

Venous Mapping of Vascular Malformations using Cranial 4D Flow MRI with Improved 'Virtual Injections'



Presenter: Grant Roberts



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Declaration of Financial Interests or Relationships

Speaker Name: Grant S. Roberts

I have the following financial interest or relationship to disclose with regard to the subject matter of this presentation:

Company Name: GE Healthcare

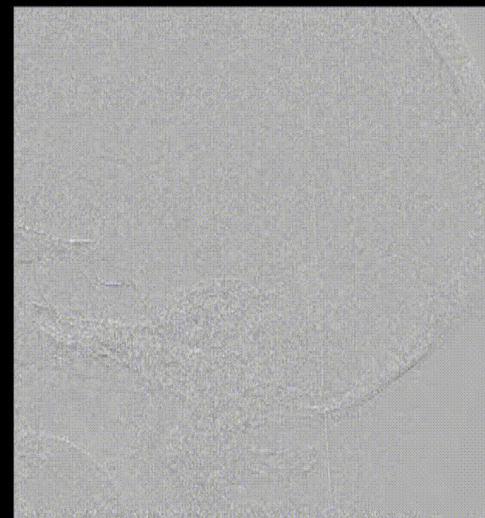
Type of Relationship: Research Support





- Management of intracranial vascular lesions can be complex with significant morbidity/mortality
- Transvenous embolization (TVE) is a common method to treat DAVFs¹
 - TVE for AVM treatment has recently gained interest²
- However, accurate characterization of venous drainage is essential to the TVE approach
- Digital subtraction angiography (DSA) is gold standard diagnostic imaging

