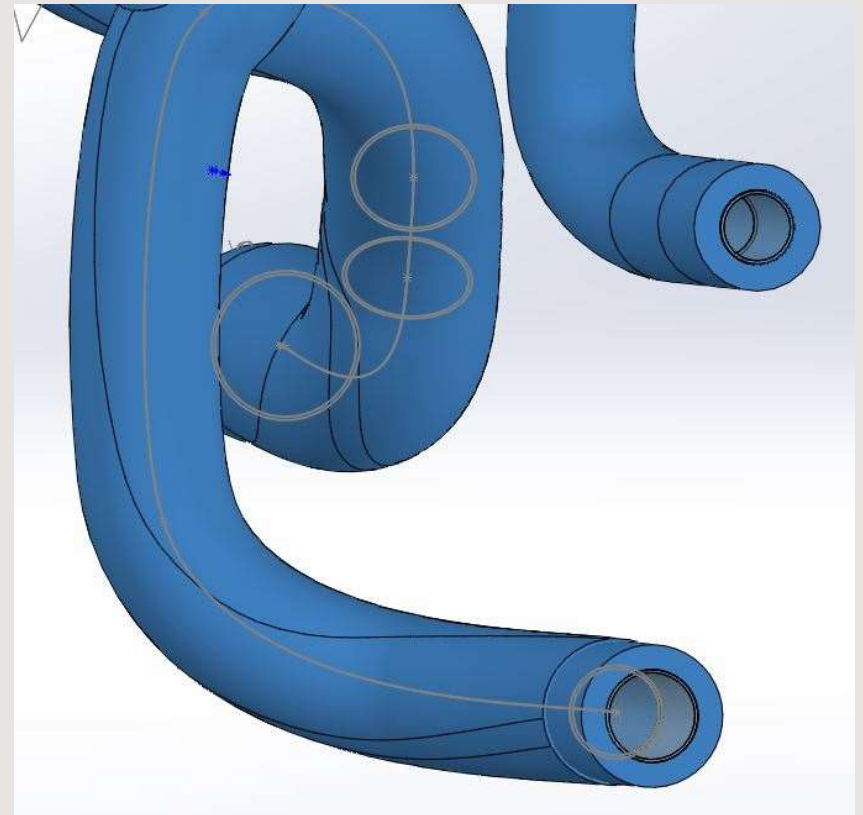
2. Allow visualization of device deployment

3. Document repeatable manufacturing, order and laboratory implementation process  
*(Future Assignment)*

# Design Requirements Summary

## CRs

- Size (CR-1)
- Easy to Connect (CR-2)
- Soft Exterior/Hard Interior (CR-3)
- Lightweight (CR-4)
- Material Selection (CR-5)
- Retains Shape (CR-6)
- Similar Properties to Organic Tissue (CR-7)
- Cost Within Budget (CR-8)



# Design Requirements Summary

## ERs

- Stiffness (ER-1)
- Thickness (ER-2)
- Compressive Modulus (ER-3)
- Frequency (ER-4)
- Poisson's Ratio (ER-5)
- Compliance (ER-6)
- Angular Acceleration (ER-7)
- Radial Force (ER-8)
- Layering (ER-9)
- Pressure (ER-10)
- Shear Modulus (ER-11)
- Hardness (ER-12)
- Strain (ER-13)
- Coefficient of Friction (ER-14)



<b>Project:</b>	3D Printing and Testing
<b>Date:</b>	Fall '21 - Spring '22
<b>Names:</b>	
Kathryn Nelson	
Luke Nelson	
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Direction of Improvement	
Maximize	▲
Target	□
Minimize	▼

Relationships	Weight
Strong	9
Medium	3
Weak	1

Correlations	
Positive	+
Negative	-
No Correlation	

Customer Competitive Assessment	
1	Poor
3	Acceptable
5	Excellent

# House of Quality

Stiffness/ E (kPa)	+																		
Thickness (mm)																			
Compressive Modules (kPa)	+	+																	
Frequency (rad/s)			-		+														
Poisson's ratio (unitless)				+		-													
Compliance (cm^3/mmHg)					+														
Angular Acceleration (rad/s)																			
Radial Force (N/mm)																			
Layering (um)																			
Pressure (mmHg)																			
Shear Modulus																			
Hardness, Modulus																			
Strain																			
Coefficient of Friction																			

