



CentraleSupélec

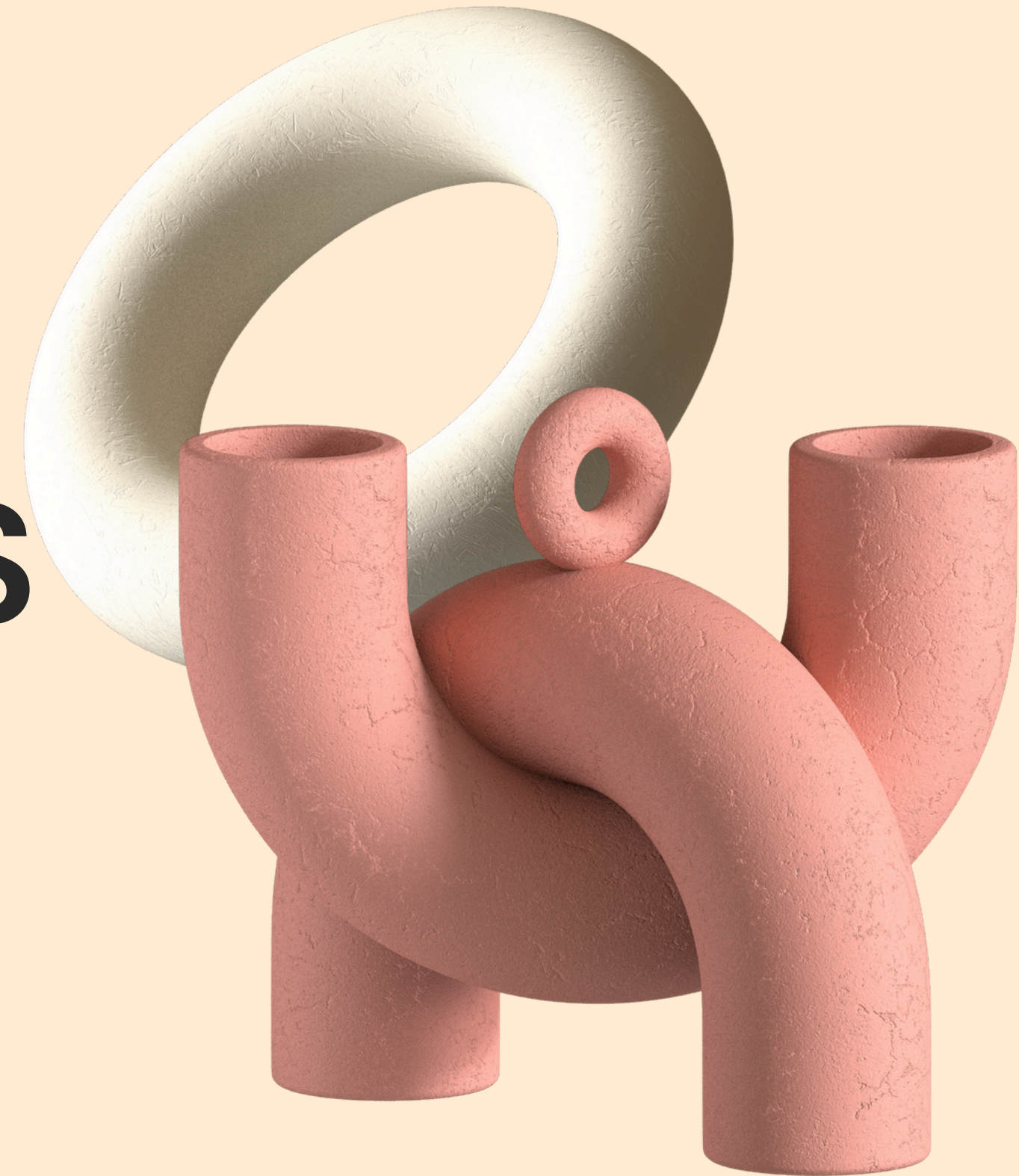


Laboratoire
de Mécanique
Paris-Saclay

DESIGN AND DEVELOPMENT OF AORTIC WALL MIMICS WITH 3D PRINTING

march 2024

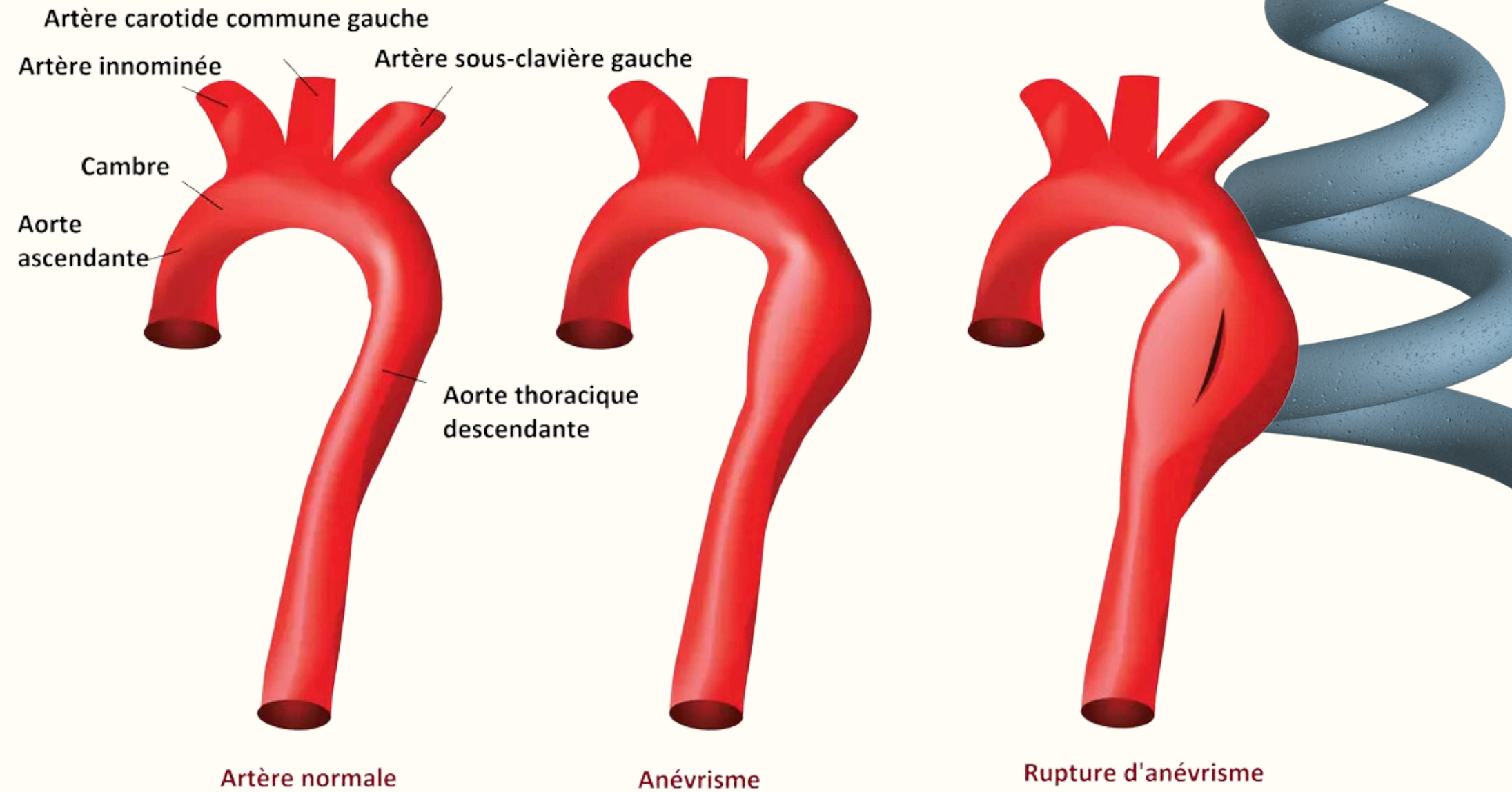
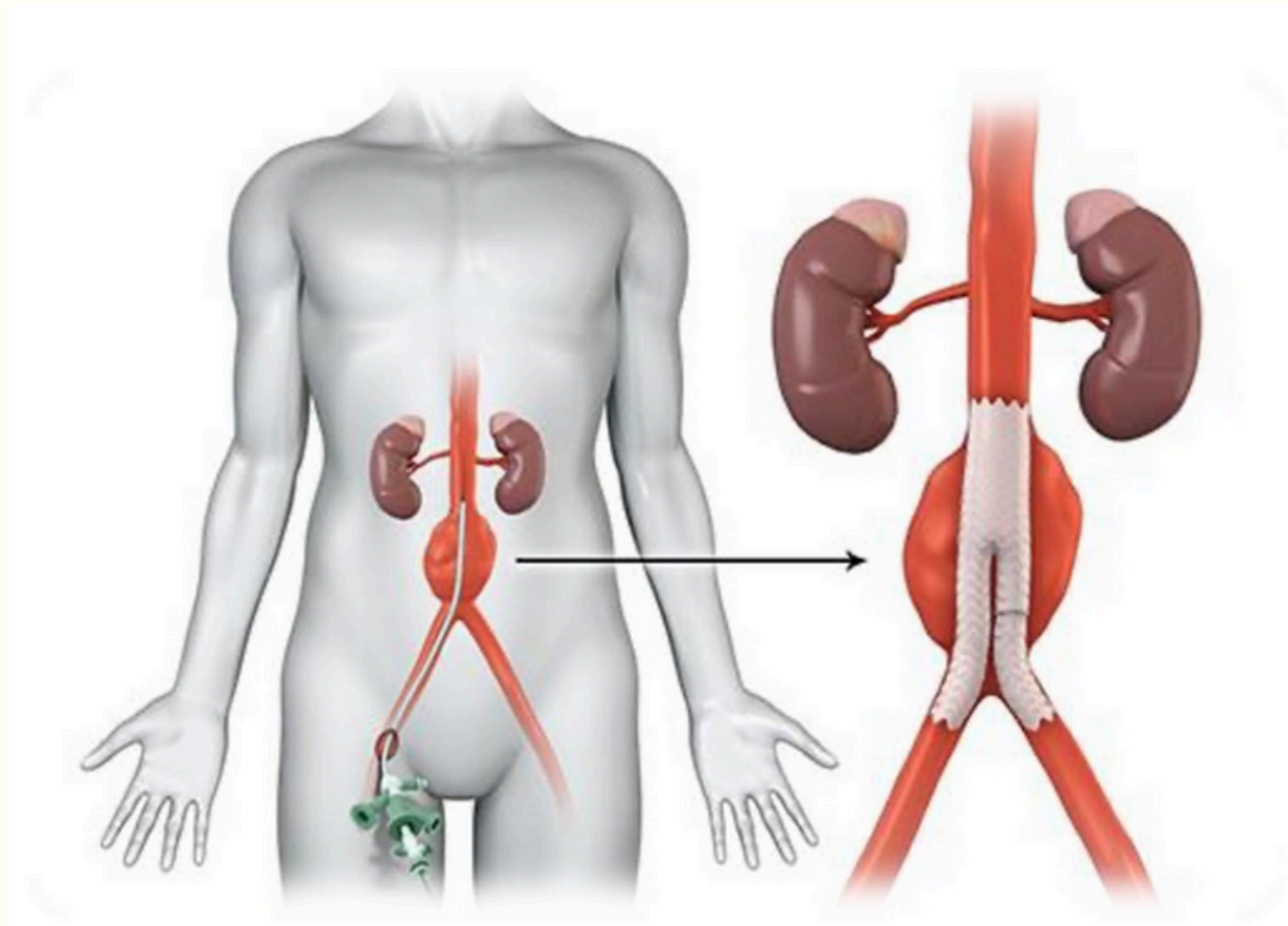
supervised by Margot Leclercq & Loic Guezou



Summary

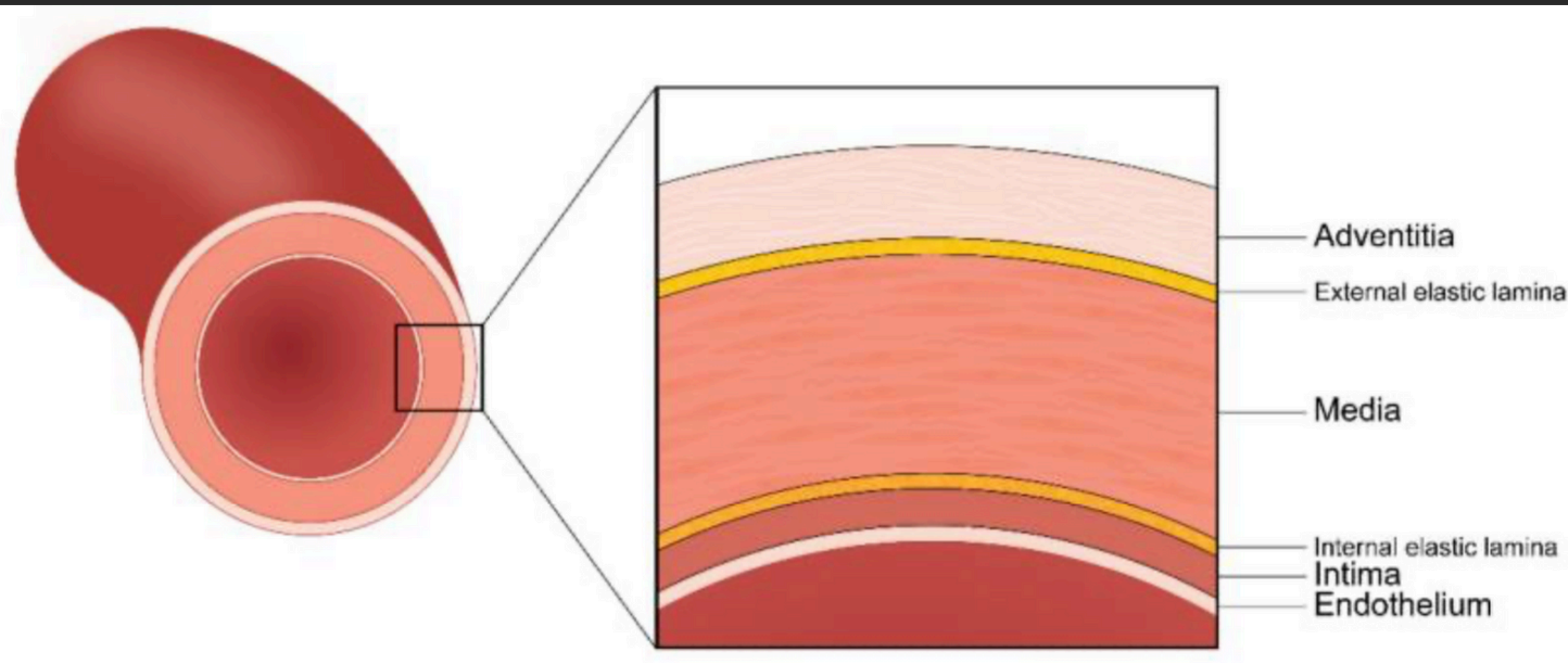
- 01** Context : aneurysm
- 02** Literature review on the aortic tissue and its hierarchical layers organization
- 03** Literature review on the PolyJet 3D printing technology
- 04** Design of the aorta
- 05** Testing numerically
- 06** Testing experimentally

Introduction : aneurysm



⇒ Build an artificial model that can be used by surgeons to train on.