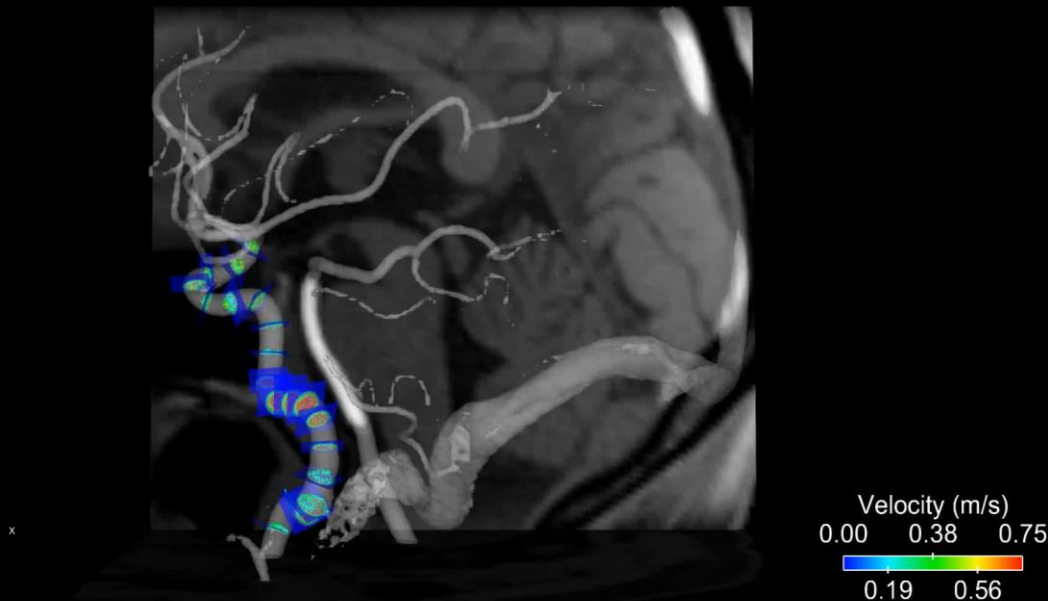
DSA



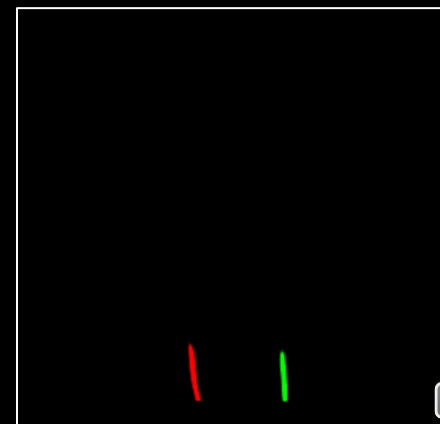
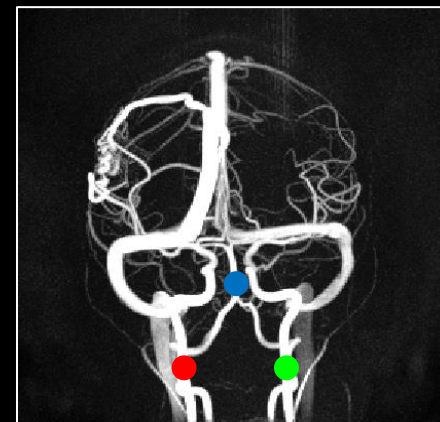
1. Urtasun, F, et al. *Radiology*. 1996; 199(1)
2. Chen, CJ, et al. *Neurosurg Focus*. 2018 Jul;45(1)



- 4D Flow MRI provides time-resolved velocity fields over a 3D volume³
 - Provides morphology and dynamic velocity fields simultaneously with high resolution
 - Significant advances over the last decade



- One compelling use of 4D flow data is streamlines traced through time, similar to contrast injection^{4,5}
 - No need for an actual injection
 - Can 'seed' at any location within volume
 - Can track retrograde or anterograde flow
 - Can greatly aid in lesion characterization prior to entering the angiography suite
- In order to track blood along longer vessel segments, 4D flow errors must be accounted for



4. Edjlali, M, et al. *Radiology*. 2014 January; 270(1).
5. Loecher, M, et al. *Proc. ISMRM 22*. 2015 June; p. 0513





- **Here, we apply a previously developed methodology⁵ in which we combine probabilistic streamlines⁶, displacement corrections^{7,8}, and fluid constraints to allow for accurate venous mapping in AVMs and DAVFs**
 - Can be used in junction with 4D flow quantitative data
- May provide valuable insight into the pre-procedural vascular anatomy and the potential impact of selective embolization

5. Loecher, M, et al. *Proc. ISMRM 22*. 2015 June; p. 0513

6. Friman, O et al. *Med Image Anal.* 2011 October; 15(5).

7. Steinman, DA et al. *JMRI*. 1997 Mar-Apr.; 7(2).

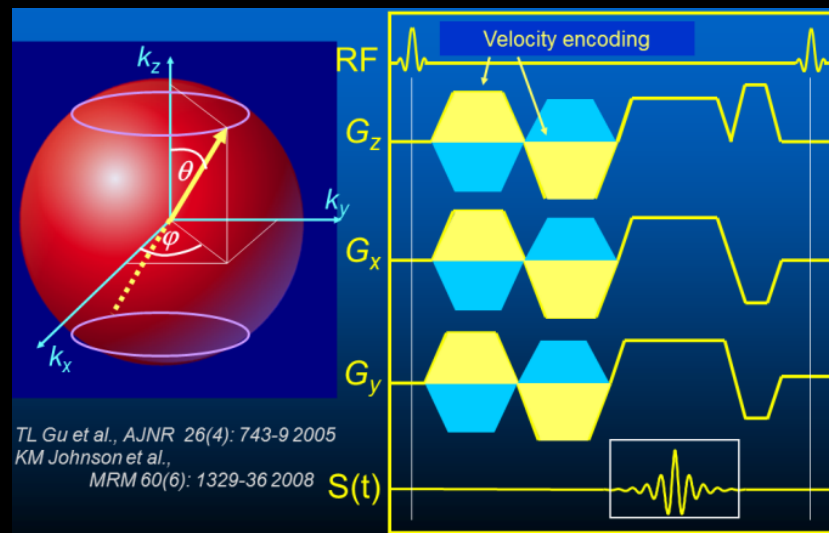
8. Thunberg, P et al. *JMRI*. 2002 November; 16(5).



