Using 3D Printing to Model Disturbed Flow Through Arteries

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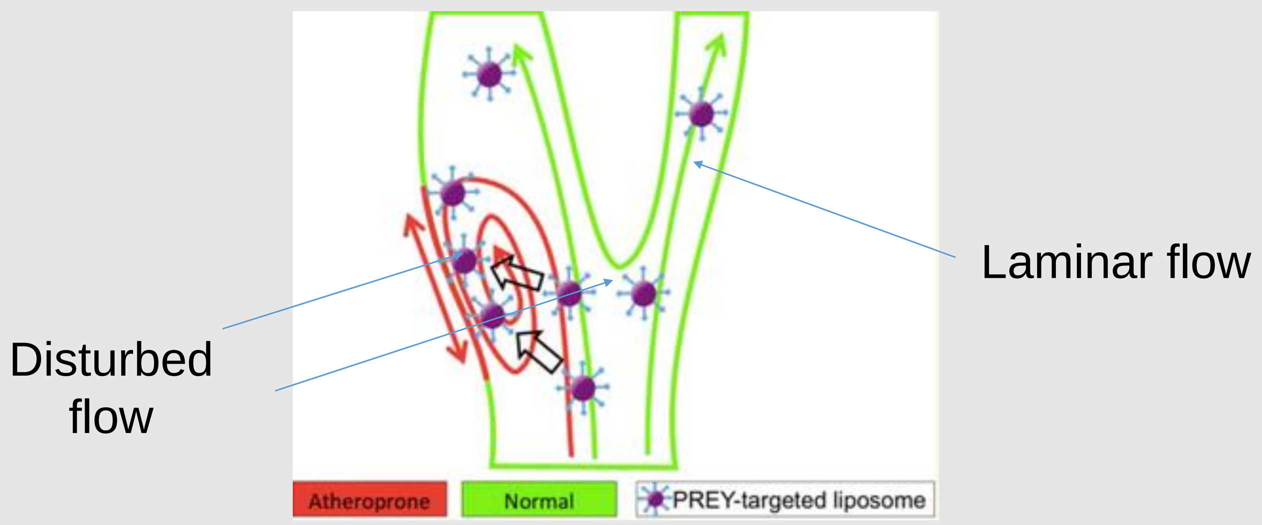
Introduction

Background

- Atherosclerosis is a disease that occurs when plaque accumulates along the walls of an artery.
- This accumulation prevents proper blood flow through the body, thus causing heart attacks and strokes.



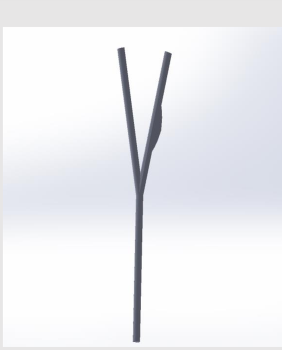
L. Hofmeister et al. ACS Nano. 2015. 28;9(4):4435-4

- Areas of disturbed flow are much more likely to experience plaque build up due to non-linear flow patterns.

Objective

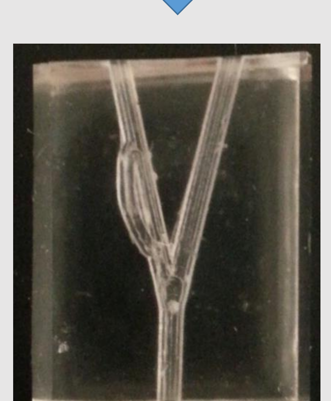
- 3D print artery-like devices that model both laminar and disturbed flow so that researchers can preform preliminary experiments on drug delivery specifically targeted to areas of disturbed flow without the use of animal models.

Fabrication Method



1. Design model using CAD

2. 3D print sacrificial template with polyvinyl alcohol (PVA), a water soluble polymer, and dip in sugar solution to fill gaps and smoothen surface.