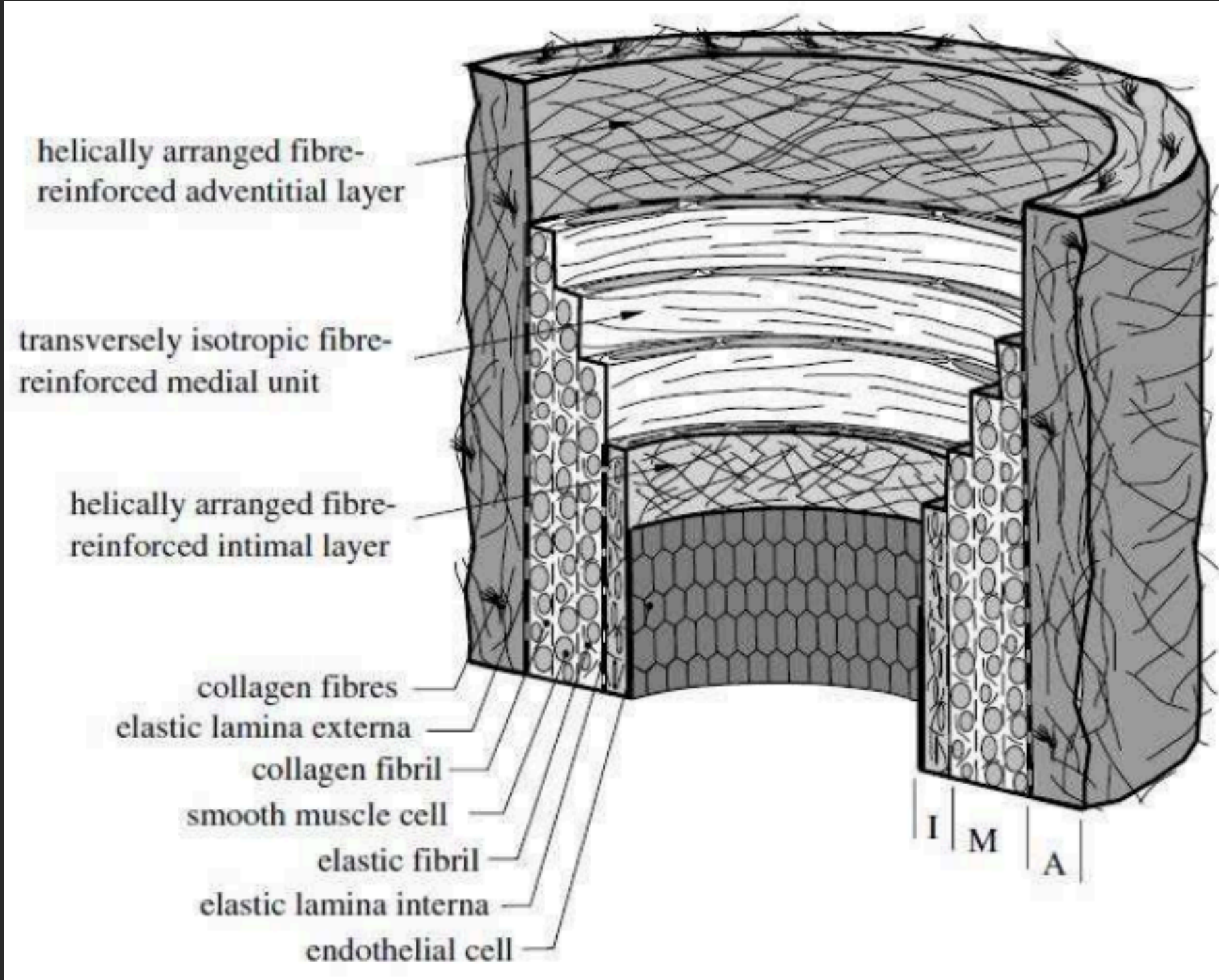
The aortic tissue & its hierarchical layers organization



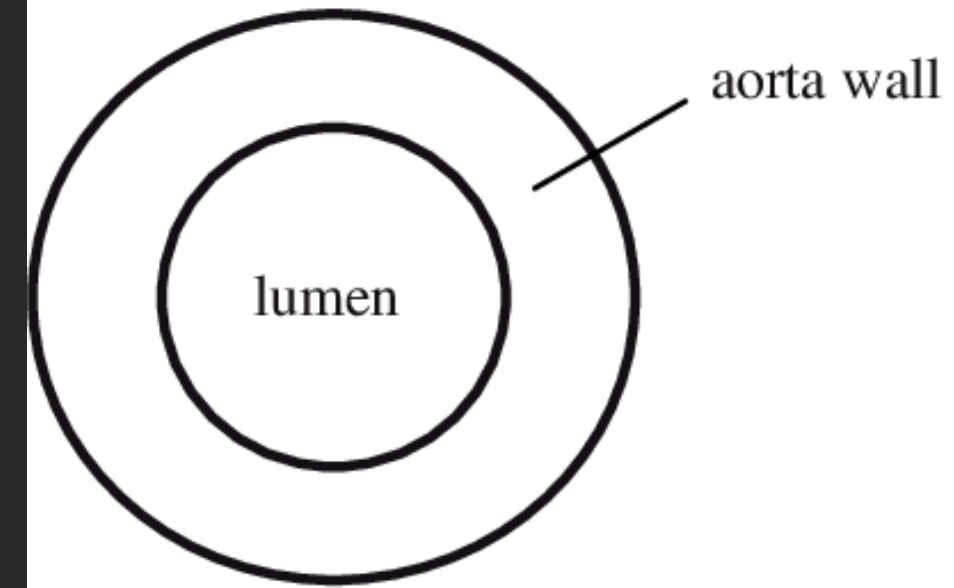
- **Intima:** Connective tissue composed of an endothelial cell layer
- **Media:** Elastic fibers (elastin + microfibrils rich in fibrillins) that form a network.
- **Adventitia:** Collagen fibers that confer resistance to stretching (against extreme deformations).

Deficiency in fibrillin-1 production \Rightarrow alterations in vascular physiology \Rightarrow risk of aneurysm.

How to model the three layers of the aorta ?



