Investigation of Changes in Flow Velocity due to Wall Motion on 3D Printed Tubes Using 2D PC and CINE MRI

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I. Purpose

Blood flow imaging and quantifying is essential for diagnosis and treatment for cerebral aneurysms [1]. In this study, elastic properties of two different commercial 3D printing materials in order to mimic real human carotid artery were investigated in order to use for imaging the flow and effect of vessel wall displacement due to pulsatile (cardiac) flow to fluid velocity using 2D PC and CINE MRI. Results were compared with the flow model which has rigid wall.

II. Materials and Method

i) Determination of Elastic Modulus:

- ***Materials:*** 'Flexible' (80A shore), and 'Elastic' (50A shore) photoreactive resins (Formlabs, USA).
- ***Production Method:*** Stereolithography 3D Printer (Formlabs 3, USA).
- ***Test Method:*** Tensile Test (Zwick Roell Z05, Austria).
- ***Samples:*** Rectangular (18 pcs. 25x5x1 mm) (Fig.1a).
- ***Printing Orientation:*** α = 0˚ , 45˚ and 90˚ (Fig.1b).

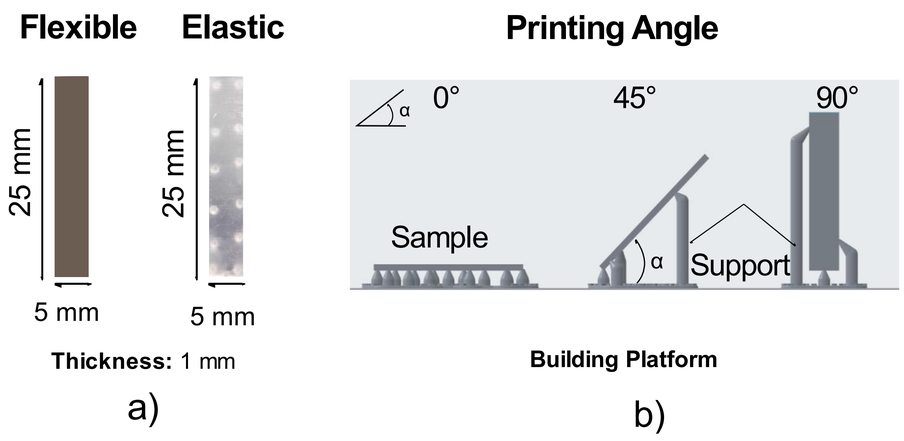

Fig. 1: Tensile test (a) and schematic view of printing setup (b).

ii) Measuring the Flow Velocity and quantification of area change due to pulsatile flow in 3D Printed Straight Tubes:

- ***Materials:*** Rigid (78D Shore) and Elastic (50A Shore).
- ***Production Method:*** Stereolithography 3D Printer (Fig. 2).
- ***Dimensions:*** Inner diameter, 6mm; wall thickness, 0˚ orientation.
- ***Fluid Mimics the Blood:*** Glycerol-water mixture (40/60 %).
- ***Flow:*** Cardiac Flow with 250 ml/min flow rate (5000 Hz PD-1100, BDC Laboratories, USA).
- ***Imaging System:*** MRI 3T (Ingenia CX, 5.6.1, Philips Healthcare, Netherlands.
- ***Velocity Measurement:*** 2D Phase Contrast MRI.
- ***Vessel Wall Displacement Imaging:*** CINE (Compressed SENSE Balanced TFE Sequence).
- ***Image Processing and Quantification of Wall Motion:*** ImageJ.

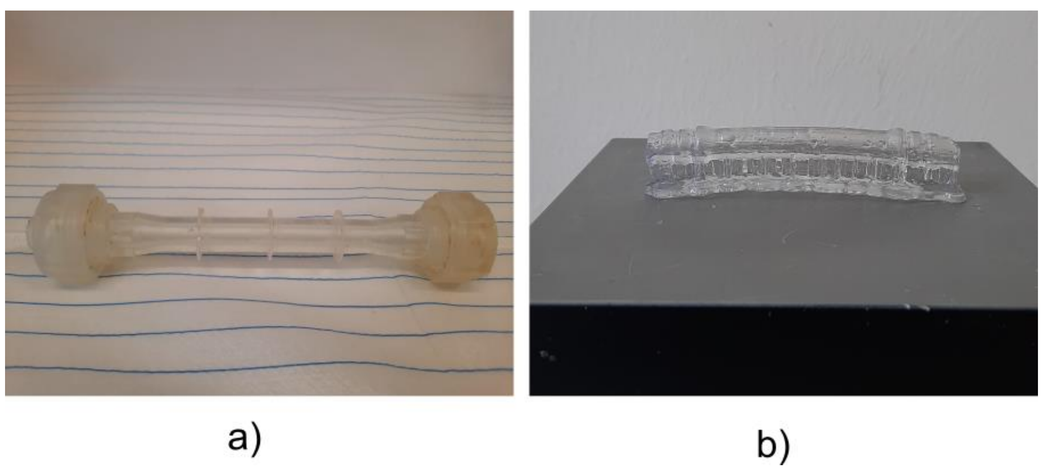

Fig. 2: Rigid Tube (a), Elastic Tube (b)

III. Results

i) Tensile Test:

- ***Number of samples:*** 18 pcs.
- *Stress-strain diagram of one elastic sample (Fig. 3a).*
- ***Elastic Modulus of Internal Carotid Artery:*** 0.75 ± 0.25 MPa [2].
- Elastic modulus of samples (Fig. 3b).