Methods: In-Vivo Experiments

- 11 AVM and 2 DAVF cases (IRB approved) were imaged with 4D flow MRI:
 - Radially-undersampled PCVIPR⁹
 - Ideal for cranial applications^{10,11}
 - 3T (Discovery 750, GE Healthcare)
 - Complete volumetric brain coverage (22 cm³).
 - Isotropic Resolution = 0.78 mm³
 - Scan time \approx 6 minutes
 - TE = 2.8 ms
 - TR = 8.2 ms
 - $V_{enc} = 80$ cm/s

PCVIPR Sequence

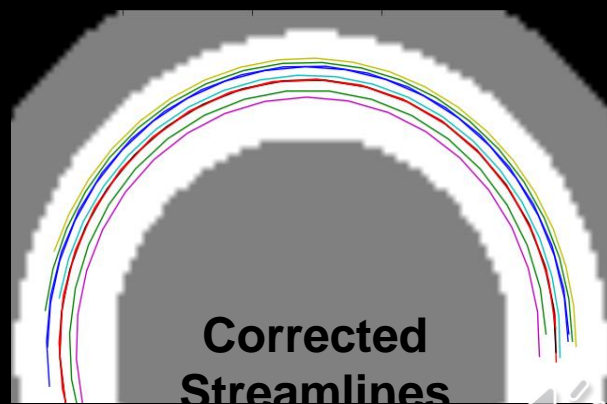
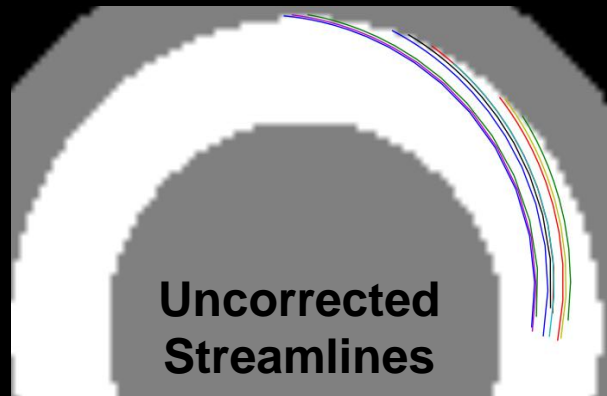
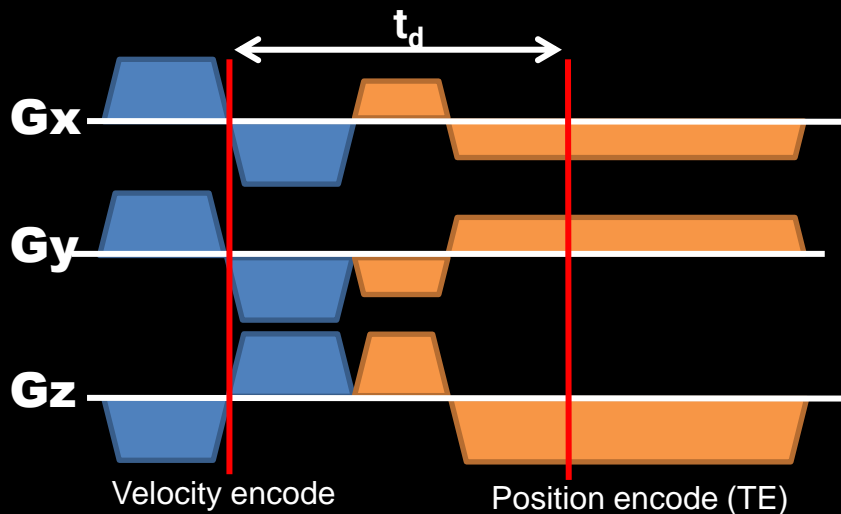


9. Gu, O, et al. *AJNR*. 2005 April; 26(4).
10. Rivera-Rivera, LA, et al. *JCBFM*. 2016 October; 36(10)
11. Chang, W, et al. *AJNR*. 2012 September; 33(1).