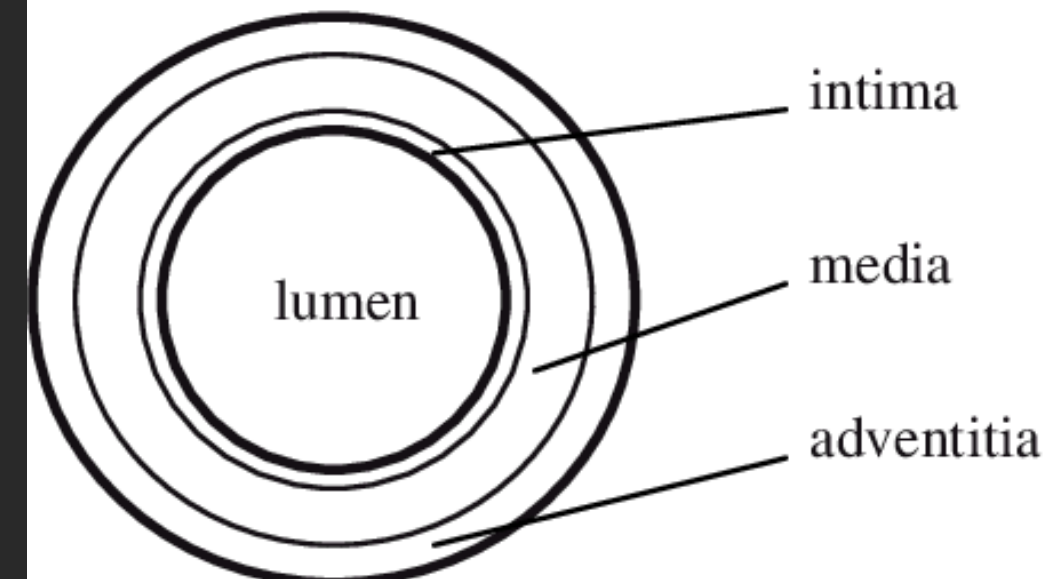
(a) One-layered model



$$t=0.002\text{m}$$

$$E=840\text{MPa}$$

(b) Three-layered model



$$t_i=0.0002\text{m}$$

$$E_i=385.643\text{MPa}$$

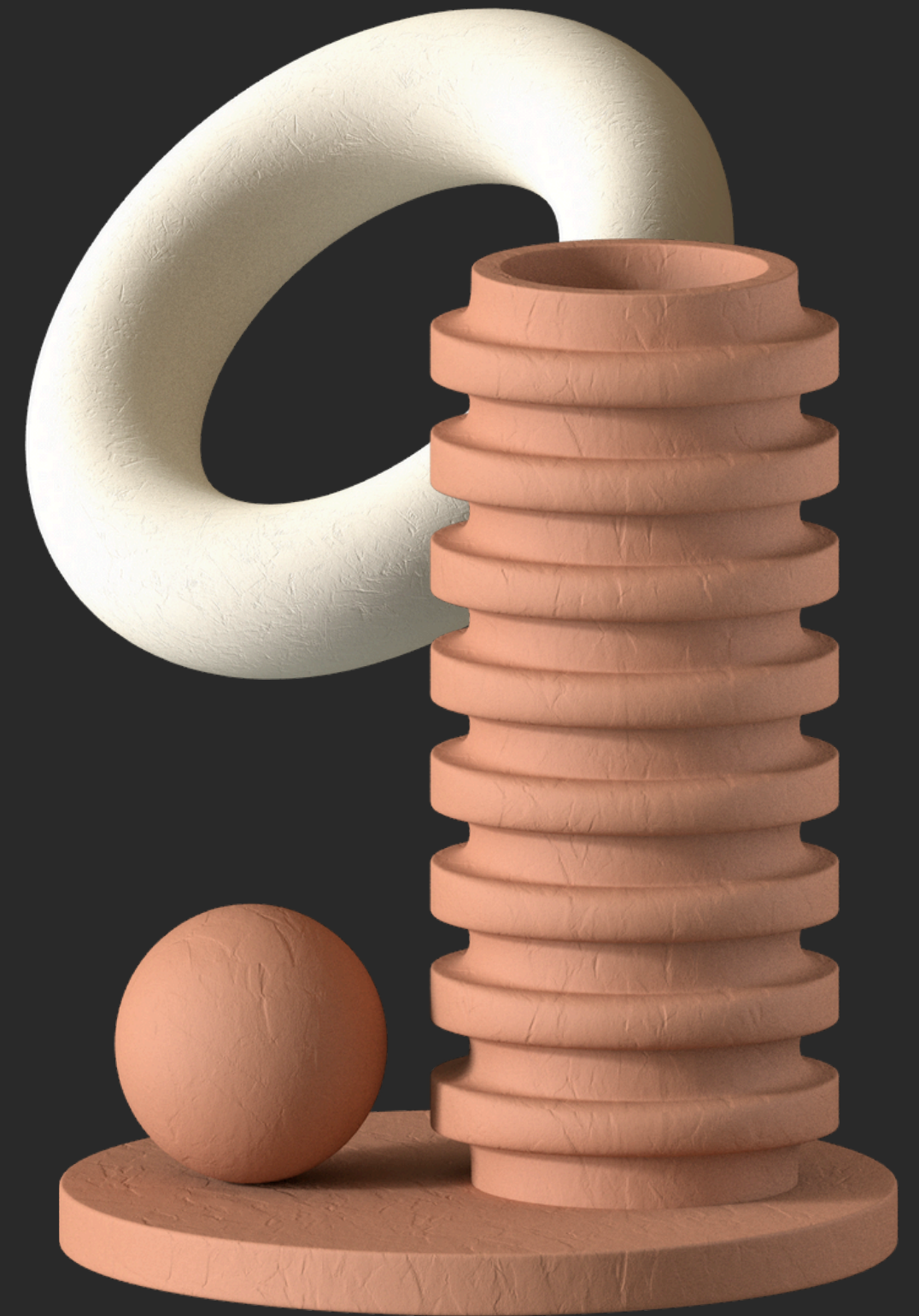
$$t_m=0.0012\text{m}$$

$$E_m=1156.928\text{MPa}$$

$$t_a=0.0006\text{m}$$

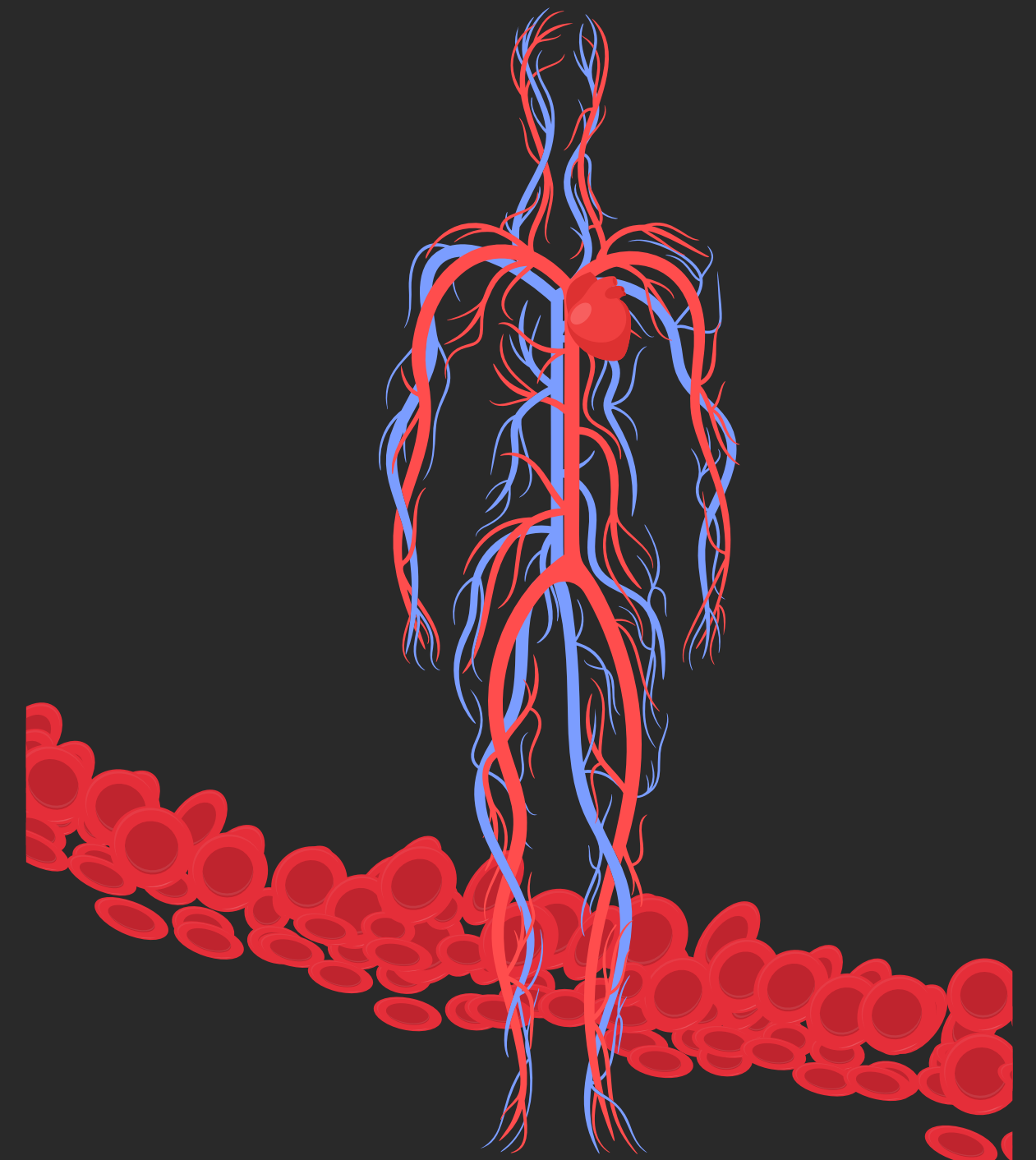
$$E_a=385.643\text{MPa}$$

Modeling of the real aorta on COMSOL



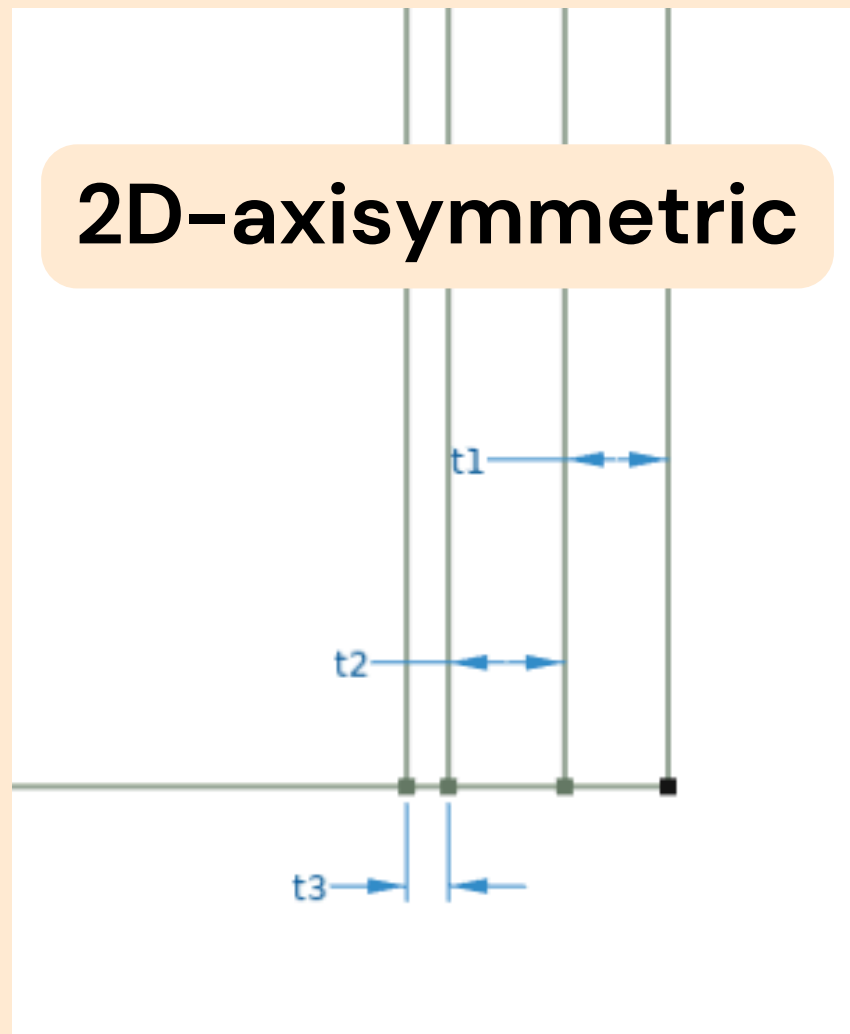
Modelization hypothesis and choices

- **Geometry**
 - 2D-axisymmetric cylinder model
 - Three-layer blood vessel
- **Blood**
 - Laminar Flow
 - Non-Newtonian power law
- **Vessel**
 - Linear elastic material
 - Roller boundary condition
- **Multiphysics**
 - Fluid-Structure interaction



Comsol Simulation

2D-axisymmetric



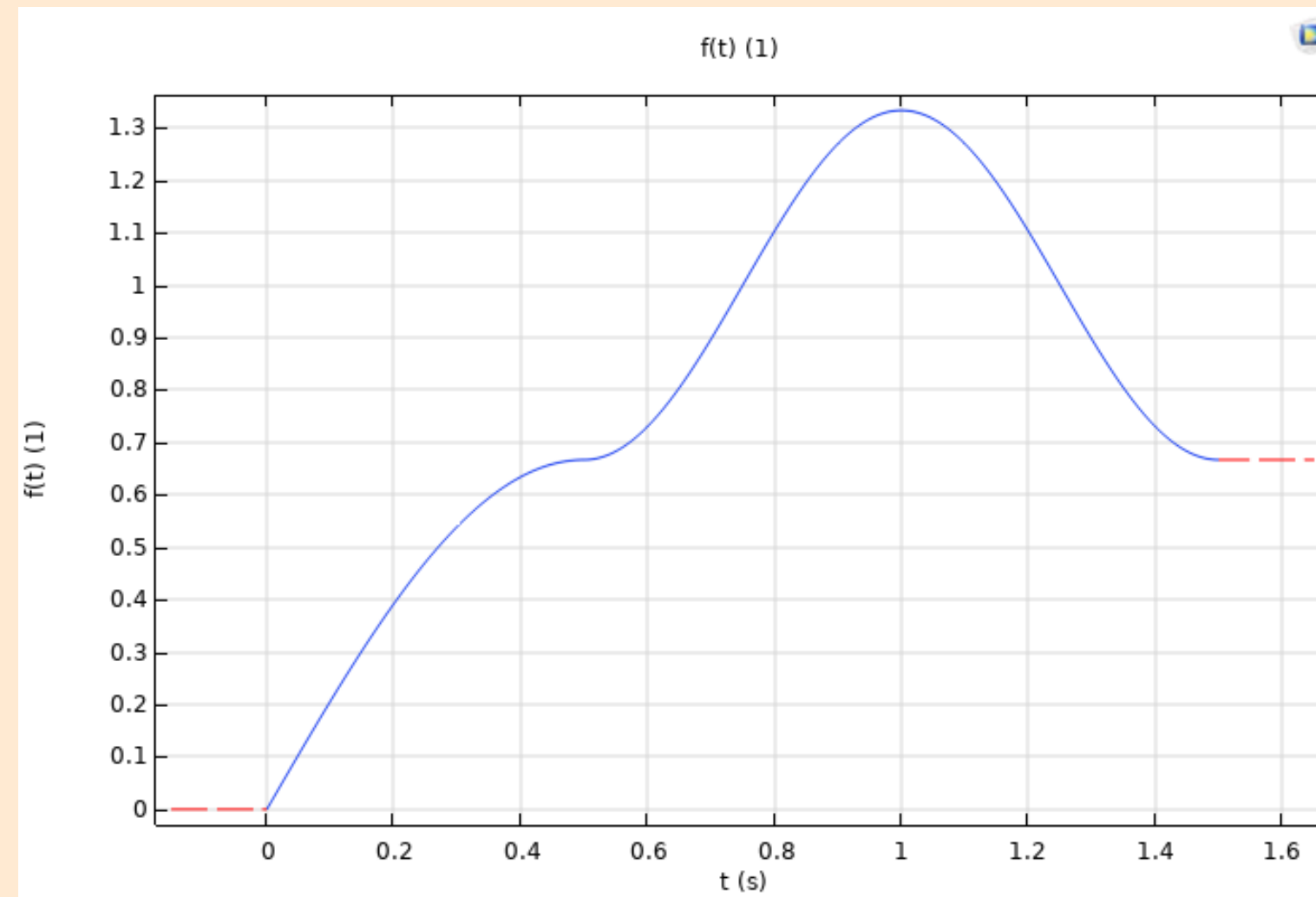
Geometry

t1: adventitia, 0.6mm

t2: media, 1.2mm

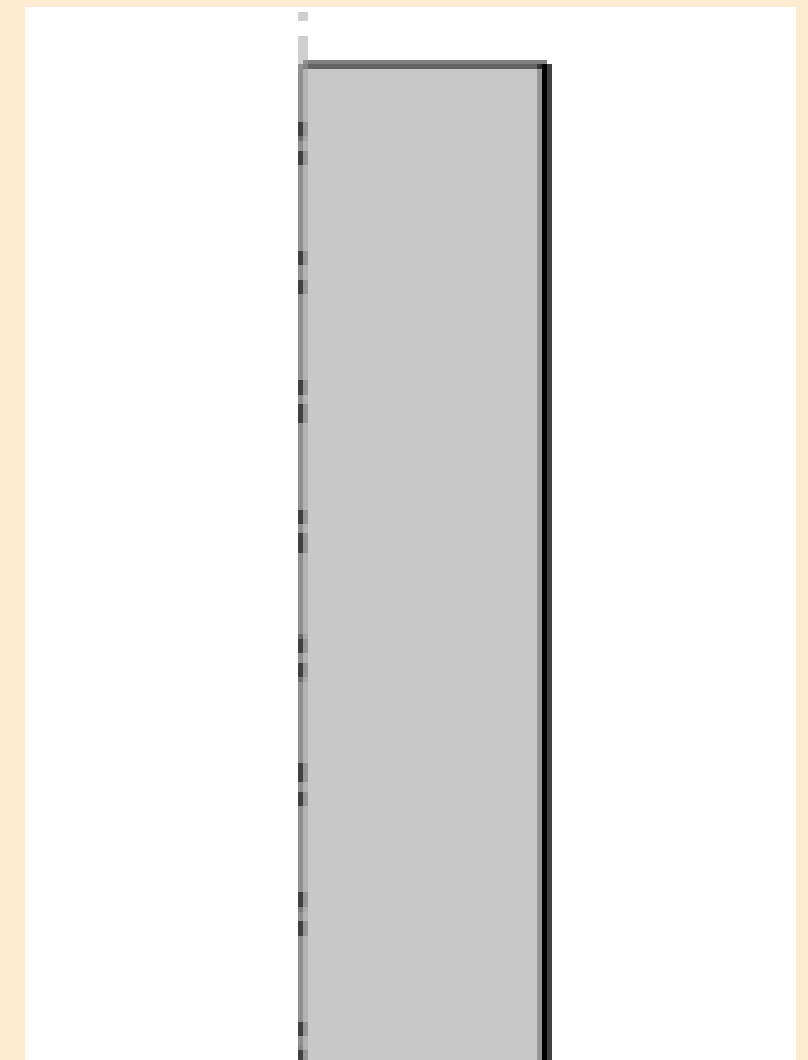
t3: intima, 0.2mm

Vessel's diameter: 40mm



Blood inlet: 126.09mmHg * f(t)

