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Challenges in Optical Flow calculation of blood velocity for 1000 fps High-Speed Angiography (HSA)

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INTRODUCTION

For vascular intervention such as treatment of vessel stenoses and aneurysms, knowledge of detailed blood flow before, during, and after an endovascular intervention may be critical[1]. This work examines the methods used in the determination of quantitative details of vascular flow using the Optical Flow (OF) method when blood velocities are high in neuro and cardio arteries.

Optical Flow provides detailed velocity for each 100 μm pixel of the 1000 fps Aries Detector. Velocity was calculated using standard OF techniques, which are based on contrast intensity changes between frames on a pixel-by-pixel basis then refined using conservation of mass. Although the 1000 fps HSA being developed by our group should have sufficient temporal resolution for accurate determination of the 20-100 cm/sec velocity distributions of blood within major vessels, various difficulties such as streamline flow of contrast media and lack of contrast edges, can be challenging for OF velocity calculations. Pulsatile blood flow and pulsatile contrast injection can help mitigate velocity underestimation of OF on streamline flow.

METHOD

A flow loop with a controllable pulsatile output was used to send a blood-like 40/60 glycerol/water mixture into a 3D-printed patient-specific vascular phantom during x-ray acquisition of an x-ray angiographic sequence. The sequence was acquired with a high-speed CdTe single-photon counting detector (Aries, from Varex). The image sequence is then processed by the OF method between successive frames to determine flow velocities. An automatic contrast injector was used for injection of omnipaque contrast.

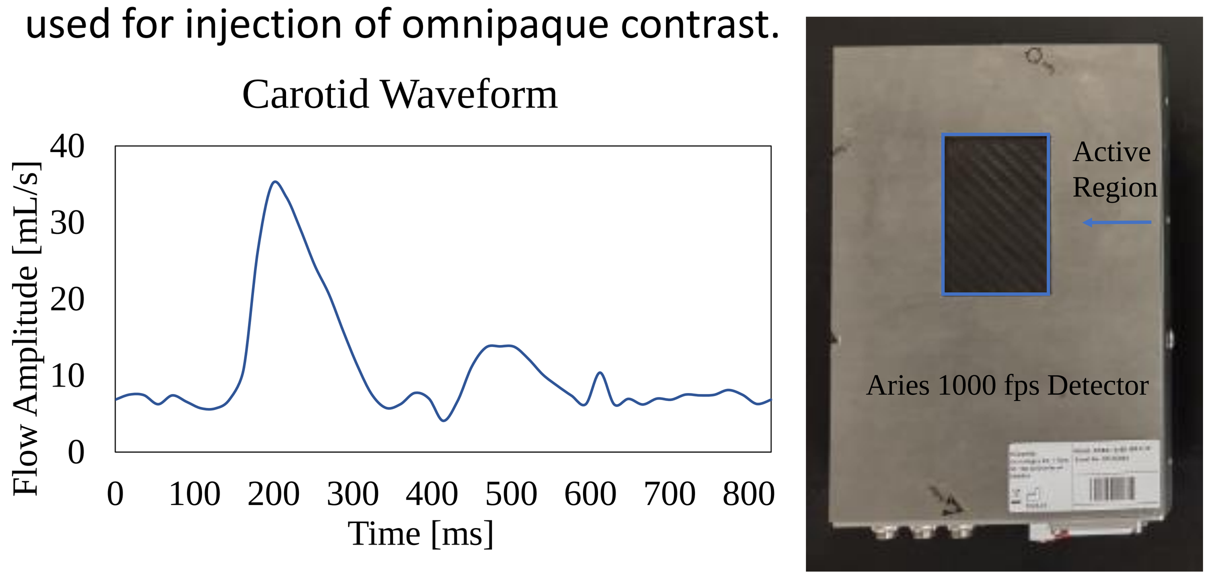


Figure 1. (Left) Carotid waveform used for pulsatile anatomically-realistic flow. (Right) 1000 fps CdTe 100 μm pixel pitch single photon-counting detector (Aries, from Varex).