Relative Weight	Customer Importance	Customer Requirements	Engineering Requirements										Benchmark Assessment			
			Stiffness/ E (kPa)	Thickness (mm)	Compressive Modules (kPa)	Frequency (rad/s)	Poisson's ratio (unitless)	Compliance (cm^3/mmHg)	Angular Acceleration (rad/s)	Radial Force (N/mm)	Layering (um)	Pressure (mmHg)	BDL	Biomedics	Stratasys	Axial3D
3%	1	Size	●	●	▼	○	▼	●	▼	▼	○	○	5	3	5	3
8%	3	Easy to connect	▼	●	▼	▼	▼	▼	▼	▼	○	▼	5	3	3	5
25%	9	Soft Exterior, Hard Interior (layered)	●	▼	●	▼	▼	○	○	○	●	●	3	5	1	1
3%	1	Light weight	●	○	○	▼	○	▼	▼	▼	○	○	3	3	3	3
25%	9	Material selection	●	▼	●	●	○	●	●	●	●	●	5	3	5	3
8%	3	Retains shape	○	○	▼	●	●	○	○	○	●	○	3	3	3	5
25%	9	Similar properties to organic tissue	●	○	●	●	●	●	○	○	●	●	5	1	3	1
3%	1	Cost Within Budget	●	●	○	▼	○	○	▼	○	▼	○	5	3	1	5
Importance Rating Sum (Importance x Relationship)			785.3333333	285.3333333	711.7777778	572.4444444	434	595.1111111	416.8888889	406.22222	794.667	728.44				
Relative Weight			14%	5%	12%	10%	8%	10%	7%	7%	14%	13%				
Technical Requirement Units			kPa	mm	kPa	rads/s		cm^3/mmHg	rads/s	N/mm	um	mmHg				

# Detailed Testing Plans: Test Summary

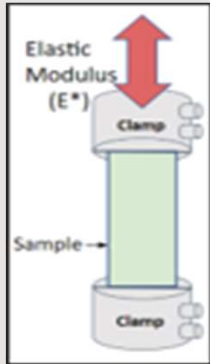
<b>Experiment/Test</b>	<b>Relevant DRs</b>
T1 - Shear	CR-5, CR-6, CR-7, ER-4, ER-7, ER-11
T2 - Compression	CR-5, CR-6, CR-7, ER-2, ER-3, ER-4, ER-7
T3 - Hardness	CR-5, CR-6, CR-7, ER-12
T4 - Poisson's	CR-5, CR-6, CR-7, ER-4, ER-5, ER-7
T5 - Radial Force	CR-5, CR-6, CR-7, ER-4, ER-7, ER-8
T6 - Tension	CR-5, CR-6, ER-2, CR-7, ER-1, ER-4, ER-7
T7 - Compliance	CR-5, CR-6, CR-7, ER-2, ER-6, ER-10
T8 - Lubricity	CR-5, CR-6, CR-7, ER-7, ER-14



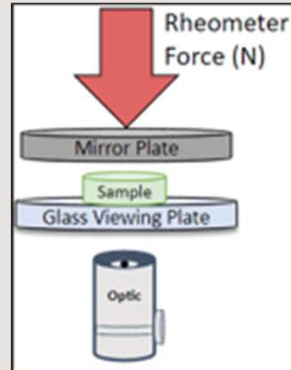
# Detailed Testing Plans: Procedure

- **Lubricity:** The rheometer pulls a tense wire through the center of a cylindrical sample, measures the amount of resistance the wire is experiencing
- **Compliance:** Fill a cylindrical sample with Conray, incrementally increase the internal pressure from 80 -280 mmHg, snap an image with Xray to measure the how much the sample expands with each new pressure
- **Tension:** The rheometer stretches a rectangular sample of a force of 100mmHg and 160 mmHg, measures the axial force
- **Hardness:** The rheometer compresses a metal ball into a disk sample at a given rate, and measures the hardness modulus and percent strain
- **Poisson's Ratio:** The rheometer compresses the disk sample, uses Dinocapture to measure axial displacement
- **Radial Force:** Compresses cylindrical sample 50% of its original height, measure the deflection
- **Compression:** The rheometer compresses a disk sample by a force of 0.9 - 1.4 N, measures the resistance to the compression
- **Shear:** A continuous oscillating force is applied to disk sample