3. Embed template in polydimethylsiloxane (PDMS) and dissolve PVA in water

4. Image velocity profile using fluorescent beads

Characterization of Particle Flow Through Channels

Step One: Image Pre-Processing

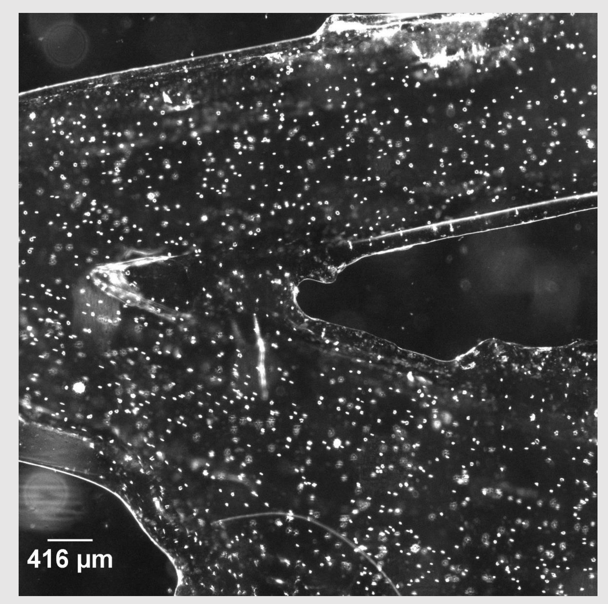


Figure 1. Original image

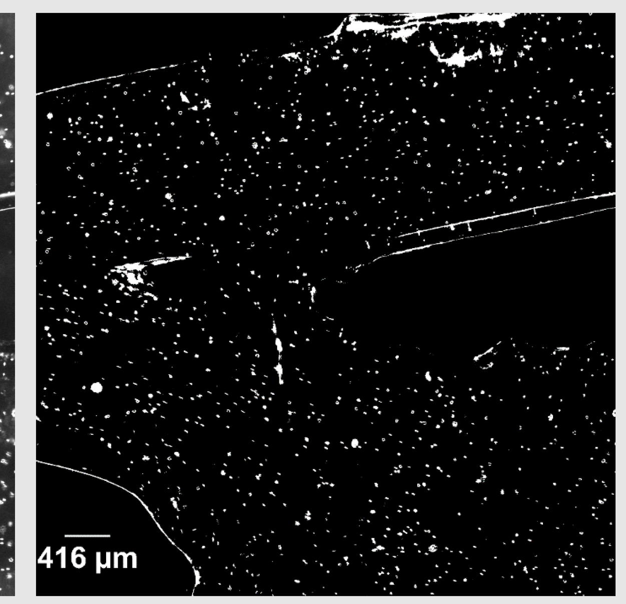


Figure 2. Thresholded image

- The first step in tracking particle flow through the channels is to threshold the image sequences.
- Purpose: to better contrast the imaging beads with the channel background

Step Two: PIVLAB Analysis

Laminar Flow

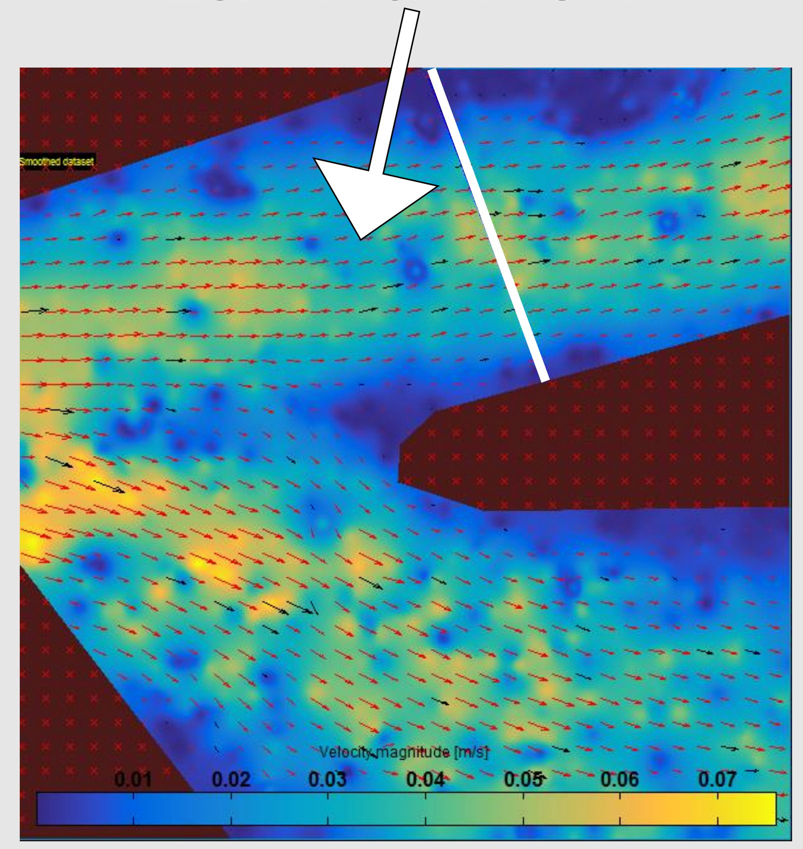


Figure 3. Velocity map given by PIVLAB analysis of device at 2.5x magnification

- PIVLAB particle tracking software visually illustrates the velocity of the fluorescent beads flowing through the channels.
- The region within the black box shows laminar flow.