RESULTS

Optical Flow (OF) begins with the Horn-Schunck method using image intensity differences based upon gradients of brightness, followed by application of the method from Liu and Shen[2] which uses physics-based conservation of mass and boundary conditions to determine velocity[3].

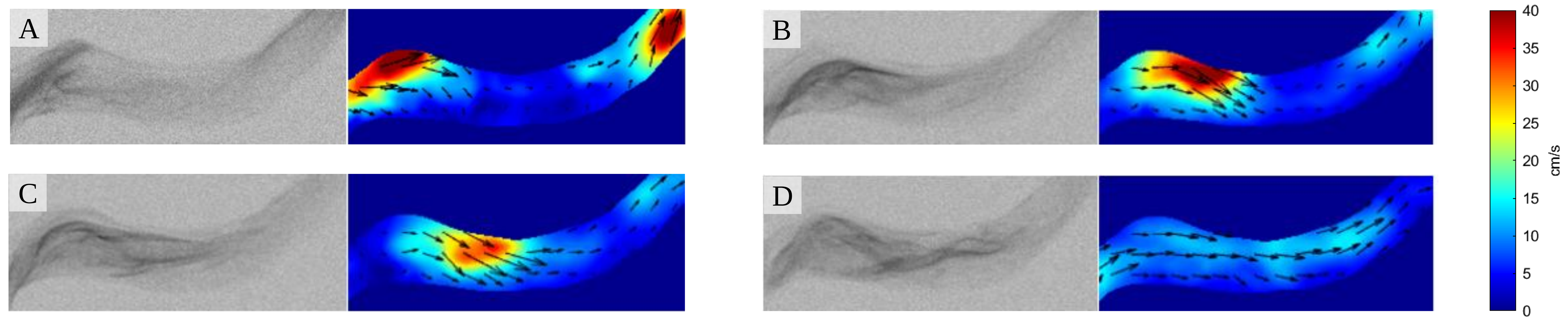


Figure 2. (A-D) Single images from 1000 fps image sequence and corresponding OF velocity calculations. In all images, flow is from left to right. These illustrate how the OF excels in locations where there is a large contrast gradient. Contrast intensity changes between frames are related to the velocity in the image plane; the motion estimates are made on a 1 ms pixel-by-pixel basis. Areas with insufficient contrast gradients are misrepresented with underestimated velocities.

