Flow Assessment in an *In-Vitro* Brain Aneurysm Treated with Intra-Saccular Endovascular Devices

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Background

- Using self-expanding mesh-like intra-saccular endovascular devices for treating cerebral aneurysms.
- Inducing thrombosis inside the aneurysm sac by altering the local hemodynamics leading to complete aneurysm lumen occlusion via deploying new design devices.
- In this in-vitro study, we quantify the peri- and intra-aneurysmal flow alterations of a set of varying Galaxy designed intra-saccular devices via optical imaging.
- identifying which device design reduces blood flow inside the aneurysm sac when compared to other prototypes and the control aneurysm.
- The flow hemodynamic parameters including the *"flow residence time"* and *"vorticity strength"* were compared among devices versus the control aneurysm. Longer residence time correlates with increasing a thrombosis formation. [1]

Materials and Methods

➢ *Aneurysm model*

- After IRB approval, a patient-specific with aneurysm sacs of different sizes was recruited.
- The Circle of Willis model was reconstructed by water white translucent silicon rubber with the thickness of ~2mm.
- The target dome in this *in-vitro study* was 4mm middle cerebral artery (MCA).(See Fig.1)

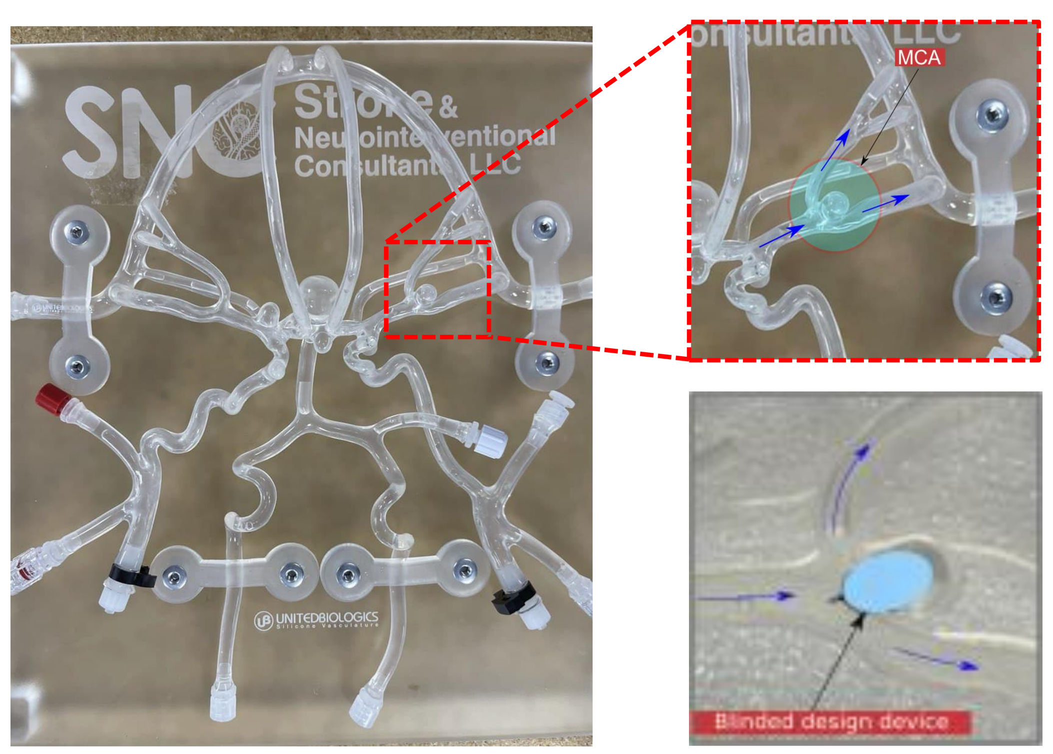


Figure1.The circle of Willis silicon model provided by Galaxy Therapeutics.

➢ *Self-expanding endovascular devices*

- A total of 10 new blinded design endovascular devices from the Galaxy Therapeutics Inc. were deployed in a common middle cerebral artery (MCA) using a patient-inspired model.
- Devices were made of Nickel-titanium with the sizes of 6mmx4mm, 6mmx4.5mm, 6mmx5mm and 5mmx3mm.