Blood outlet: 125.89mmHg * f(t)



$$\mu = \mu_0(\dot{\gamma})^{n-1},$$

where $\mu_0 = 0.035$ and $n = 0.6$

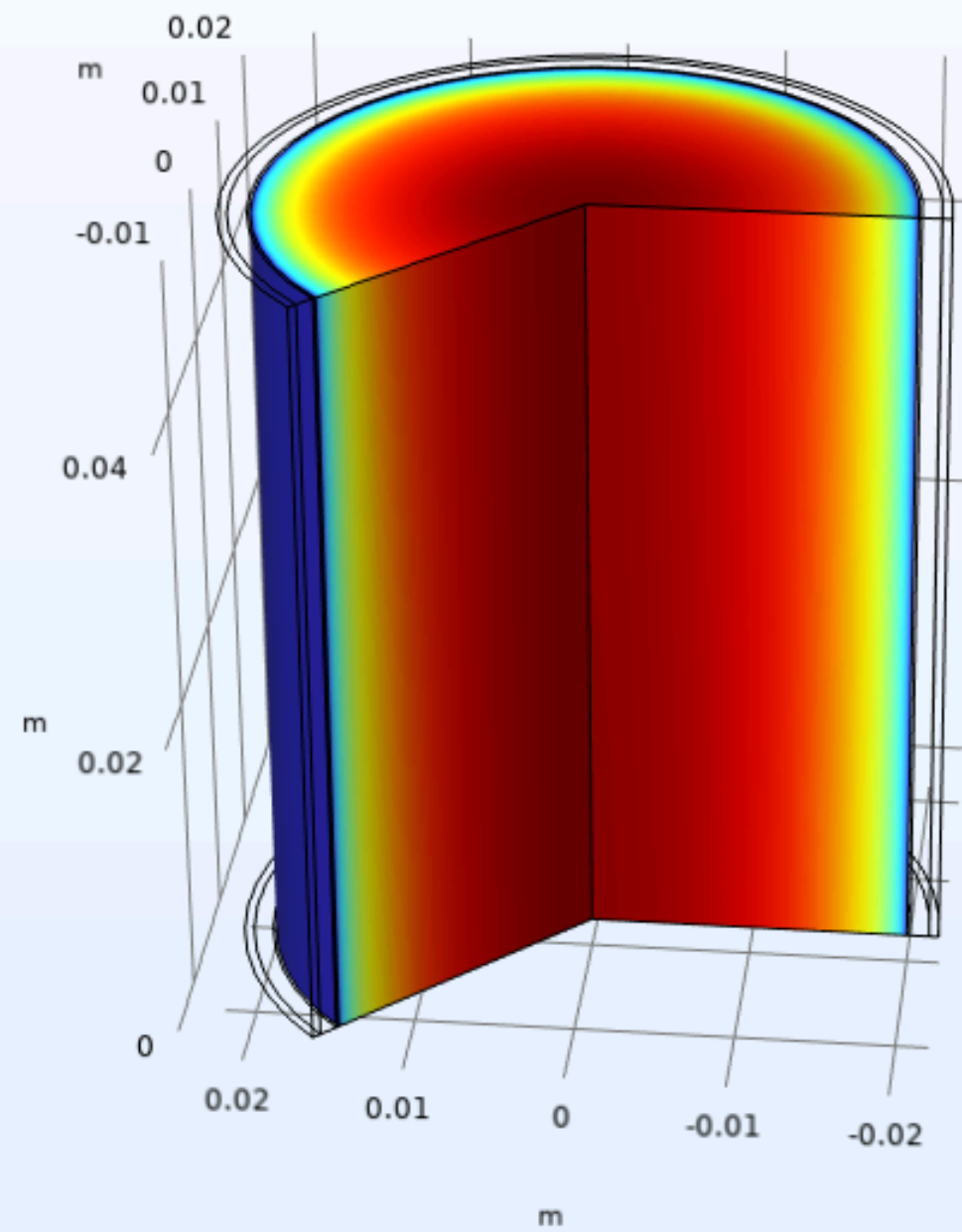
Fluid model:

non-Newtonian power law

Comsol Simulation

Time=1.5 s

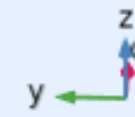
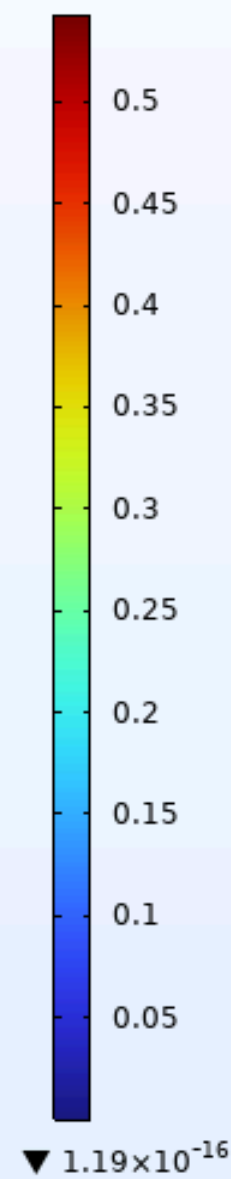
Velocity Field - "Real" Aorta



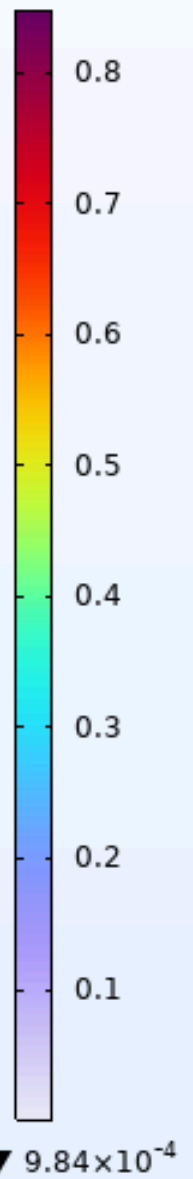
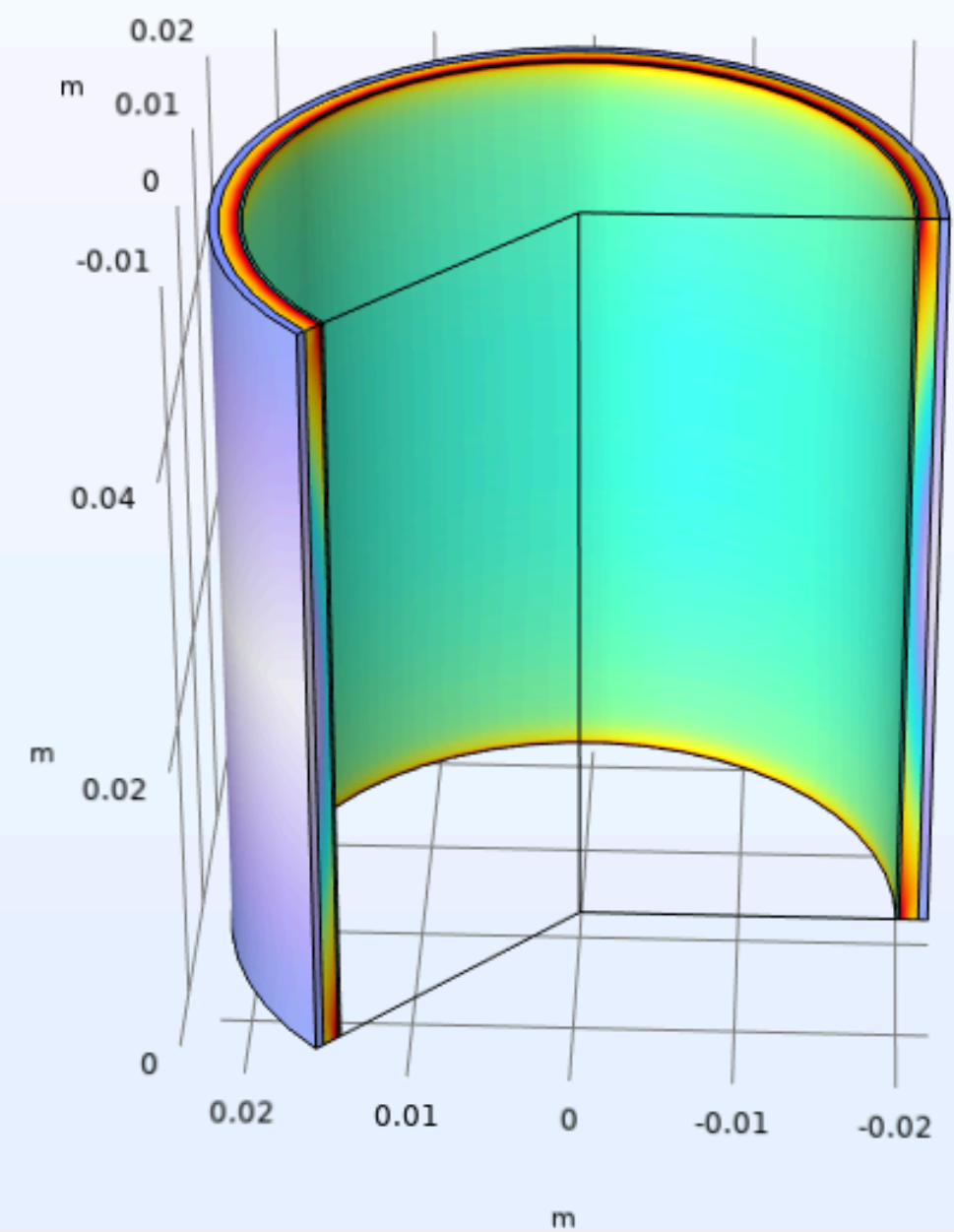
Time=1.1 s

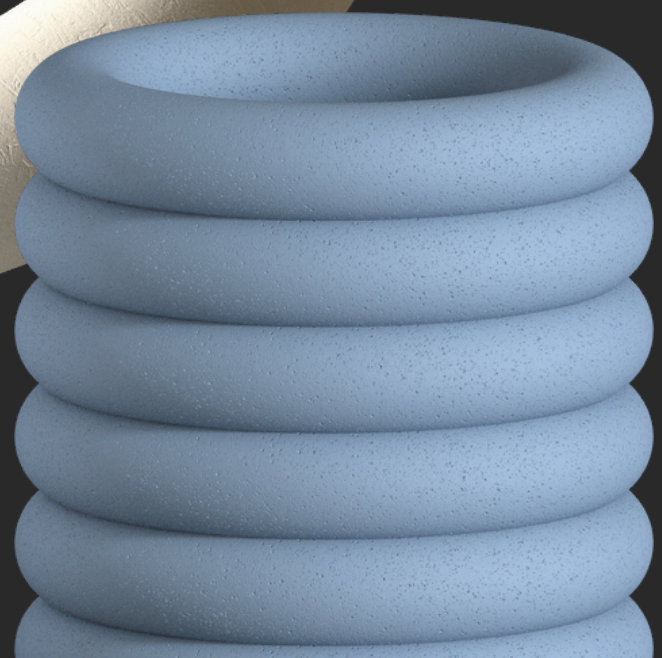
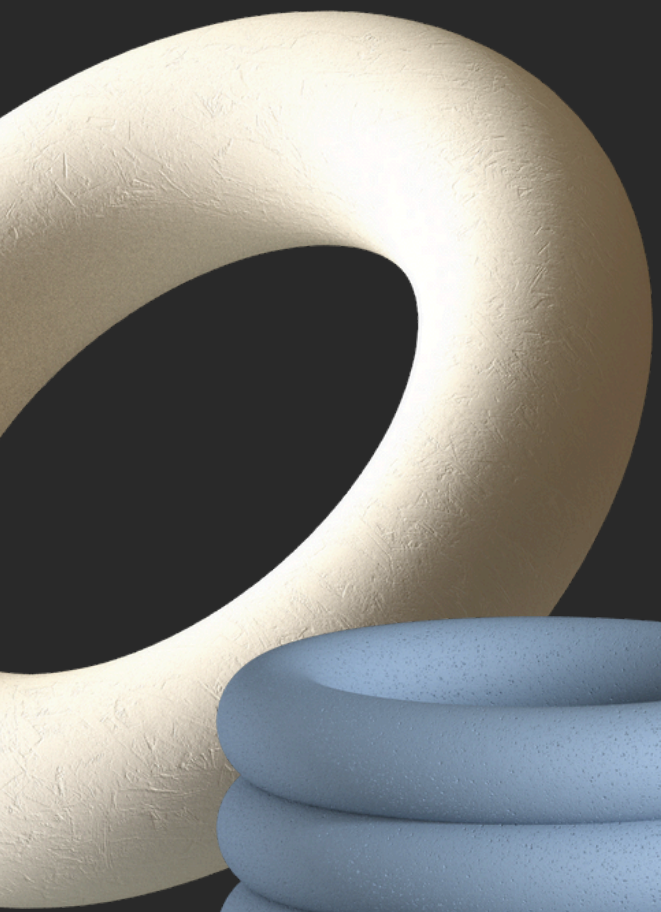
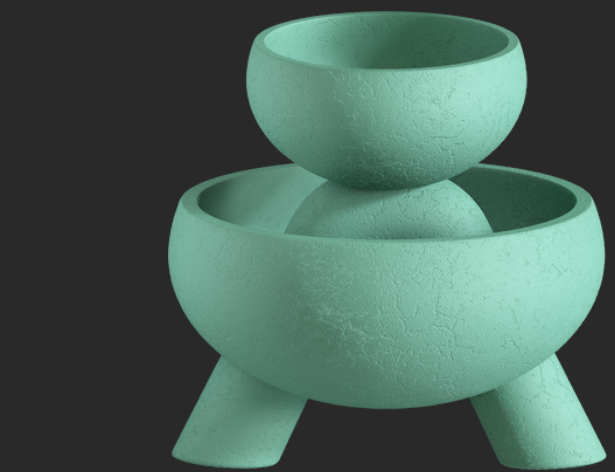
von Mises Stress - "Real" Aorta

▲ 0.543

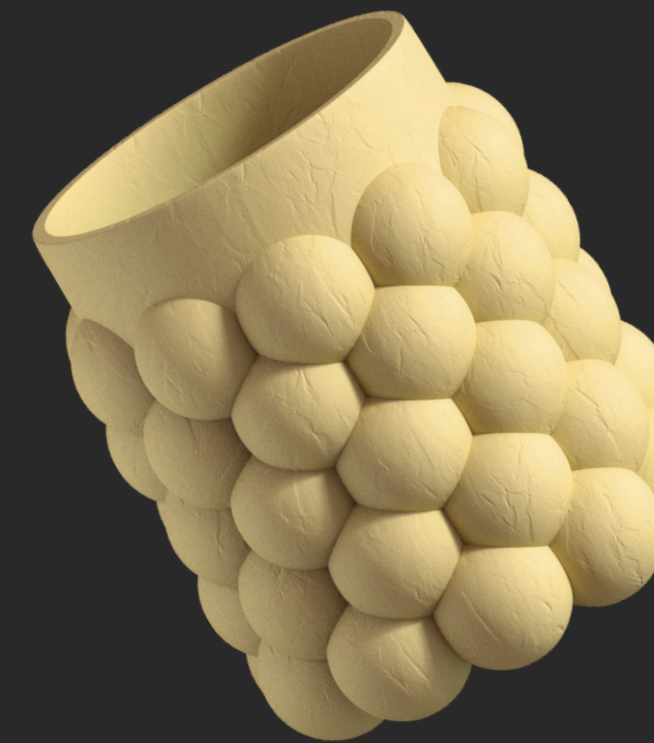


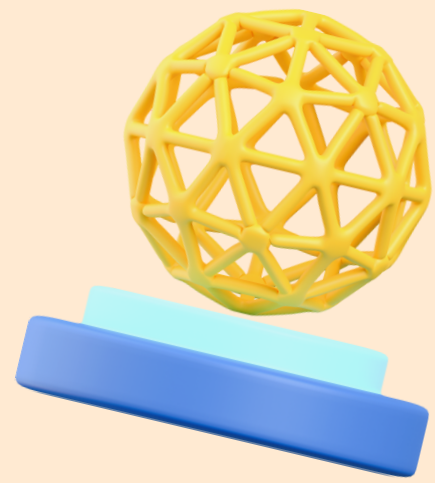
▲ 0.848





Design of the aorta





Model Materials



Agilus 30 / Elastico



Material Type: PolyJet photopolymer
Key Feature: Exceptional tear resistance
Resistance to tension: 2.4–3.1 MPa
Elongation at break: 220–270%