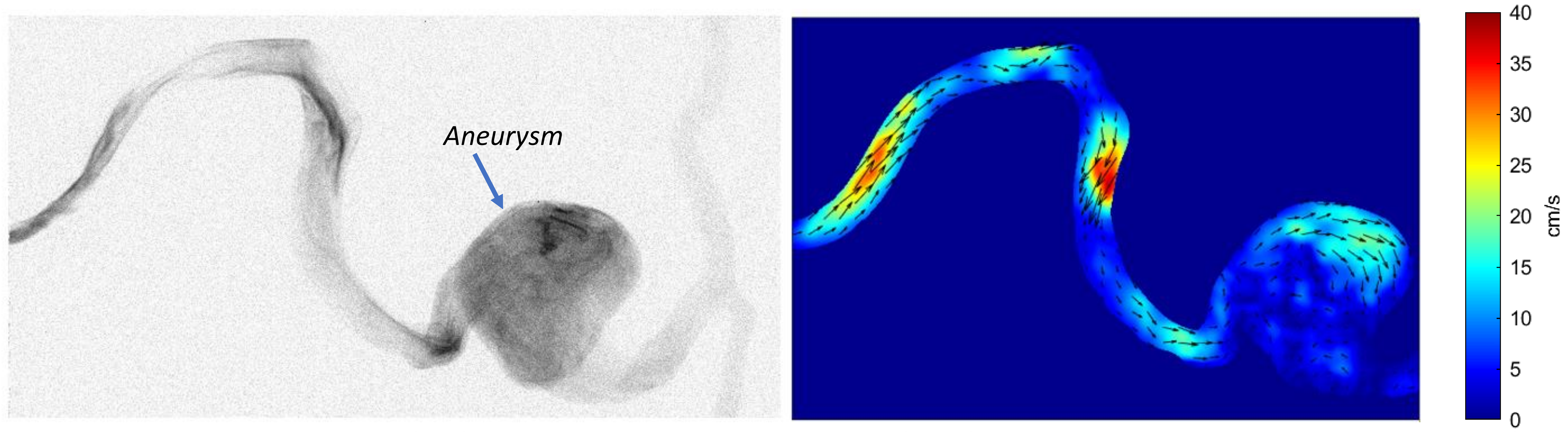


Figure 3. Model 1: HSA 1-ms frame (Left) and its corresponding OF 1-ms frame (Right) from HSA acquisition of internal carotid artery (ICA) aneurysm. In areas where the contrast intensity changes dramatically, such as at the front of a contrast bolus, velocity is effectively and accurately measured. Some models such as this one, with its bends and curves, are able to break up the contrast media as it flows in.

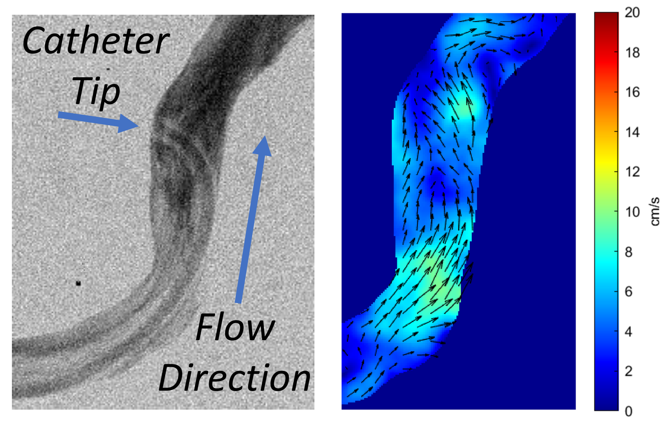


Figure 4. 1-ms frames of contrast injection with curved catheter with multiple holes.

Regions with little change in contrast intensity exhibit low velocity in the OF image. When analyzed in the full image angiographic sequence, a more consistent higher velocity in the inlet region would be seen. As contrast is less streamlined in Figure 4, OF calculations become more accurate though there are still areas of underestimated velocity.

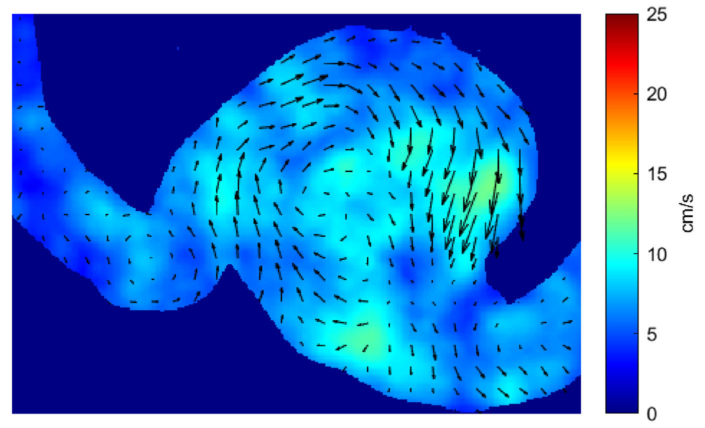


Figure 5. (Left) Model 1: OF 15-frame velocity average illustrating flow within aneurysm.