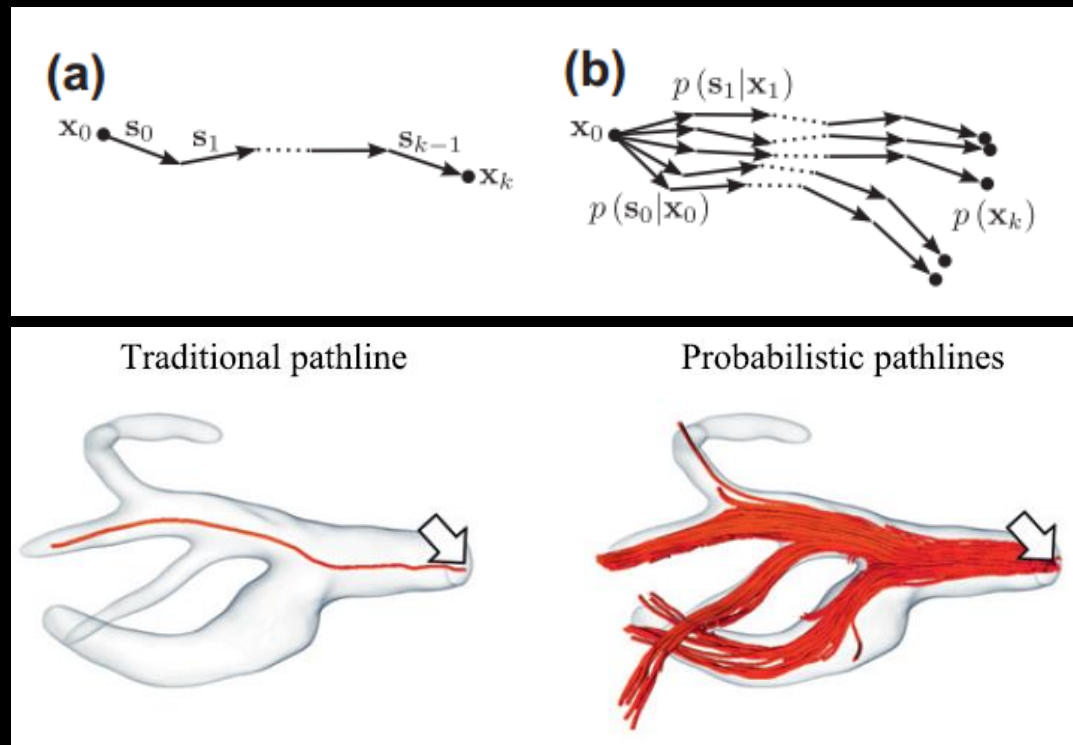
Methods: Displacement Correction

- Velocity measurements become displaced due to finite timing of encoding gradients
 - Artifacts if acceleration is present
- If time difference (t_d) between encodes is known, displacement can be approximated⁴



Methods: Probabilistic Streamlines

- Create Gaussian distribution of noise based on local signal and variance measures³
- Randomly sample from this distribution at every step (Monte Carlo)
 - Create many random streamlines
- Fluid constraints
 - Minimize ΔKE
 - Non-binary vessel boundaries