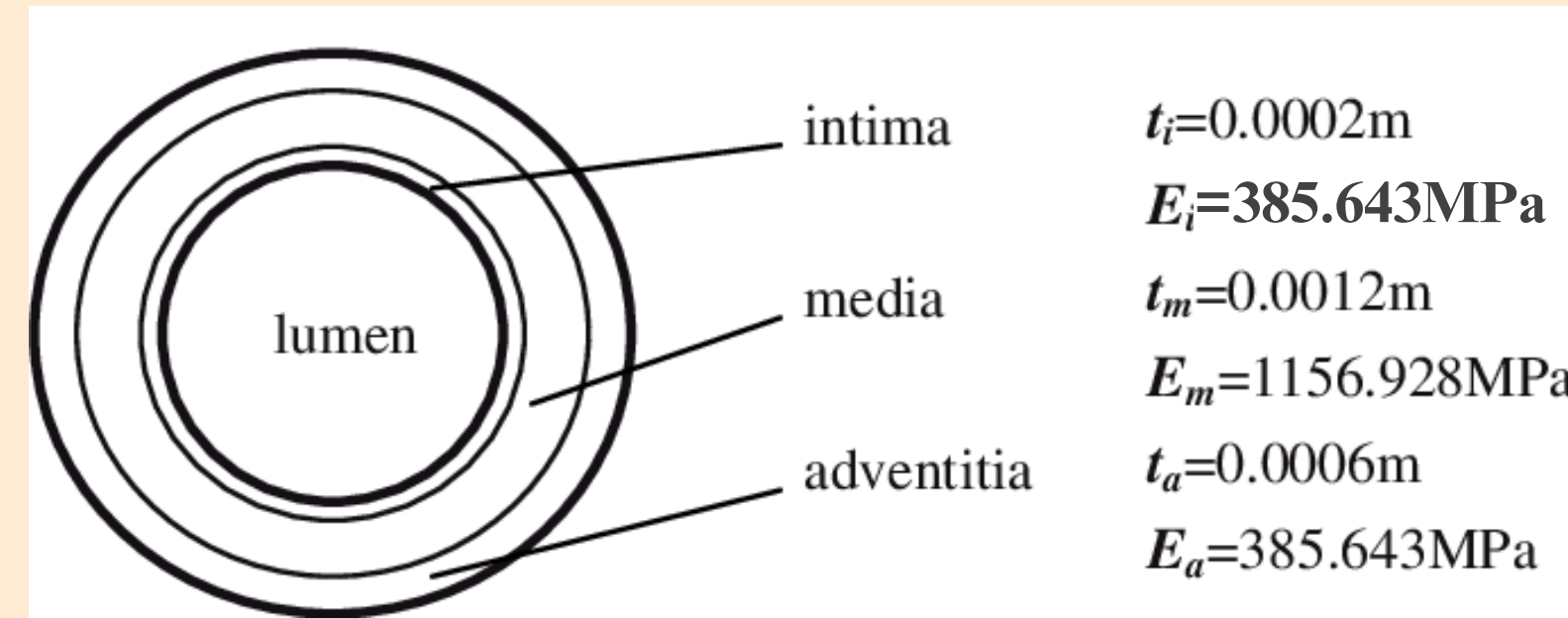
Vero



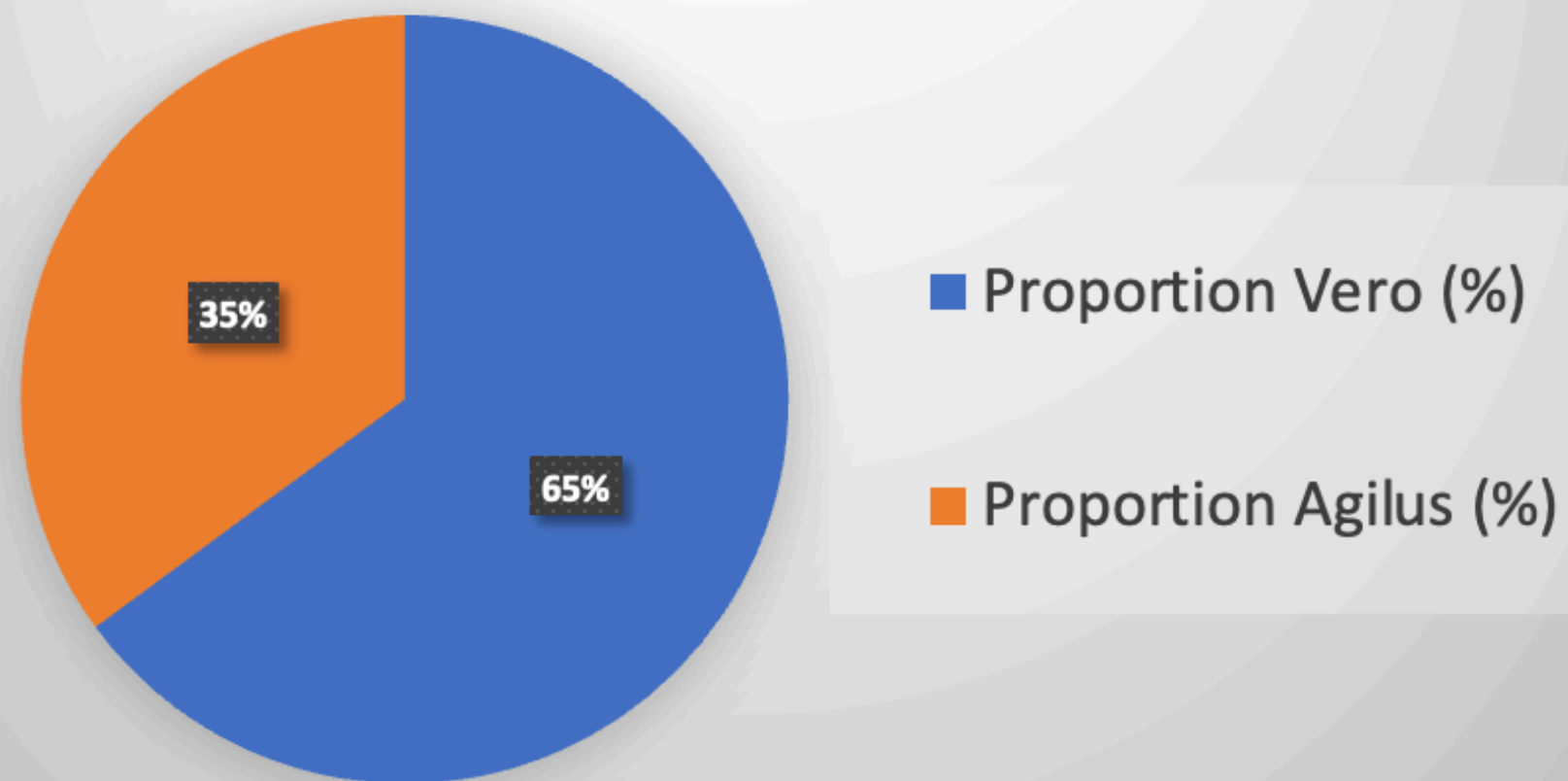
Material Type: PolyJet photopolymer
Key Feature: rigid
Resistance to tension: 50–60 MPa
Flexural Strength: 80–100 MPa

Model Materials: Young's Modulus

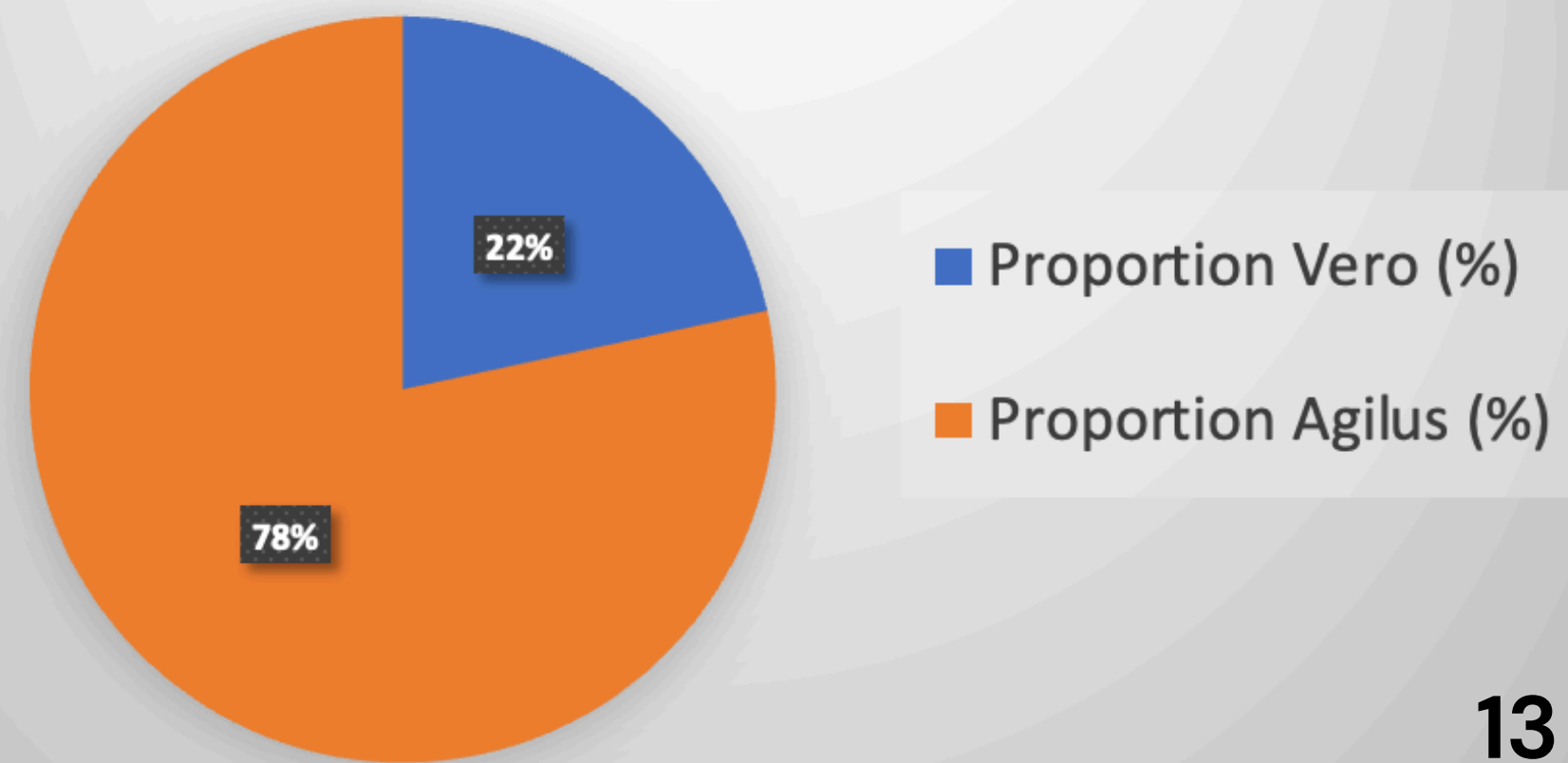
For composite materials: $E_L = E_f V_f + E_m (1 - V_f)$



Proportion of dry Vero and Agilus in the Media layer



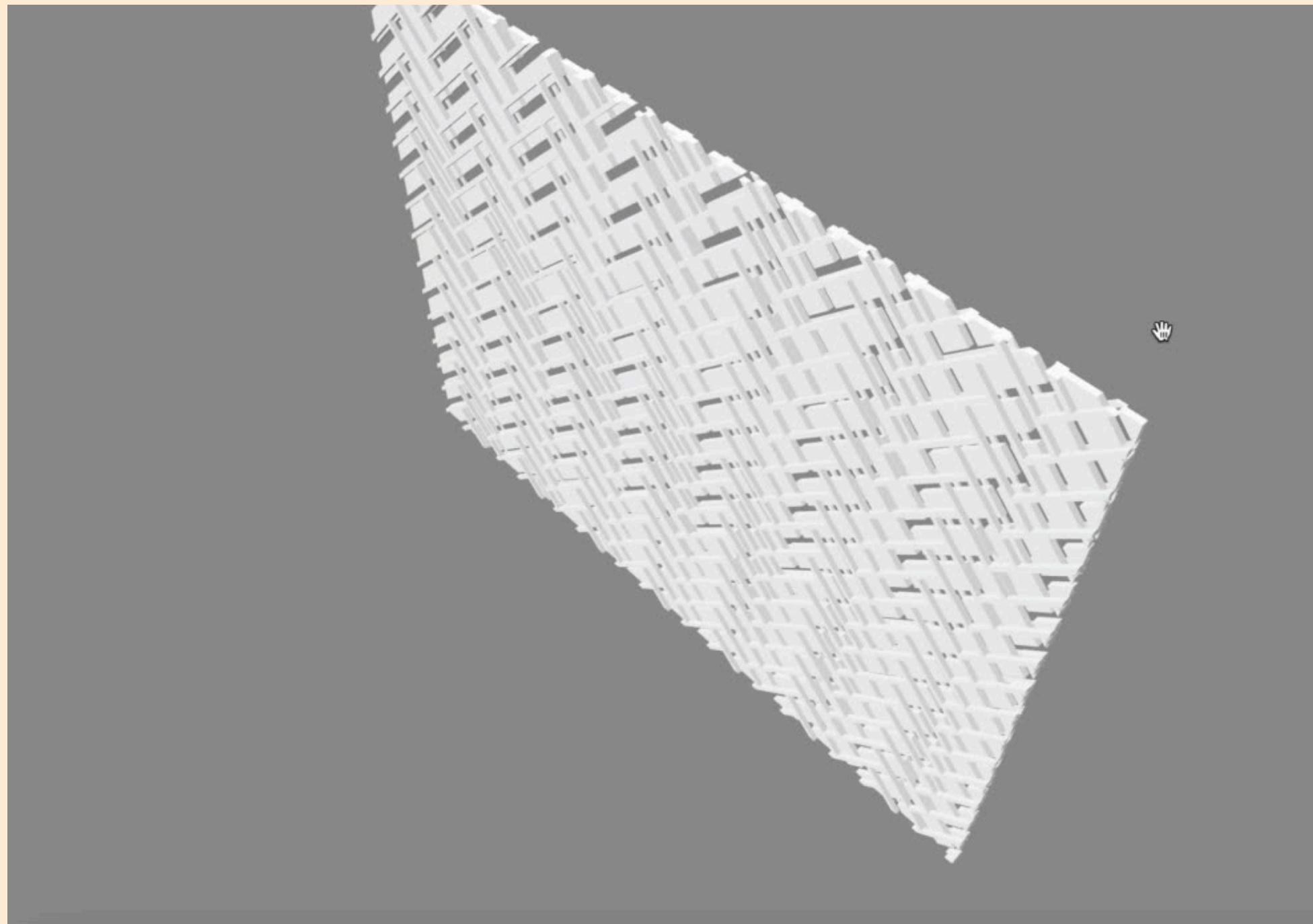
Proportion of dry Vero and Agilus in the Intima and Adventitia layers