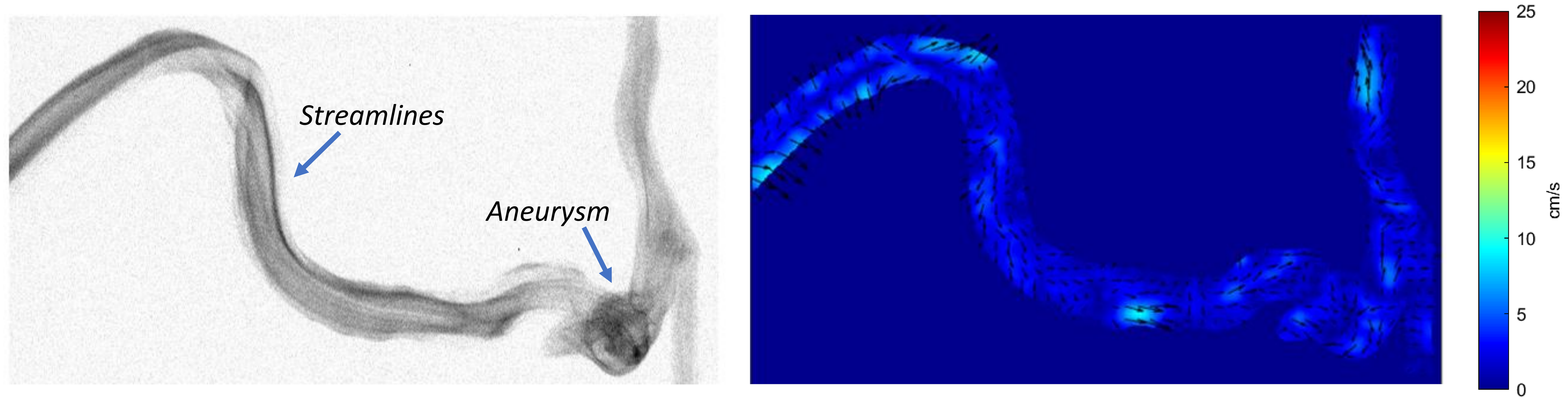


Figure 6: Model 2, HSA 1-ms frame (Left) and its corresponding OF 1-ms frame (Right). Flow direction is from left to right. Even 20 ms later, the streamlines look almost identical and there is no clear contrast difference due to the streamlined flow. Due to the extreme uniformity of the streamlines of contrast, velocity measurements are severely underestimated. Flow velocity should be closer to 20 cm/s during this time. A larger temporal filter may contribute to the lower velocities. With this model it is more difficult to get clear contrast bolus leading edge and its geometry and catheter output do not break apart the contrast for OF calculations.

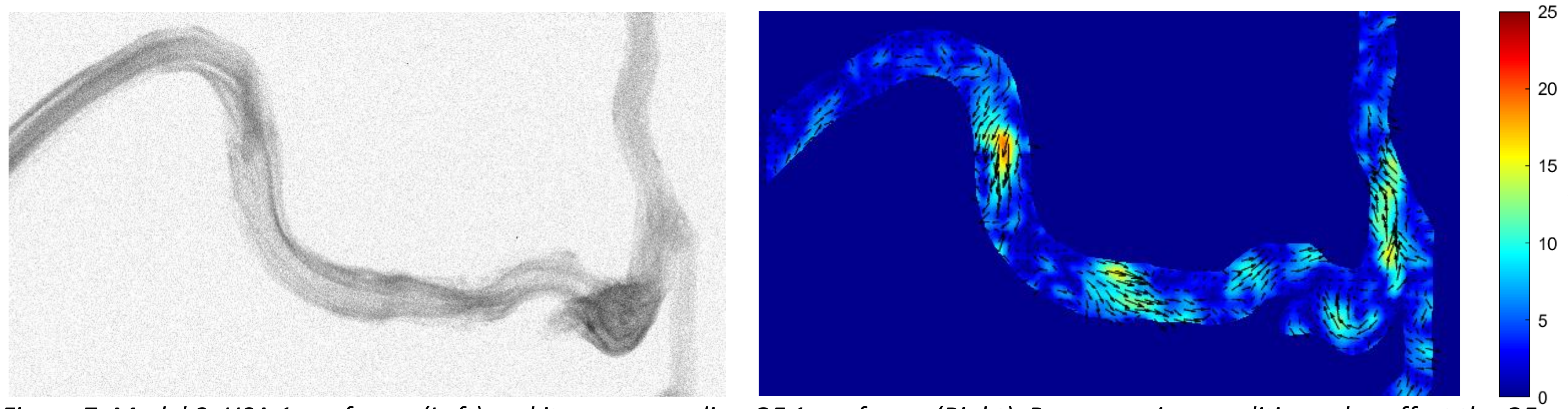
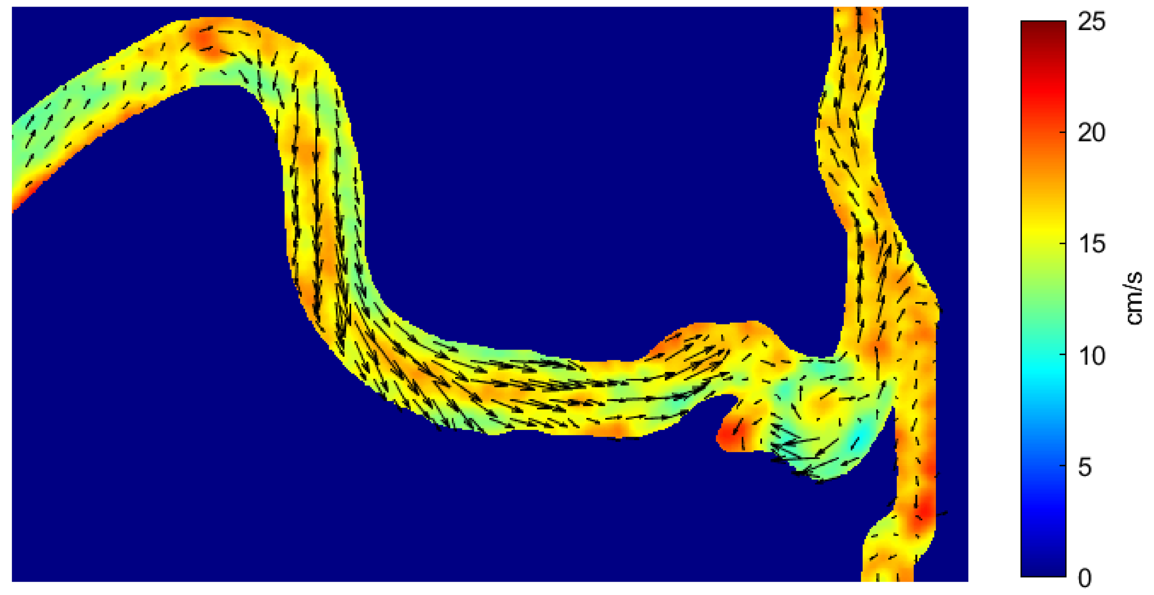