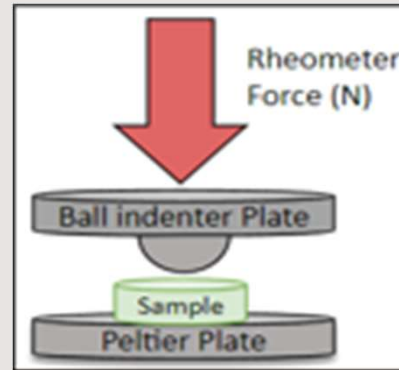
# Testing Diagrams



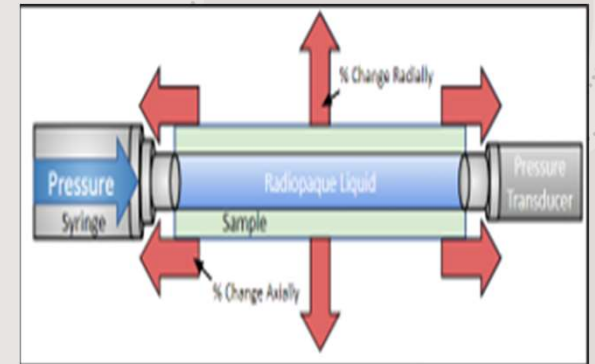
Tension



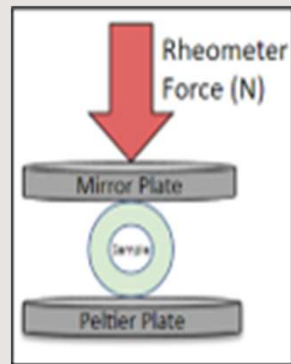
Compression/Shear



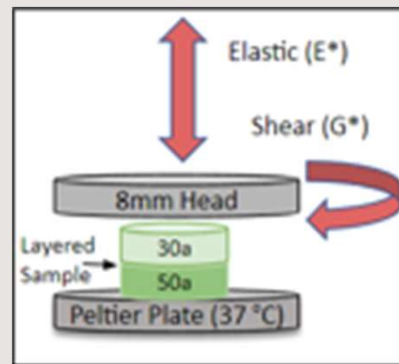
Hardness



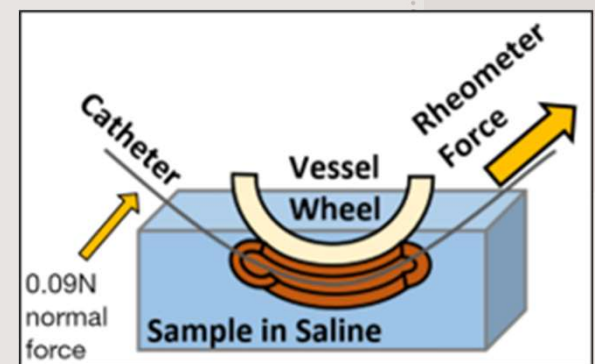
Compliance



Radial Force



Poisson's Ratio



Lubricity



# Detailed Testing Plans: Results

4 Day Soak				
	30-50		40-60	
	% diff.	p value	% diff.	p value
Compressive moduli				
Donor 1	-22.30	<0.001	-23.59	<0.001
Donor 2	-76.71	<0.001	-77.10	<0.001
Donor 3	-82.82	<0.001	-83.10	<0.001
Avg	-60.607941	<0.001	-61.2647	<0.001
Shear moduli				
Donor 1	-84.75	<0.001	-86.41	<0.001
Donor 2	-95.88	<0.001	-96.33	<0.001
Donor 3	-95.22	<0.001	-95.74	<0.001
Avg	-91.9496843	<0.001	-92.8247	<0.001
Lubricity				
Donor 1	27.33	<0.001	27.39	<0.001
Donor 2	33.39	<0.001	33.45	<0.001
Donor 3	31.33	<0.001	31.39	<0.001
Avg	30.68	<0.001	30.74	<0.001