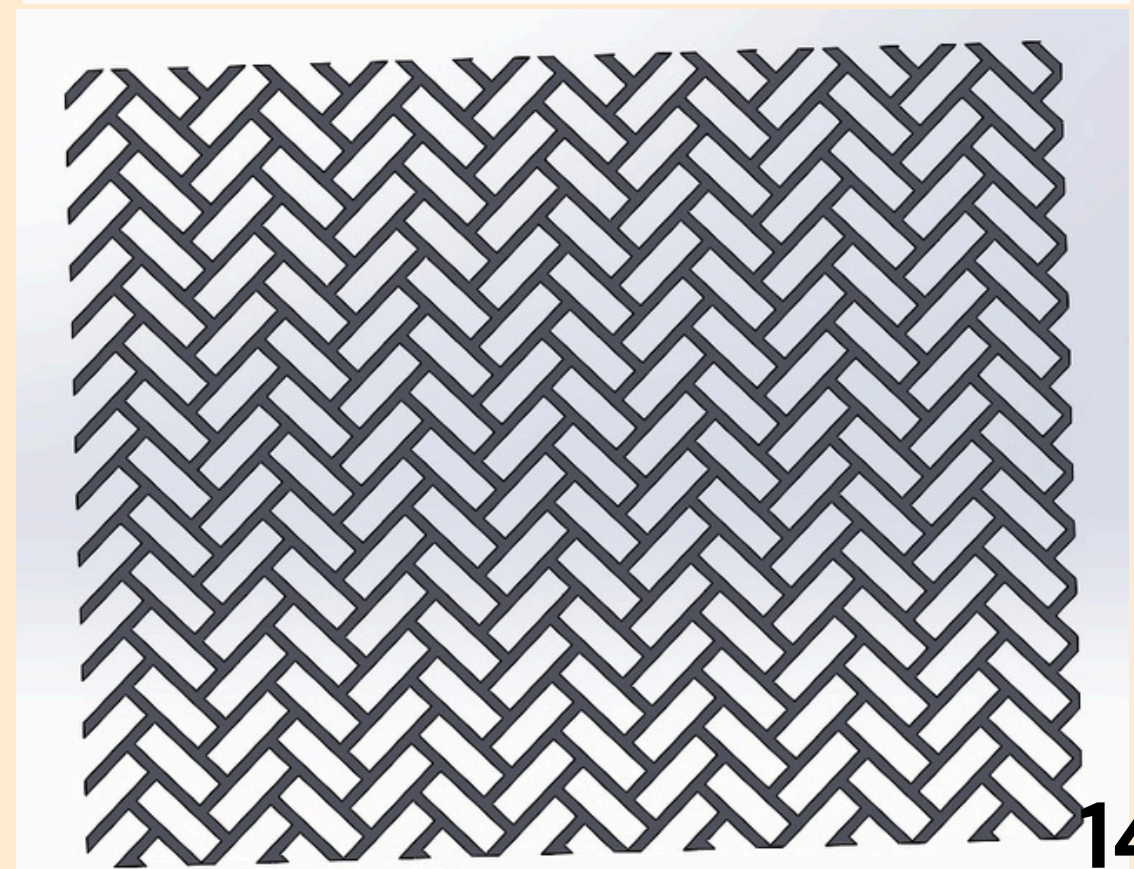


Pattern design on Solidworks

Agilus pattern

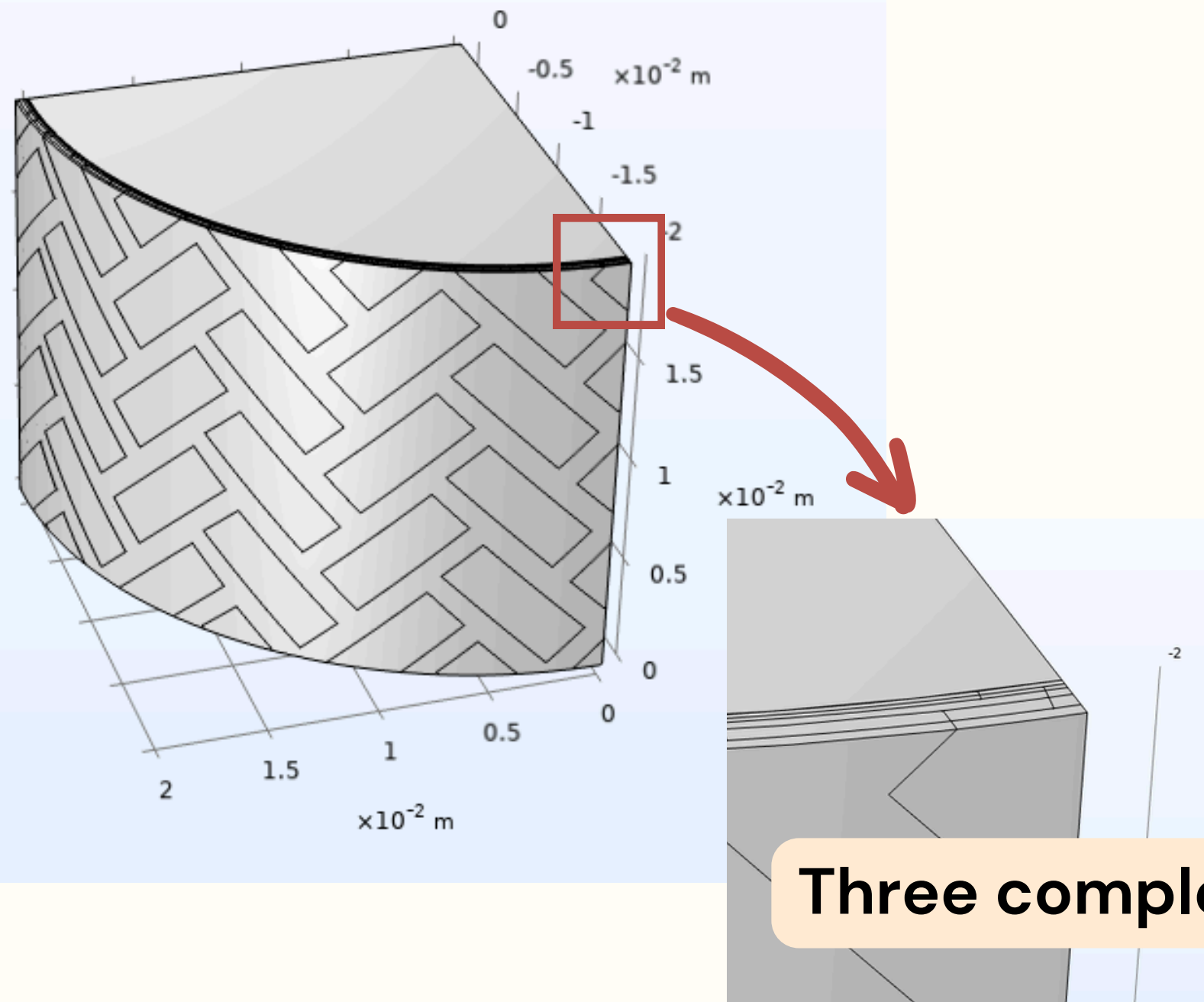


Intima
Media



COMSOL Tests

Designed Aorta Model

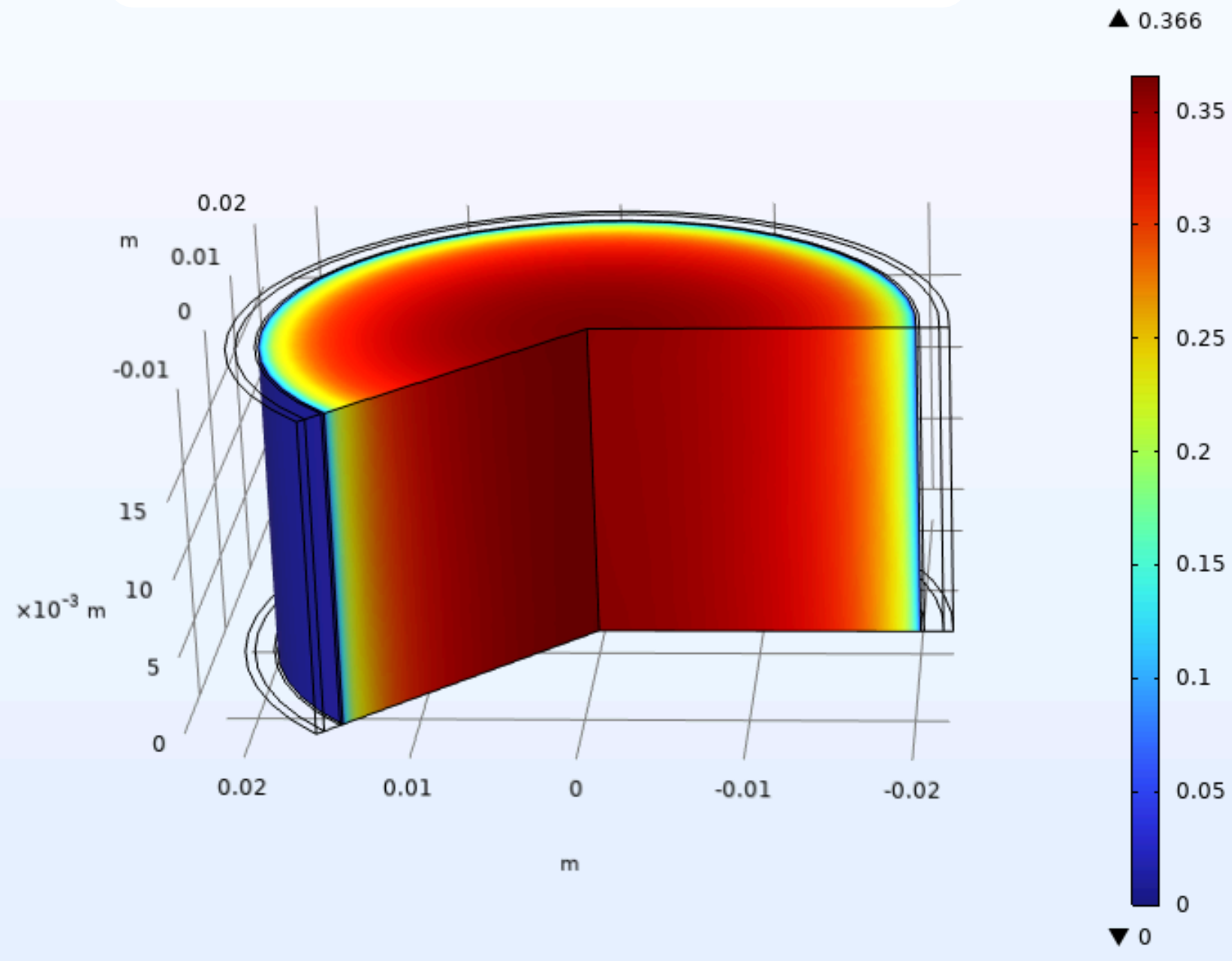


- Use one quarter of the whole cylinder and reduce the length to simplify the calculation
- Remain the same assumption as the “real” model to compare the results