Figure 7. Model 2, HSA 1-ms frame (Left) and its corresponding OF 1-ms frame (Right). Preprocessing conditions also affect the OF calculation, specifically harsh temporal filters can lower calculated velocity. Figure 6 has a higher temporal filtering (0.8 bias Kalman filter) than Figure 7 (0.8 weighting recursive filter) which makes Figure 7 have more accurate velocities.

Figure 8. (Right) Model 2: OF 200-frame (200 ms) velocity average. Circulation in the aneurysm is clearly visible along with expected velocity and direction. By combining the results of the sequence of 1-ms frames, overall understanding of the velocity magnitude and direction can be evident without showing the entire 1-ms sequence.



OF calculations rely upon spatial and temporal changes of the contrast from pixel to pixel. Slight filtering can suppress noise while enhancing these contrast gradients for better OF calculations.

CONCLUSIONS

Optical flow excels where there are large contrast intensity gradients, such as where there are boluses of contrast. Pulsatile contrast injection or disturbed injection via an angled catheter tip can create better boluses of contrast and may be better suited for OF velocity calculations. Preprocessing of the image sequence can also affect the OF velocity calculations, optimal filtering in both spatial and temporal direction will be beneficial, while over- or under-filtering can hinder OF calculations. These improvements will be implemented in future HSA OF calculations.

REFERENCES

[1] Yang, Z., Optical Flow Method for Blood Flow Velocimetry Based on Digital X-Ray Subtraction Angiography: A Brief Review. Research and Reviews: Journal of Medical and Health Sciences, 2017. 6: p. 8-12.
[2] Liu T, & Shen L (2008). Fluid flow and optical flow. *Journal of Fluid Mechanics*, 614, 253–291. 10.1017/s0022112008003273.
[3] Liu T (2017). OpenOpticalFlow: An Open Source Program for Extraction of Velocity Fields from Flow Visualization Images. *Journal of Open Research Software*.

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