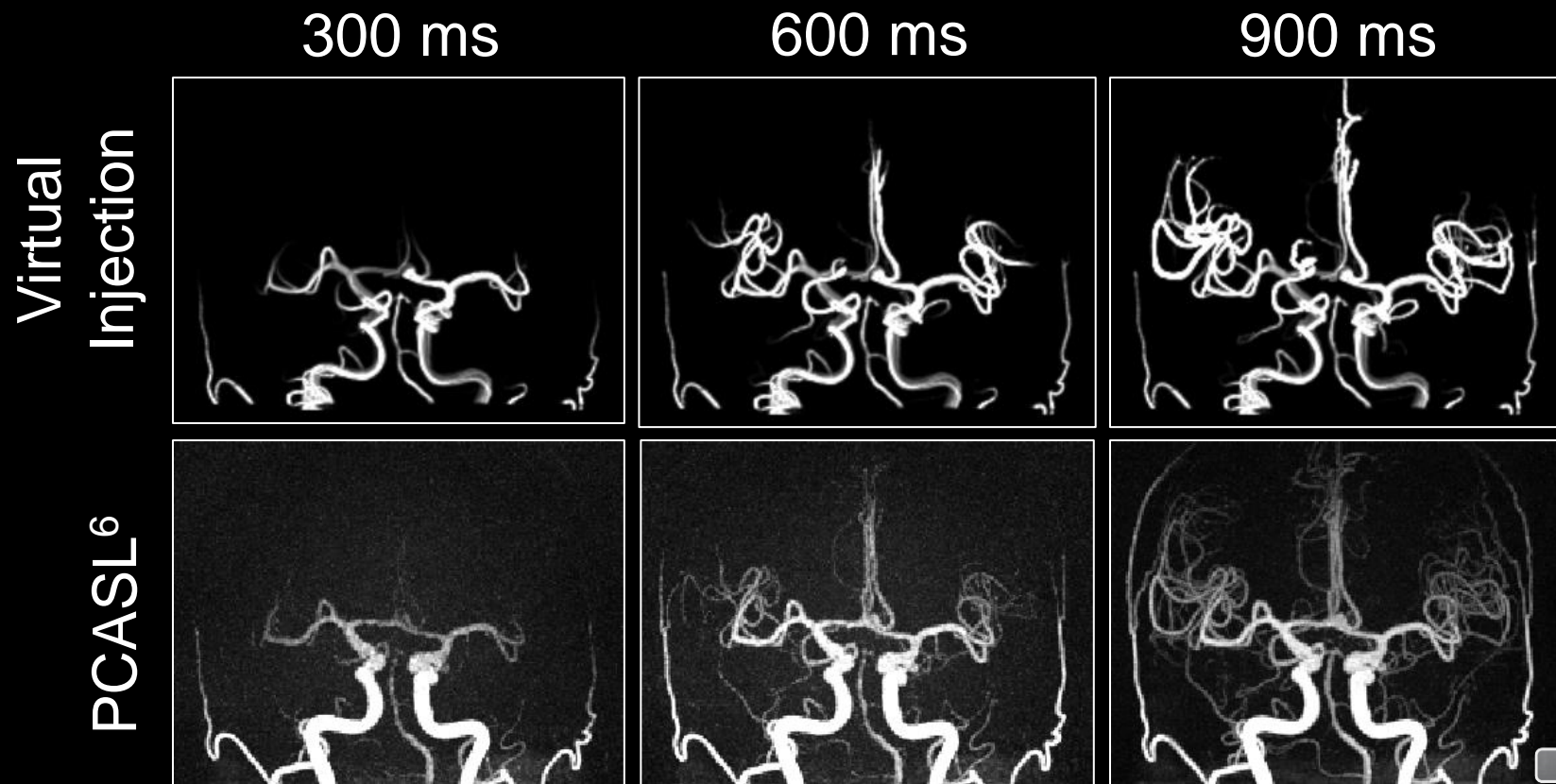
3. Friman, O et al. *Med Image Anal.* 2011 October; 15(5)