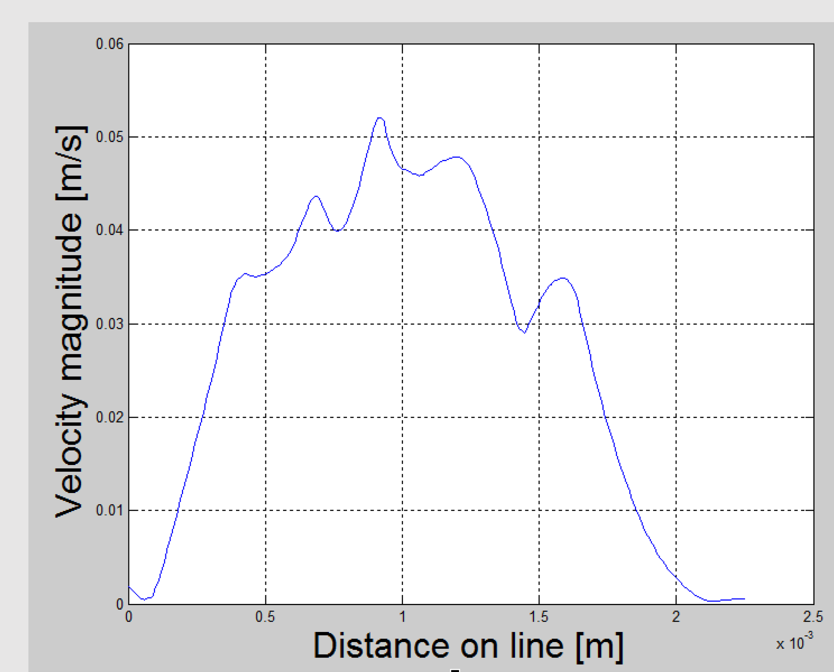


Figure 4. Graph shows velocity profile of the region denoted by the white line on figure 2. This graph shape is characteristic of fluid flow through a pipe.

Disturbed Flow

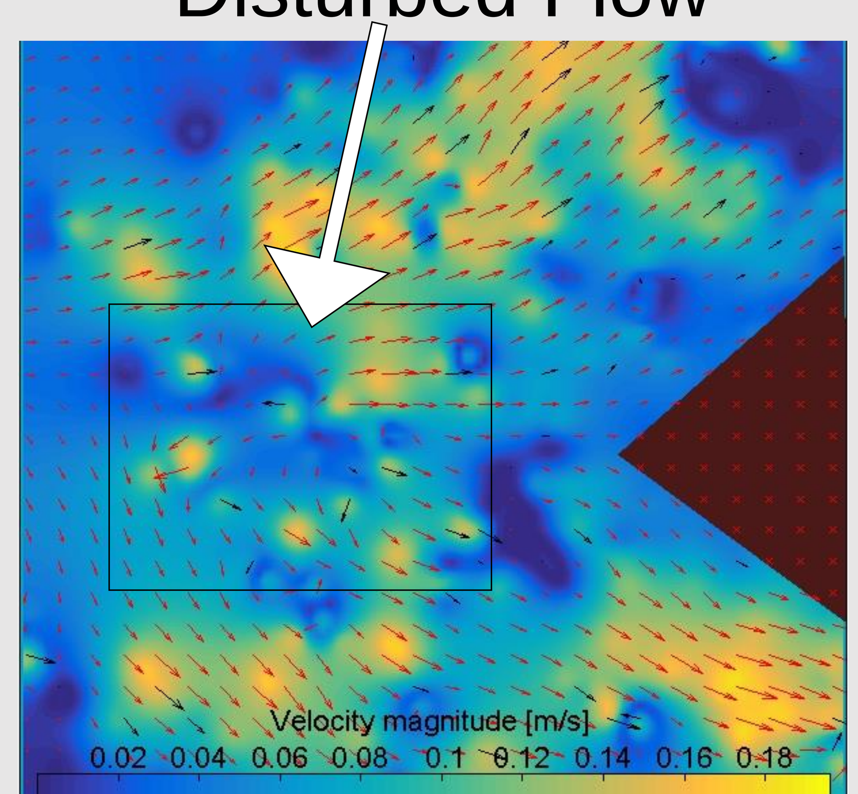


Figure 5. Velocity map given by PIVLAB analysis of device at 5x magnification

- Some branching points displayed vortical flow which is characteristic of atheroprone sites.
- **Goal**: To see more distinct vortex patterns at the branching points and sections where channel widens.