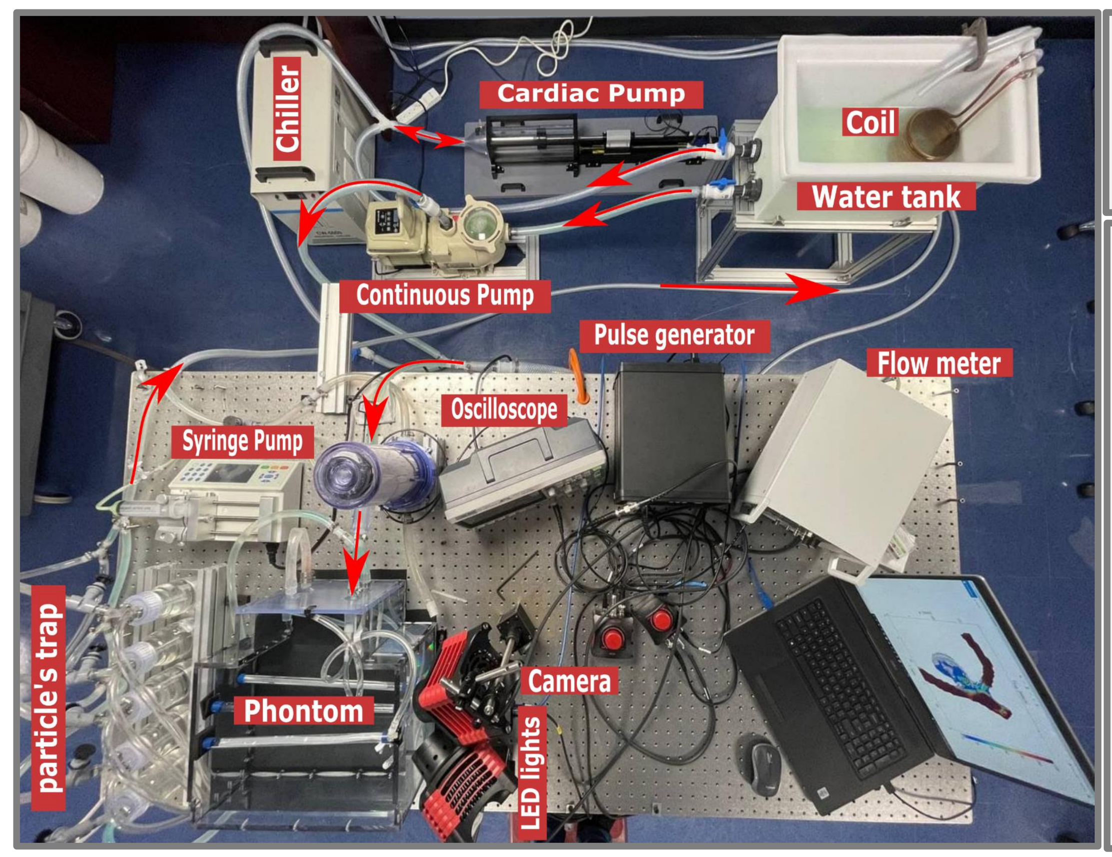
➢ *Tracer beads*

- Cospheric Fluorescent Green Polyethylene.
- Micro sphere shape.
- Size range 38-45 µm.

Materials and Methods

➢ *Experimental setup*

- The model was placed in an in-house developed flow loop where physiologically accurate steady-state and pulsatile flows can be imposed.
- The major components of the experimental setup developed for the purpose of PIV/PTV measurements are shown in Figure 2.
- The flow loop is schematically illustrated in Figure 3 which has been developed to provide the instrumentation for the *in vitro* PTV.



- High speed camera
- LED lights
- Ultrasonic flow meter
- C.F pump & pulsatile pump
- Pulse generator
- Syringe pump