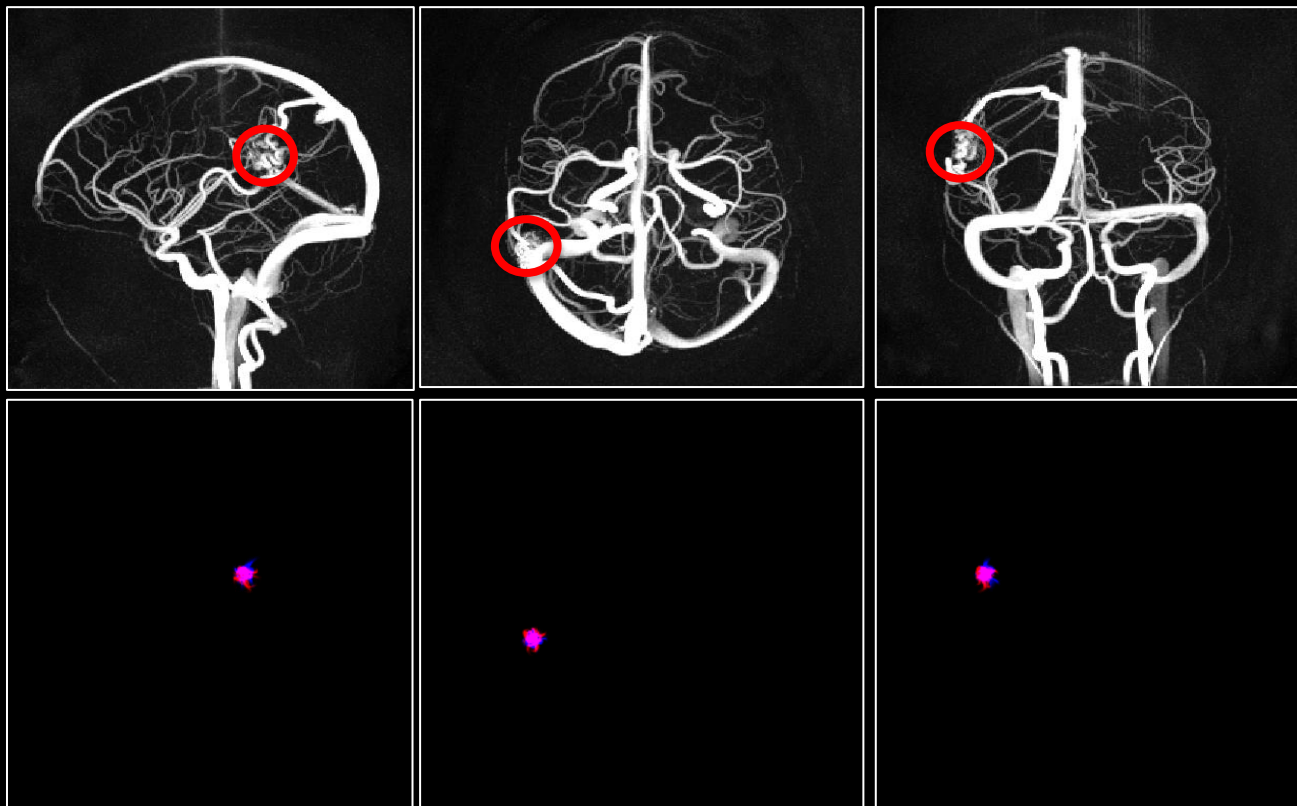


- Virtual injection methodology⁵:
 - 40,000 probabilistic streamlines were generated
 - Computed from time-averaged velocity maps
 - Displacement time = 2.6 ms
 - Compute time = 10 minutes/seed
 - Streamline starting positions (seeds) were placed within a masked plane in the neck or from a manually-positioned seeding sphere

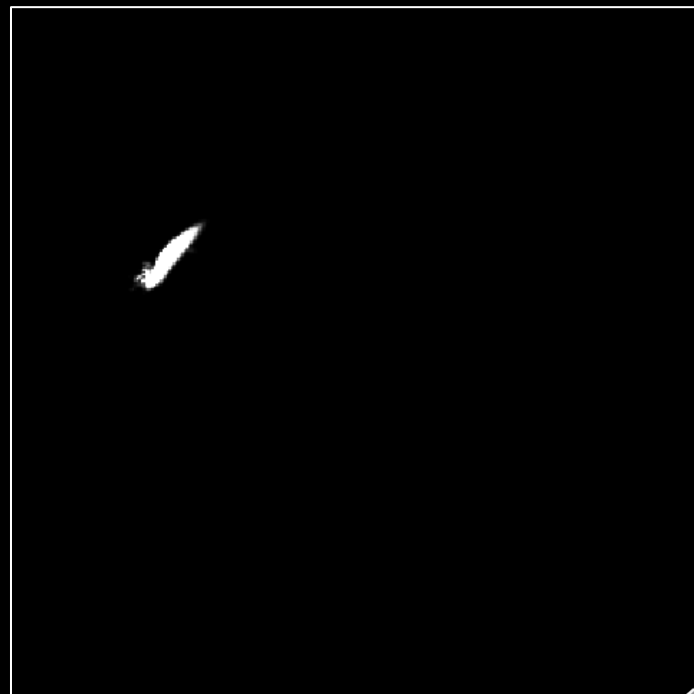
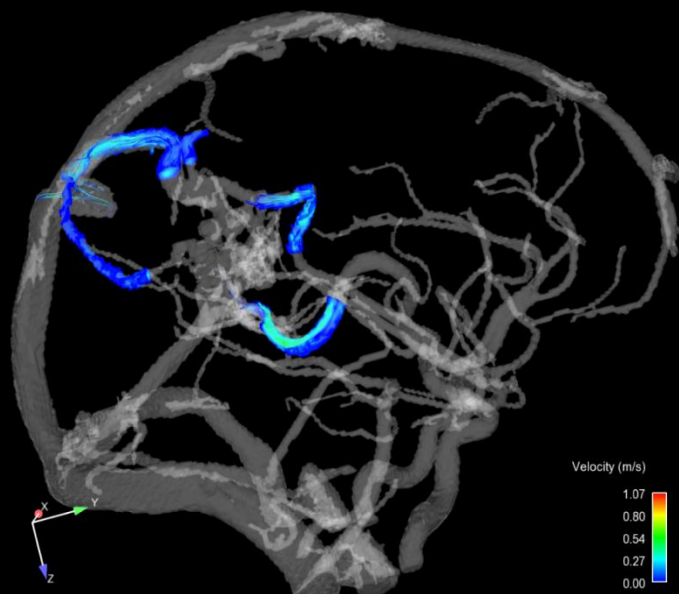