Device Characteristics

Average Diameter: 1.4mm +/- 0.3
Pump Rate: 0.020 ml/min
Reynolds Number 0.080

Modeling Mouse Artery Conditions

We want to modify these devices to simulate mouse artery conditions as closely as possible so that they can be used as a replacement for animal testing.

- Fluid flow rate has been increased from 0.020 ml/min to 0.28 ml/min to better model blood flow in a mouse.
- Slower flow patterns have been observed in the wider channel. This is likely due to differences in external tubing position during imaging.

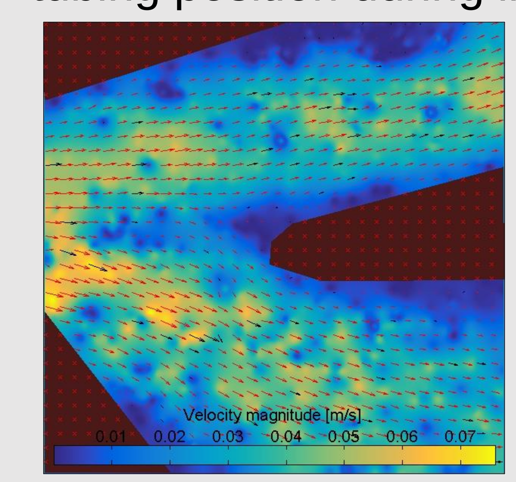


Figure 6. 0.020 ml/sec shows slightly faster flow through the widened channel

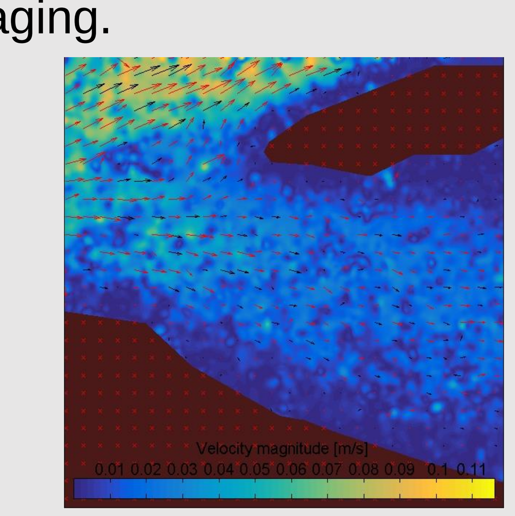


Figure 7. 0.280 ml/sec shows slower flow through the widened channel

- We have reduced the scaffold diameter from 1.4mm to about 0.50mm, which is roughly the diameter of the extruder nozzle.
- A smaller extruder nozzle would allow for both a more precise print and a diameter closer to that of a mouse.

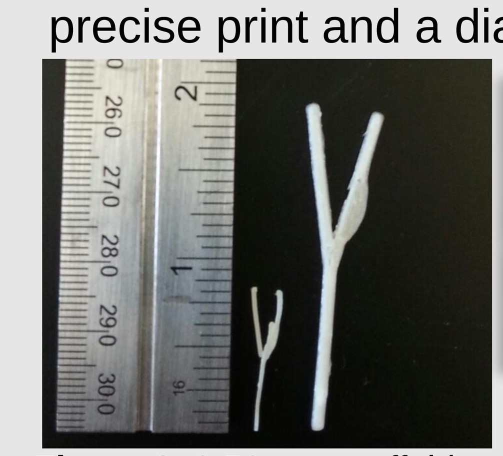


Figure 8. 0.50mm scaffold compared to 1.4mm scaffold

Mouse Coronary Artery Characteristics

Diameter[1]: 0.16mm
Blood Flow Rate[2]: 0.28 ml/min

[1]J.W. Thüroff et al. Basic Research in Cardiology. 1984. 10.1007/BF01908306
[2]Davis & Morris, Pharmaceutical Res 10, 1093, 1993.

Conclusion/Future Work

- Artery-like devices that exhibit realistic flow patterns can be produced using the 3D printer.
- Next steps:
  - Image smaller devices
  - Reduce channel diameter to 0.16mm
  - Adjust flow rate and channel geometry to increase amount of disturbed flow
  - Grow endothelial cells along channel walls

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