4 Day Soak				
	30-50		40-60	
	% diff.	p value	% diff.	p value
Tensile Moduli				
Donor 1	10.01	<0.001	13.85	<0.001
Donor 2	322.15	<0.001	336.87	<0.001
Donor 3	170.04	<0.001	179.45	<0.001
Avg	167.4	<0.001	176.7233333	<0.001
Hardness Moduli				
Donor 1	-99.45508184	<0.001	-17.53586506	0.58538
Donor 2	-98.99409741	<0.001	52.22632096	0.00013
Donor 3	-99.1554222	<0.001	27.81254555	0.00117
Avg	-99.20153382	<0.001	20.83433382	0.195559748
Radial force				
Donor 1	144.9151017	<0.001	143.059413	<0.001
Donor 2	837.2157986	<0.001	830.1146406	<0.001
Donor 3	149.0323857	<0.001	147.1455008	<0.001
Avg	377.0544286	<0.001	373.4398515	<0.001

## Detailed Testing Plans: Results Cont.

4 Day Soak				
	30-50		40-60	
	% diff.	p value	% diff.	p value
Poisson's Ratio				
Donor 1	46.01	0.016712	85.8154	0.024648
Donor 2	102.1	<0.001	94.63431	<0.001
Donor 3	61.85	0.001303	55.87271	0.002055
Avg	69.9878633	0.009007	78.77251	0.013351
Compliance				
Donor 1	55.76	<0.001	70.03	<0.001
Donor 2	90.18	<0.001	93.35	<0.001
Donor 3	70.32	<0.001	79.89	<0.001
Avg	72.08612986	<0.001	81.09184806	<0.001

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## Detailed Testing Plans: Results Cont.

# Specification sheet

Customer Requirements		CR Met (Y/N)	Client Acceptable (Y/N)	Notes / Verification
CR -1	Size	Y	Y	Anatomically similar CAD & Layering.
CR -2	Easy to Connect	Y	Y	UV Cured Printing (integrated) W/ original base.
CR -3	Soft Exterior, Hard interior	Y	Y	20%-80% Layer
CR -4	Lightweight	Y	Y	Design <500g, CW <200g, Samples <5g each.
CR -5	Material Selection	Y	Y	Aguilus & VeroClear
CR -6	Retains Shape	Y	Y	Unless plastically deformed.
CR -7	Similar to properties to human tissue	Y/N	Y	Test results: closer values- not exact. Improved.
CR -8	Cost within Budget	Y	Y	Test & Sampling <\$600, Approx. \$400 remaining.