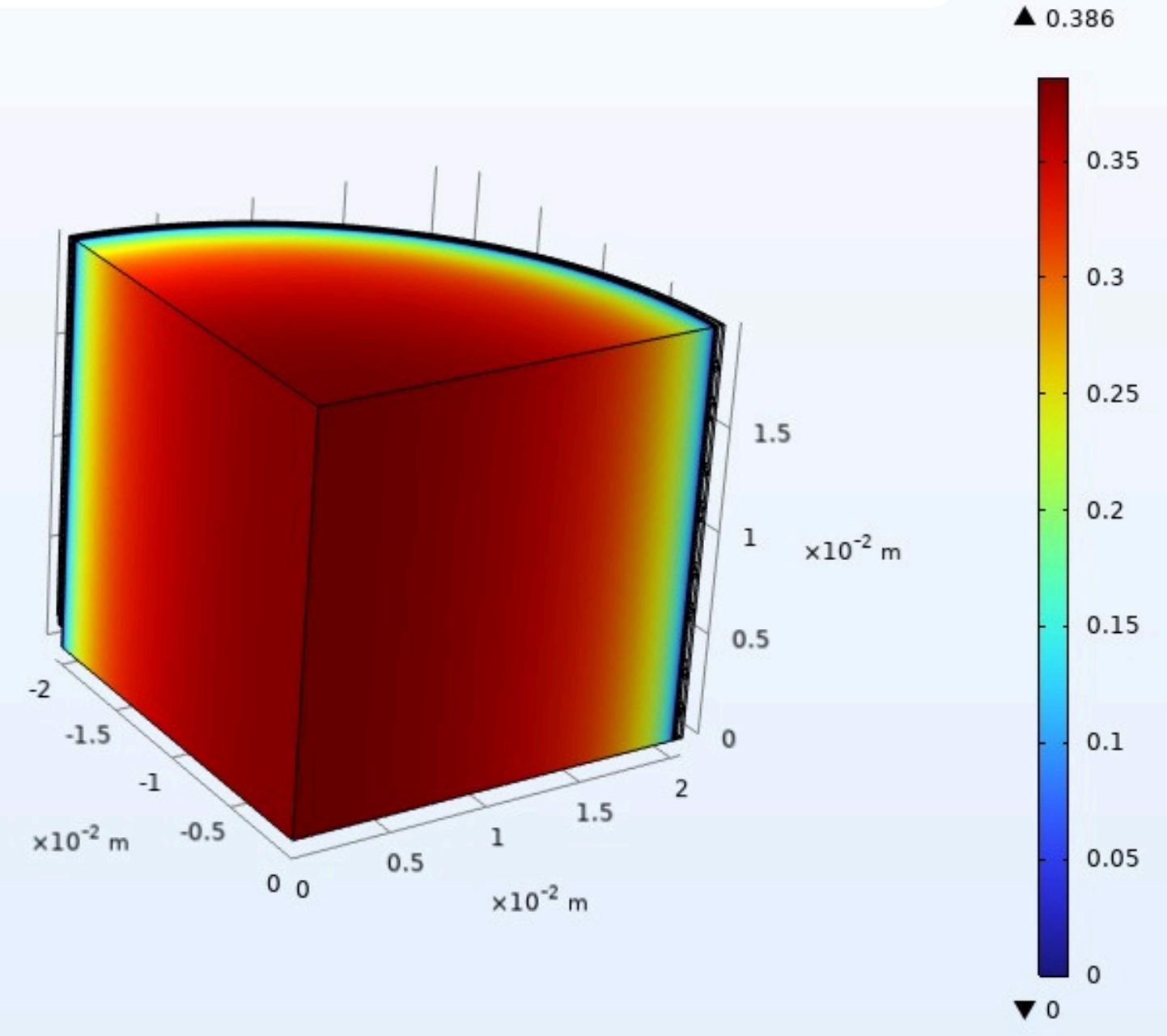
COMSOL Tests

Fluid-Structure Multiphysics

Velocity Field - "Real" Aorta



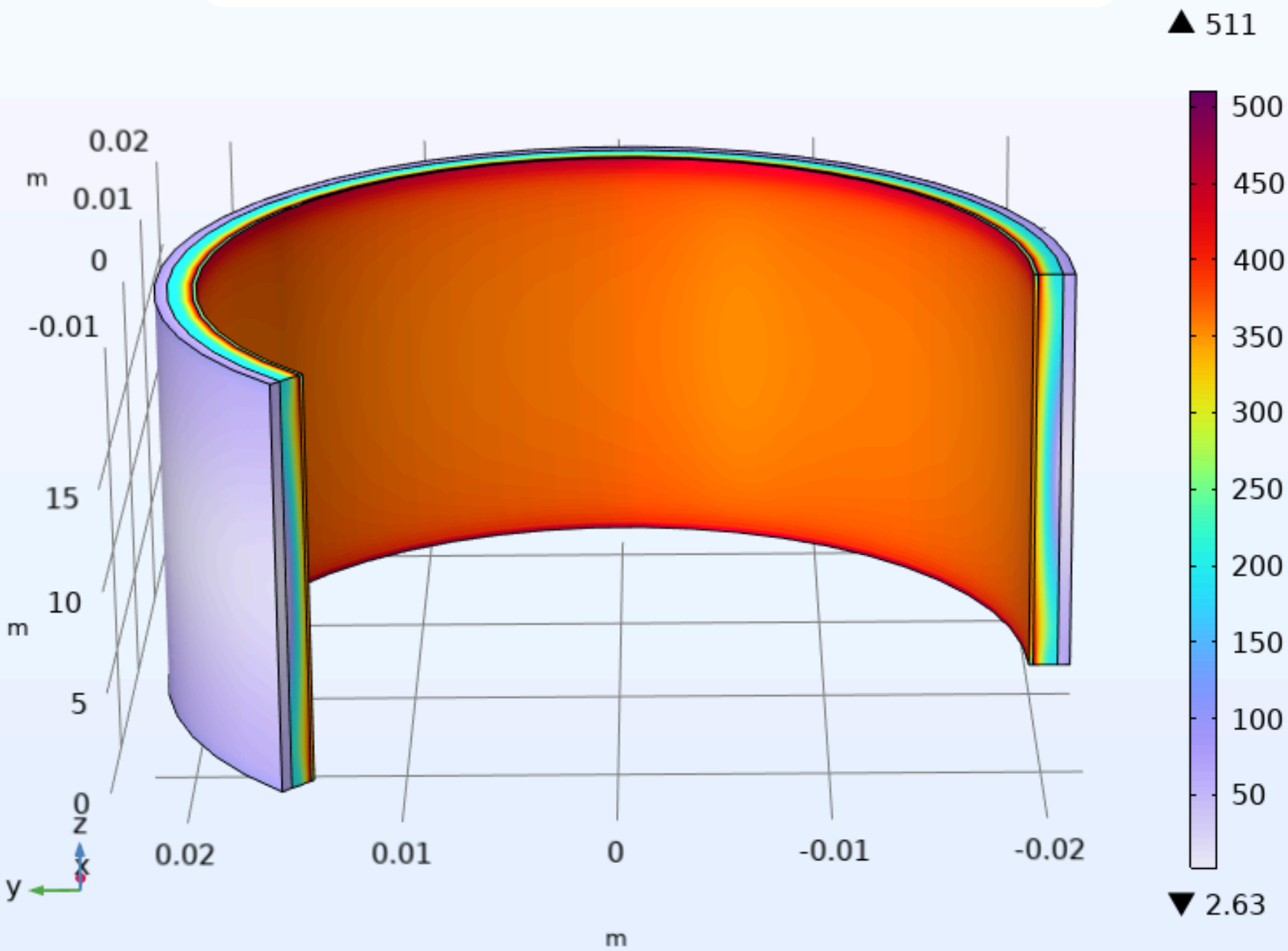
Velocity Field - Designed Aorta



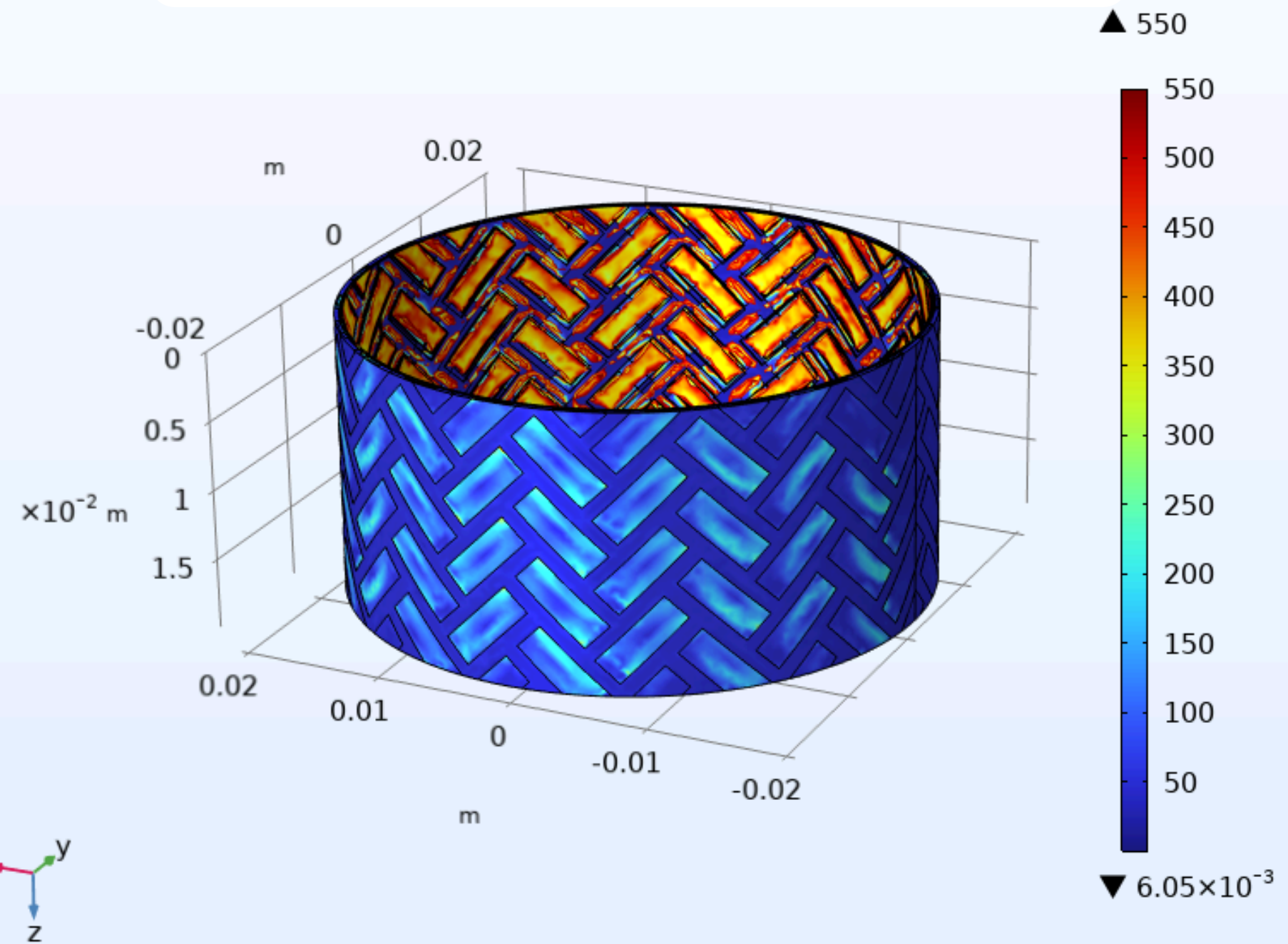
COMSOL Tests

Solid Mechanics

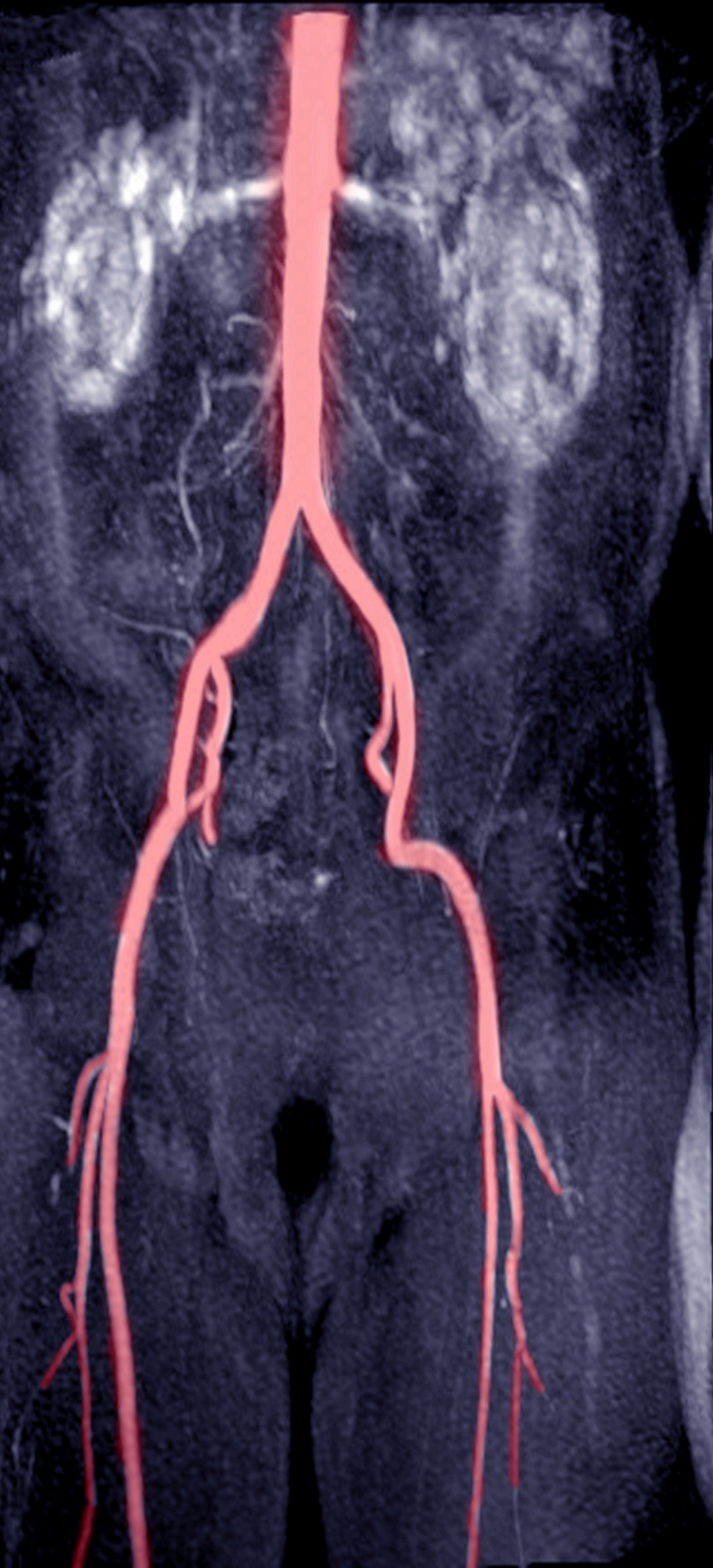
von Mises Stress - "Real" Aorta



von Mises Stress- Designed Aorta



Intraluminal pressure 160mmHg
Abdominal pressure 12mmHg

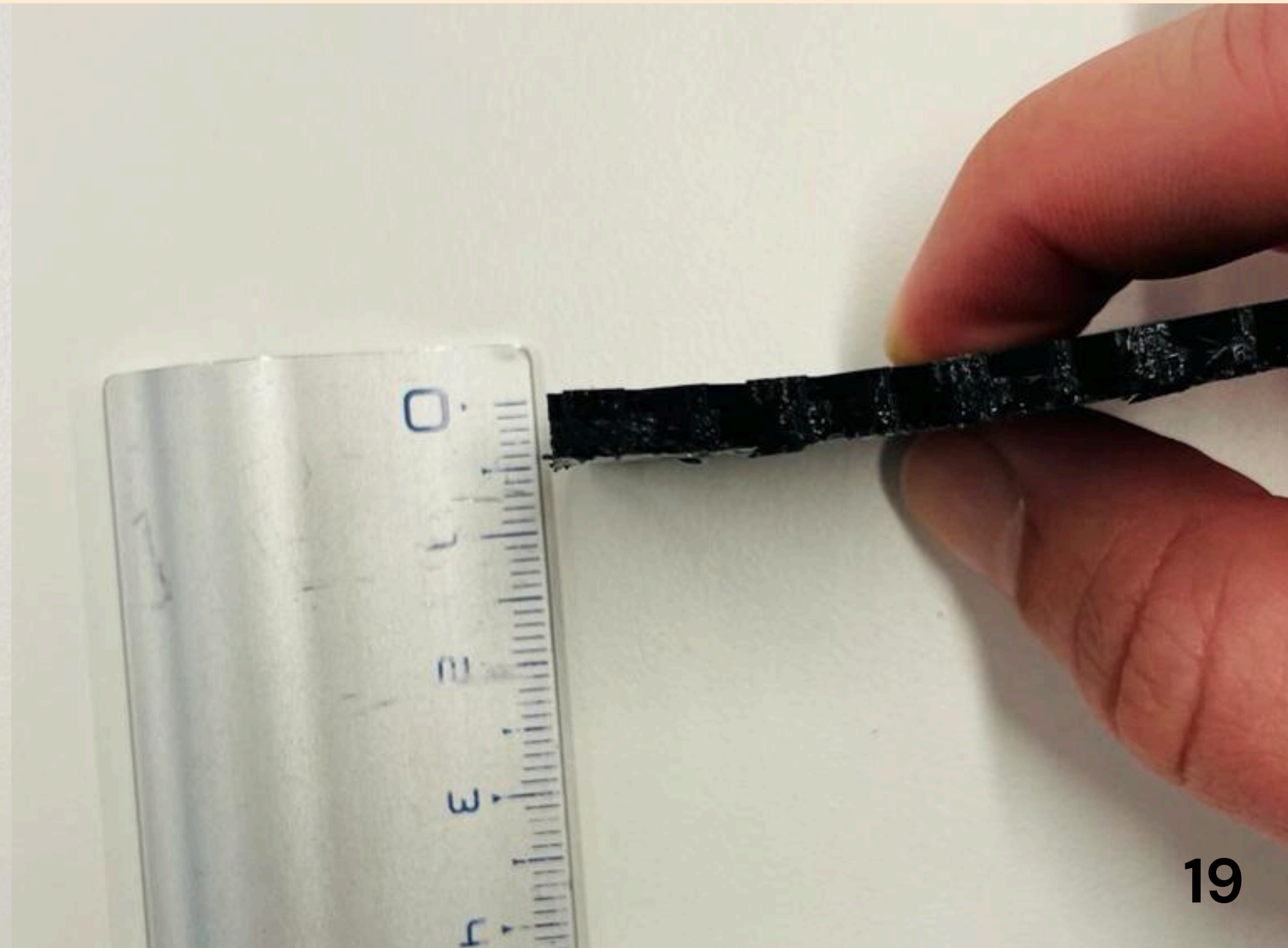


3D printing

First 3D printing of the pattern

Scale: x5

Materials: TPU