Anterograde + Retrograde Nidus Seeding



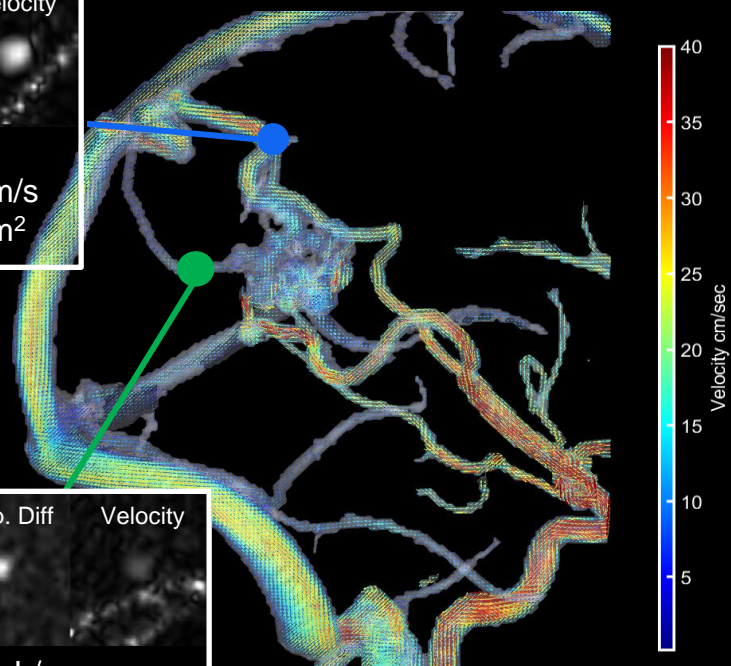
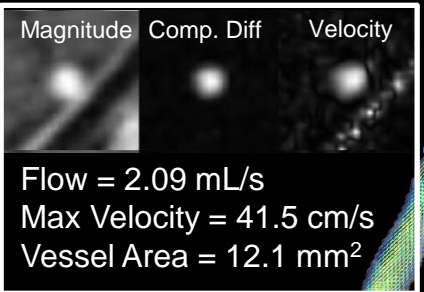
Results: Venous Mapping in AVM



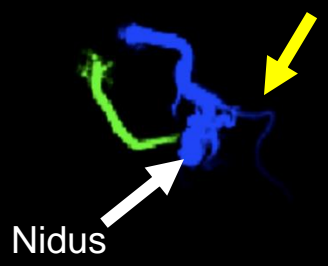


Results: Venous Mapping in AVM

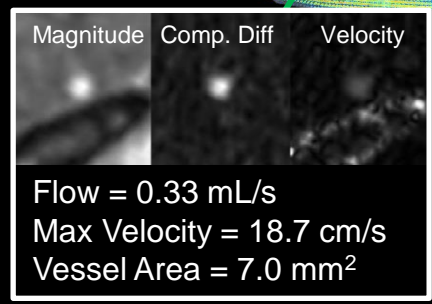
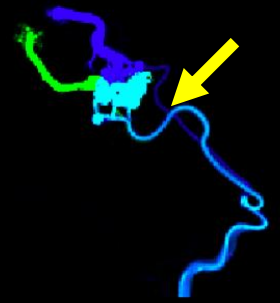
Venous Mapping (GIF)