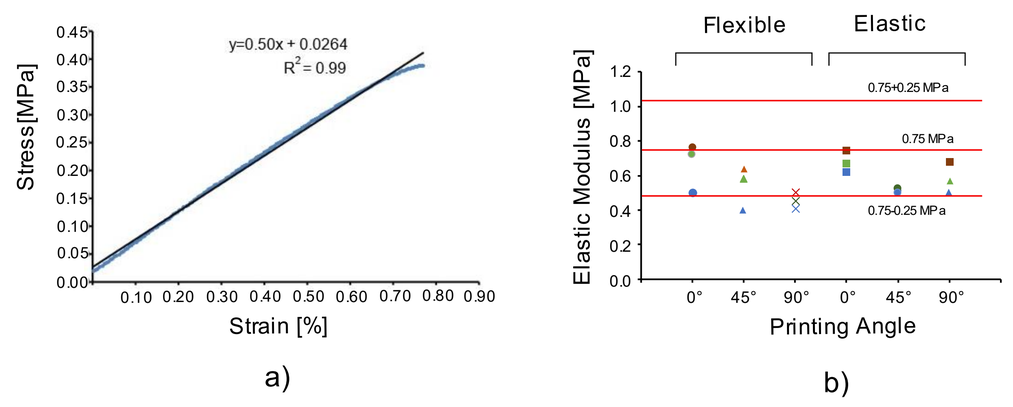

Fig. 3: Stress-strain diagram of one elastic sample (a). Elastic modulus of samples (b).

ii) Flow Velocity Measurement:

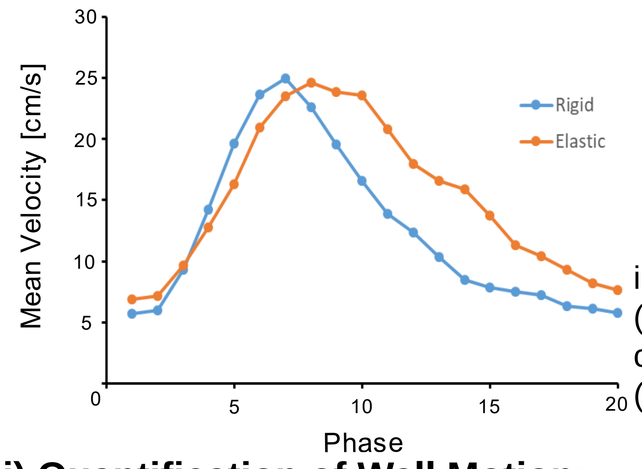

Fig. 4: Flow mean velocities in rigid (blue) and elastic (orange) tubes in one cardiac cycle with 20 phases (frames).

iii) Quantification of Wall Motion:

- ***Image Processing:*** Resizing the voxels, smoothing interpolation and thresholding (Fig.4a,b,c,d).
- **Counting voxels:** 20 Frames with voxel counting Java Script (Fig.5a).
- Area change due to number of voxels was obtained for each frame (Fig. 5b).

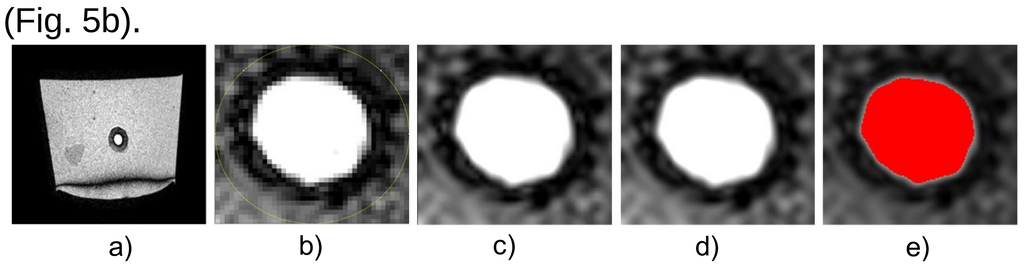

Fig. 5: CINE image (a). Cropped (b). Resizing (c). Smoothing (d). Thresholding (e).

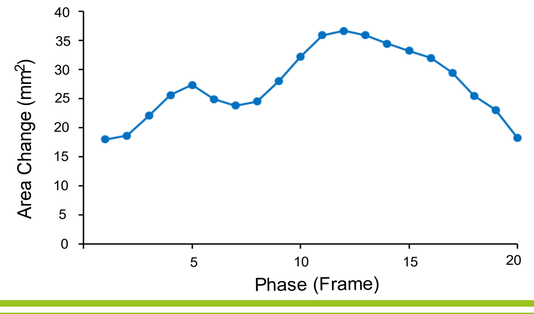

Fig. 5: Area change in elastic

IV. Discussion and Conclusion

- 0˚ oriented elastic sample can mimic real artery with elastic modulus 0,76 MPa. Flow models can be printed in this orientation.
- Mean velocity changes due to the wall displacement.

References:1.Brain Aneurysm Statistics and Facts. Brain Aneurysm Foundation. https://www.bafound.org. 2. Kamdaeng, T. et.al. Arterial stiffness identification of human carotid artery using the stress-strain relationship in vivo, UltraSonic 2012:52/3;402-411.

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