3D printing with PolyJet printer

Bimaterial

Test the resolution (smallest pattern: 0.3mm)

← aorte.margot.objzf

+

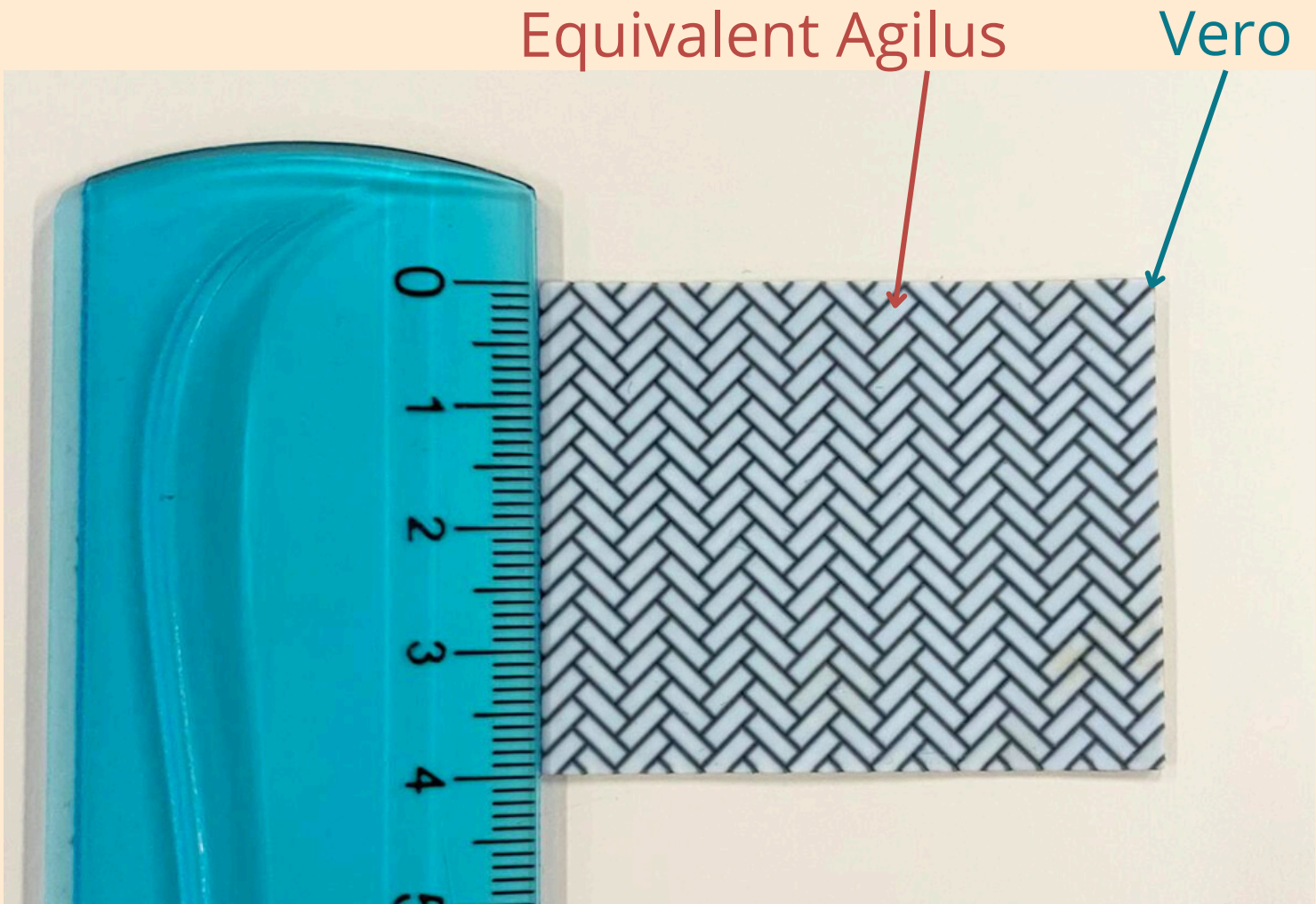
End Time ----

Duration 0h 33m / 0h 33m

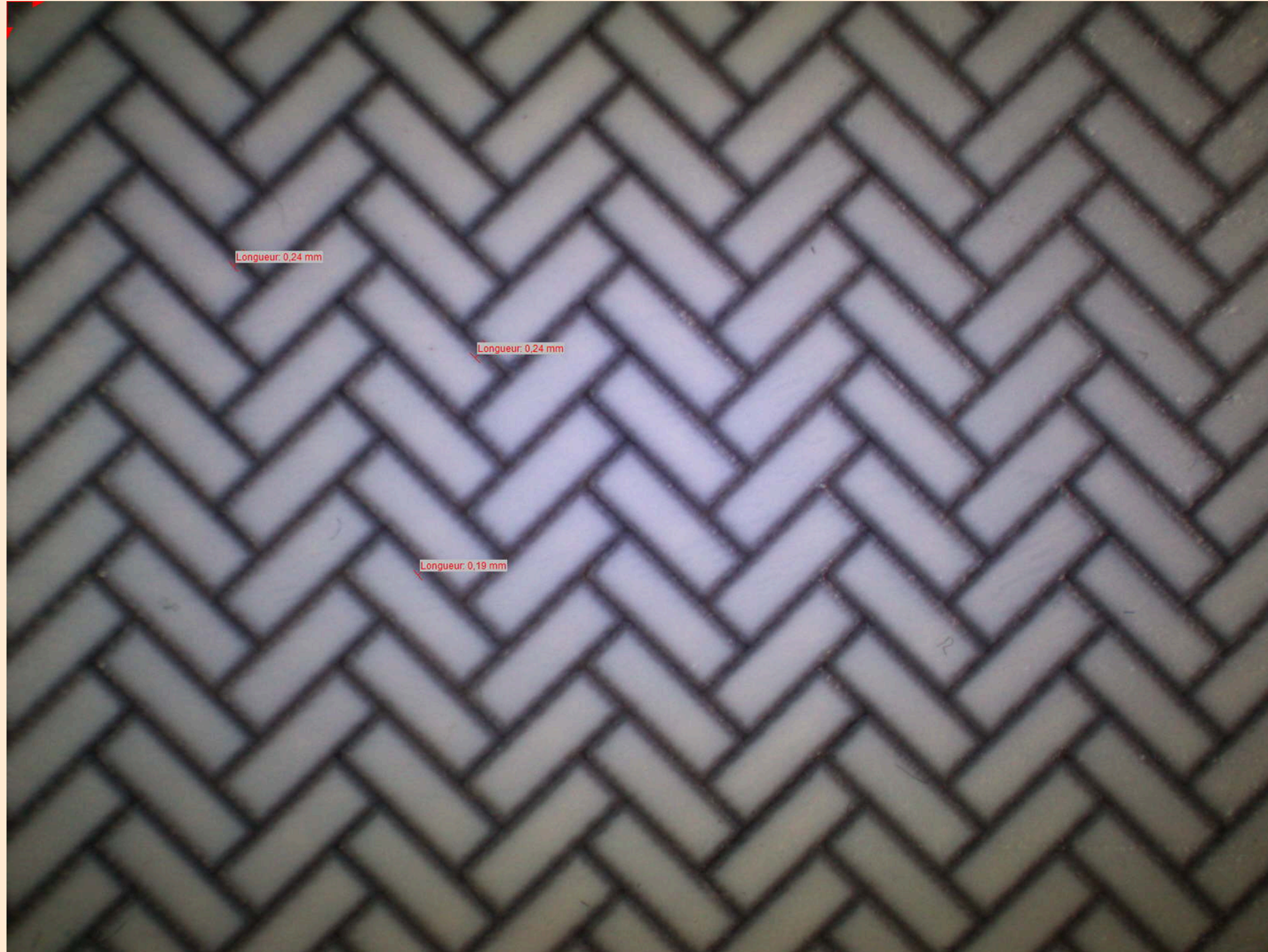
Slices Printed 214 / 214

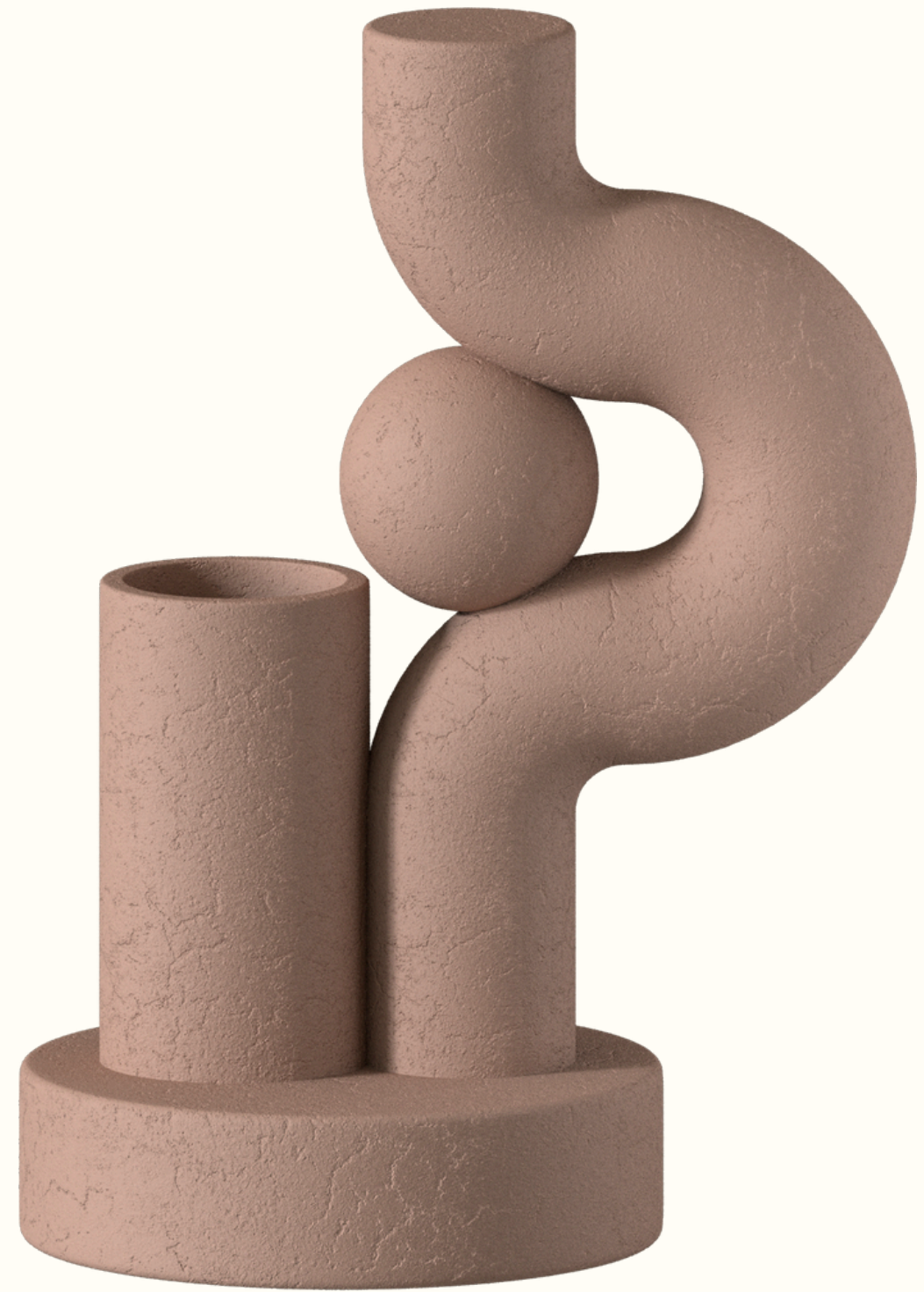
Materials	Consumed	Estimated
Elastico Black	1.0 g	5.3 g
RGD515	0.2 g	4.0 g
Ultra White	2.8 g	7.2 g
SUP710	10.3 g	13.5 g

Reprint



Microscopic observation





Conclusion

Bibliography

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