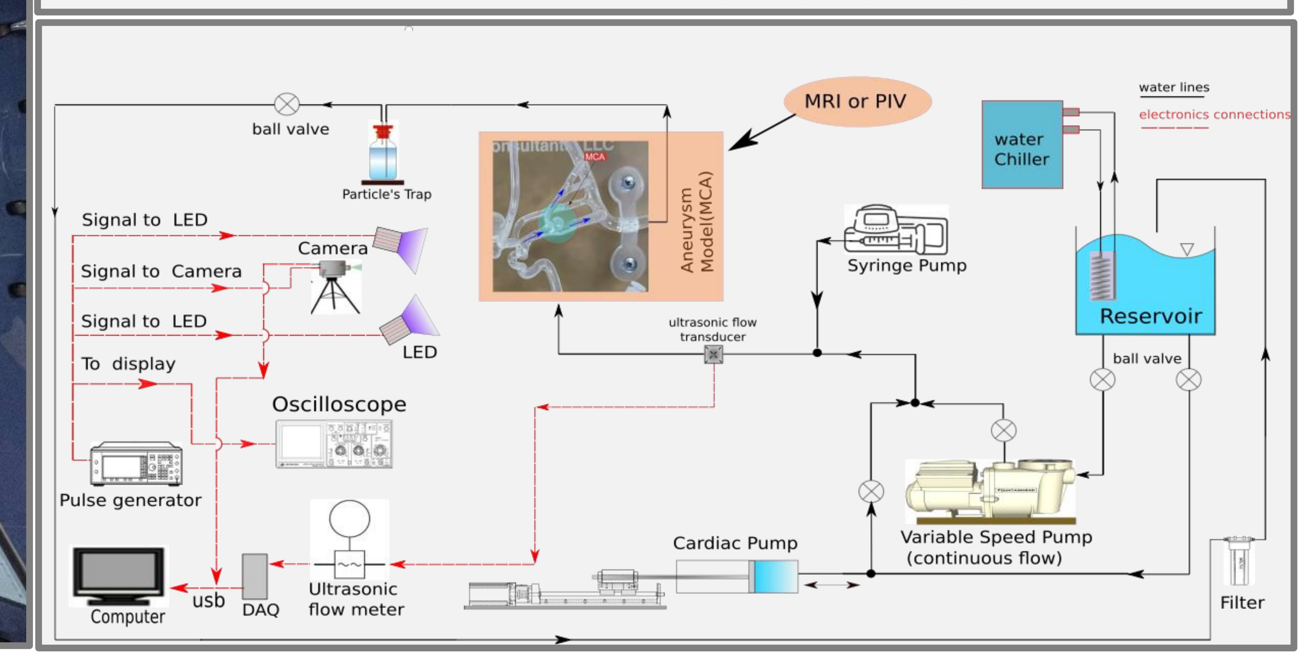


Figure2.The experimental setup for PIV/PTV

Figure3. Schematic diagram of universal experimental setup for PIV/PTV.

➢ *Flow circuit and optical imaging*

- Water was used as working fluid and then all the experimental properties are dynamically scaled as if the working fluid was blood.
- A steady-state imposed flow rate of Q=175 mLPM was considered. [2]
- A high-speed camera at a frame rate of 700 fps is utilized to capture more than 10,000 images for each case.

Results

➢ *Flow Streamlines*

- The flow pattern inside the aneurysm sac and parent vessel under the same inflow condition are shown in figure 4 for the control and select cases.
- A strong dominant vortex residing inside the sac is noticeable in the control case (Baseline).
- Depending on the device design, the persistent vortex is disrupted and replaced by a slower flow pattern.