# Specification Sheet Part 2

Engineering Requirements		Units	Target Range	Tolerance	Measured / Calculated Value	ER Met (Y/N)	Client Acceptable (Y/N)	Test / Method Associated
ER -1	Stiffness/ E	Kpa	100 to 20,000	100	30-50: 70,000 to 120,000; 40-60: 90,000 to 160,000	N	Y	Tension
ER -2	Thickness	mm	1.2	0.05	CAD: 1.2mm; Capiler: 1.2mm	Y	Y	N/A
ER -3	Compressive Module	KPa	90,000 to 500,000	50	30-50:500,000 to 680,000; 40-60: 590,000 to 810,000	N		Compression
ER -4	Frequency	rad/s	0 to 20	0.01	Rheometer controlled	Y	Y	Most
ER -5	Poisson's ratio	unitless	0.30 to 0.50	0.05	30-50:0.18 to 0.29   40-60: 0.21 to 0.30	N	Y	Poison's Ratio
ER -6	Compliance	cm <sup>3</sup> /mmHg	0 to 0.006	0.0001	30-50: 0.00052 to 0.00066; 40-60: 0.00034 to 0.00046	Y	Y	Compliance
ER -7	Angular Acceleration	rad/s	0 to 20	0.01	Rheometer controlled	Y	Y	Most
ER -8	Radial Force	N/mm	.003 to .01	0.001	30-50: 0.03 ; 40-60: 0.03	N	Y	Radial Force
ER -9	Layering	mm	0.96, 0.24	0.01	CAD measured; printer tolerance	Y	Y	N/A
ER -10	Pressure	mmHg	80 to 320	5 mmHg	Pressure Gauge; Pressure Transducer (readings varied)	Y	Y	Compliance
ER -11	Shear Modulus, E	KPa	5 to 30	5	60-50:70,000 to 145,000; 40-60: 90,000 to 150,000	N	Y	Shear
ER -12	Hardness, Modulus	KPa	1,000 to 5000	100	30-50: 5478.26 ; 40-60: 829041.9	Y/N	Y	Hardness
ER -13	Strain	%	55 to 90	1	Rheometer controlled	Y	Y	Hardness
ER -14	Coefficient of Friction	unitless	0.15 to 0.5	0.01	30-50: 0.3351; 40-60: 0.3353	Y	Y	Lubricity