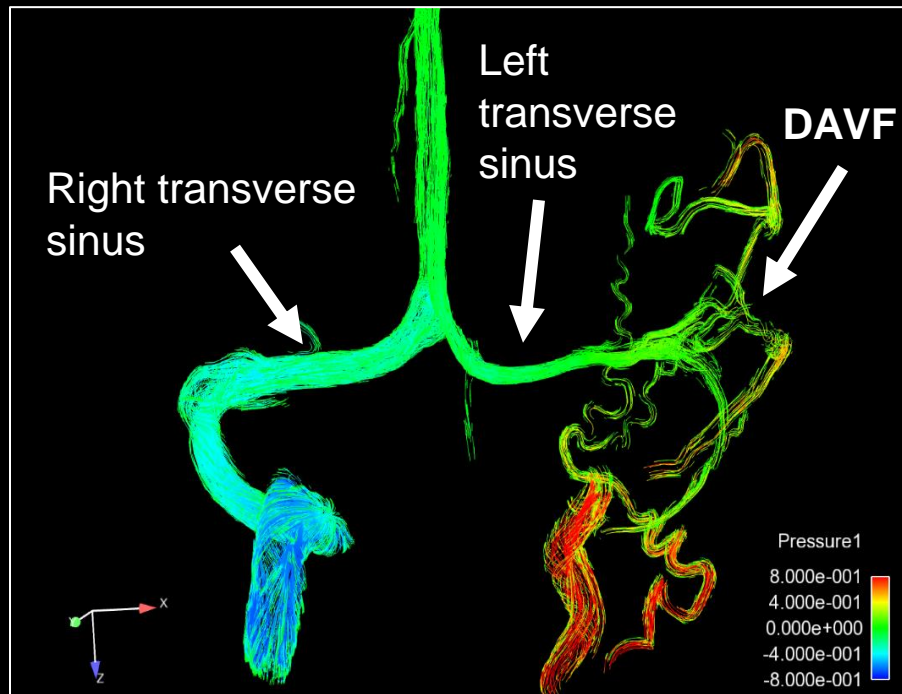
Frame 5 (180ms)



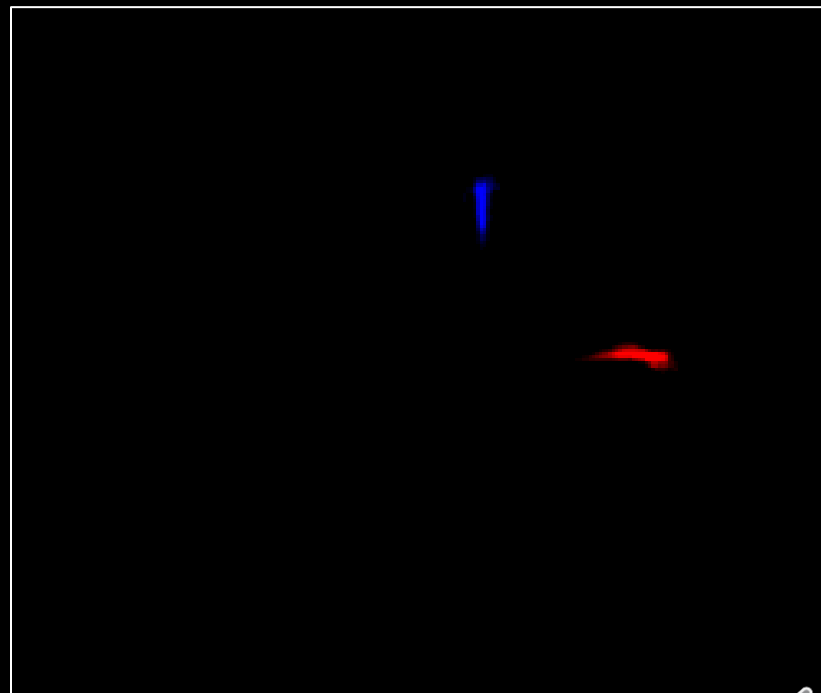
Frame 20 (630ms)



Pressure Mapping



Virtual Injection





- Demonstrated a novel method combining probabilistic streamlines, displacement corrections, and fluid constraints to create virtual injections
 - Can track blood movement throughout the whole brain using only 4D flow MR
- Unlike DSA and ASL, seed locations can be (1) chosen retrospectively, (2) at multiple locations, and (3) placed in downstream vessel segments for retrograde tracking
- Complementary to the quantitative flow analysis provided by 4D flow acquisitions





- Virtual injections for complex venous mapping in vascular malformations which could have high impact in vascular lesion characterization prior to and after treatment
- Future studies:
 - Needed to assess the actual impact on improved pre-procedure planning and patient outcomes
 - Will incorporate an interface allowing for semi-automatic seed placement
 - Needed to quantitatively compare virtual injection data to other MR methods.





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