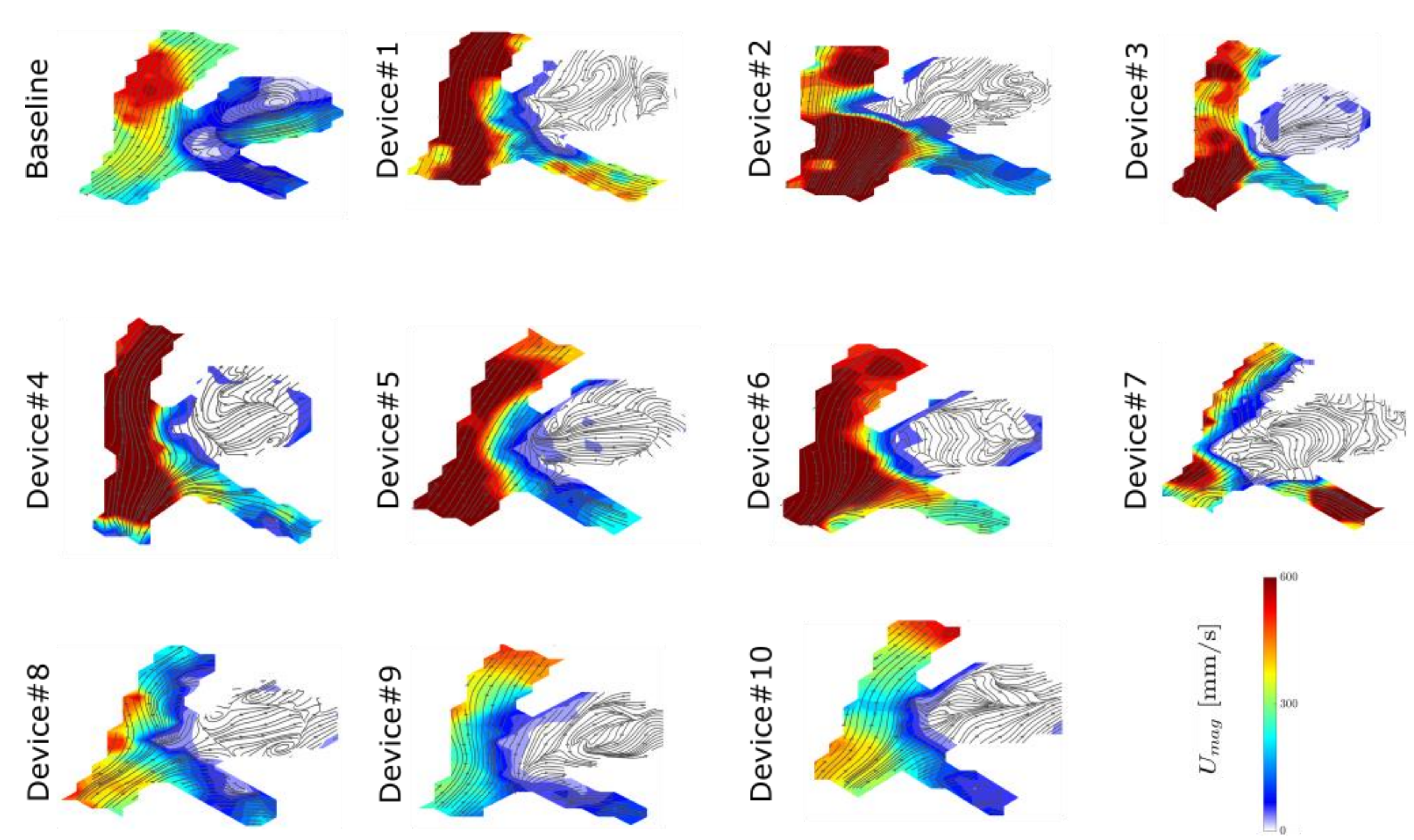


Figure 4.Flow streamline colored by the magnitude of the local velocity for the control and select cases.

Results

➢ *Flow Residence Time (RT) and Vorticity strength*

- Residence time is defined as a mean time in which tracer particles remain in the sac domain and *vorticity* measures the local rotation of fluid inside the sac.
- Once the clotting process is triggered, the thrombus is likely to form in the regions of flow separation characterized by low shear stresses and increased RT. [3]
- The longest mean RT (3.368 sec) was found for the device#7 among all devices . This device was associated with approximately the minimum value of vorticity.
- The lowest mean RT and the largest vorticity values were obtained for the Control aneurysm (Baseline).

Table1. Residence time and vorticity for all devices and baseline

Device's code	RT(s)	vorticity(1/s)
Control	0.03	91.24
Device#1	1.68	2.46
Device#2	0.63	1.73
Device#3	0.56	1.09
Device#4	1.12	1.43
Device#5	0.28	0.25
Device#6	0.60	3.30
Device#7	3.37	0.39
Device#8	0.24	2.30
Device#9	0.47	0.63
Device#10	0.43	1.73

Conclusions

- This study provides a proof of concept and methodology of estimating hemodynamic parameters qualitatively and quantitatively within the cerebral aneurysm silicon patient-inspired model.
- These data may provide the foundation of in-vitro hemodynamic quantification to be further expanded and verified/correlated against animal studies and clinical data aneurysm thrombosis and occlusion rate.

References

[1]. Long, C. C., et al. "Computation of residence time in the simulation of pulsatile ventricular assist devices." Computational Mechanics 54.4 (2014): 911-919.

[2]. Zarrinkoob, Laleh, et al. "Blood flow distribution in cerebral arteries." *Journal of Cerebral Blood Flow & Metabolism* 35.4 (2015): 648-654.

[3]. Rayz, V. L., et al. "Flow residence time and regions of intraluminal thrombus deposition in intracranial aneurysms." Annals of biomedical engineering 38.10 (2010): 3058-3069.