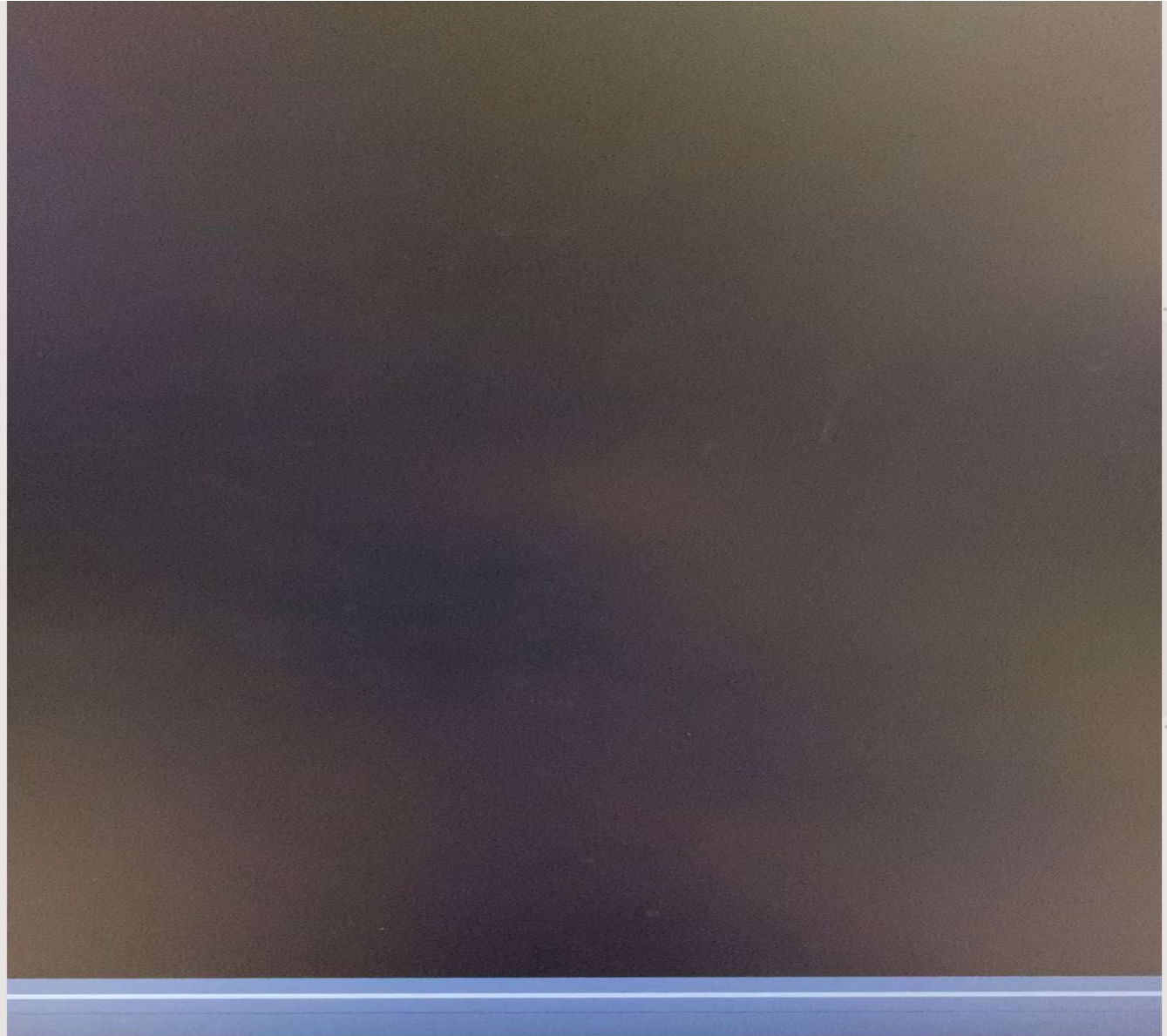
# Top Level Testing Summary

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Experiment/Test	Relevant DRs
T1 - Shear	CR-5, CR-6, CR-7, ER-4, ER-7, ER-11
T2 - Compression	CR-5, CR-6, CR-7, ER-2, ER-3, ER-4, ER-7
T3 - Hardness	CR-5, CR-6, CR-7, ER-12
T4 - Poisson's	CR-5, CR-6, CR-7, ER-4, ER-5, ER-7
T5 - Radial Force	CR-5, CR-6, CR-7, ER-4, ER-7, ER-8
T6 - Tension	CR-5, CR-6, ER-2, CR-7, ER-1, ER-4, ER-7
T7 - Compliance	CR-5, CR-6, CR-7, ER-2, ER-6, ER-10
T8 - Lubricity	CR-5, CR-6, CR-7, ER-7, ER-14

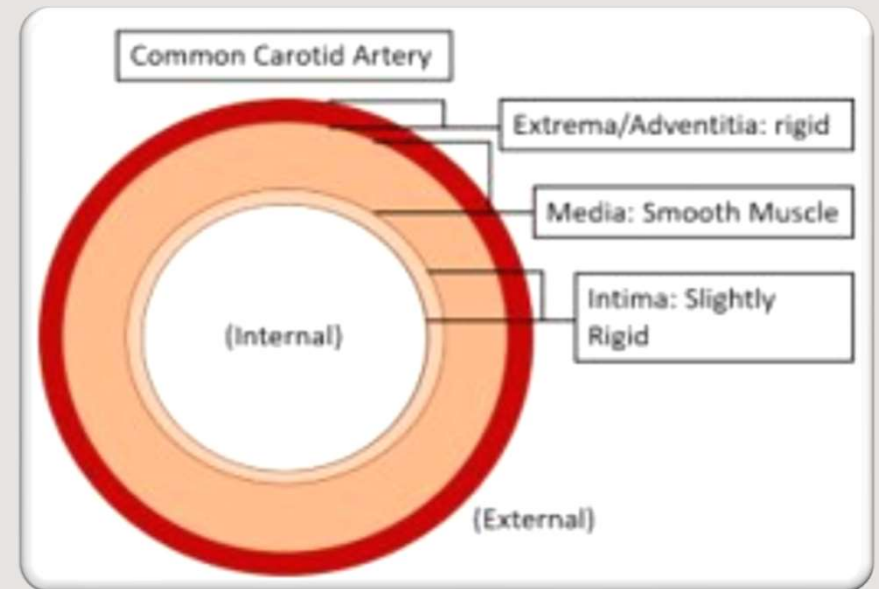


# Product Demonstration



# Future Work

- Testing 30-40 and 40-50 ratios
- Full model integration (*will be done for Ugrads*)
- Adding a third layer
- Adding an aneurysm sack





Questions?