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

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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

Background: Transvenous Embolization (TVE)

- Management of intracranial vascular lesions can be complex with significant morbidity/mortality
- Transvenous embolization (TVE) is a common method to treat DAVFs[1]
  - TVE for AVM treatment has recently gained interest[2]
- 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 Focos*. 2018 Jul;45(1)

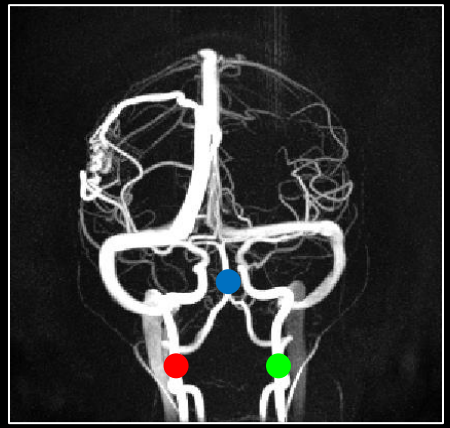
Background: 4D Flow

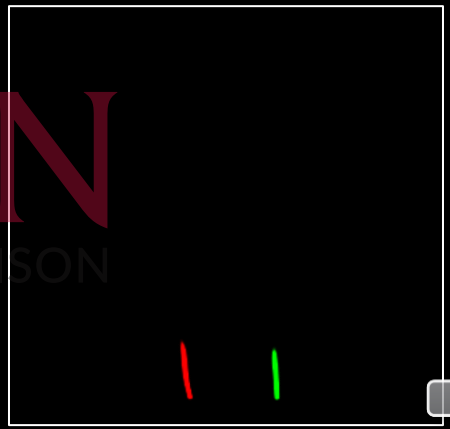
- 4D Flow MRI provides time-resolved velocity fields over a 3D volume[3]
  - Provides morphology and dynamic velocity fields simultaneously with high resolution
  - Significant advances over the last decade

3. Markl, M, et al. *JMRI*. 2012 November; 36(5).

Background: Virtual Injections

- 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

Motivation

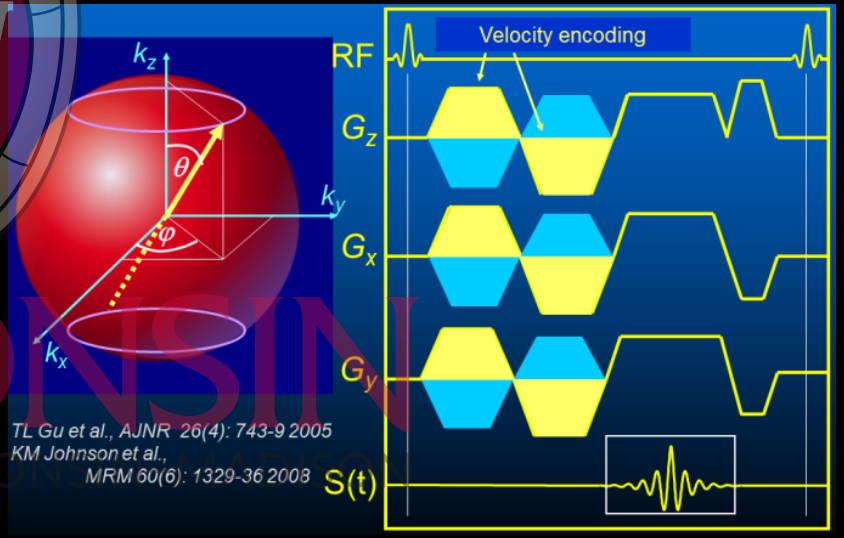
- **Here, we apply a previously developed methodology[5] in which we combine probabilistic streamlines[6], displacement corrections[7,8], and fluid constraints to allow for accurate venous mapping in AVMs and DAVFs**
  - Can be used in junction with 4D flow quantitative data
- May provide valuable insight 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 PCVIPR[9]
    - Ideal for cranial applications[10,11]
  - 3T (Discovery 750, GE Healthcare)
  - Complete volumetric brain coverage (22 cm^3).
  - Isotropic Resolution = 0.78 mm^3
  - Scan time ≈ 6 minutes
  - TE = 2.8 ms
  - TR = 8.2 ms
  - V_{enc} = 80 cm/s

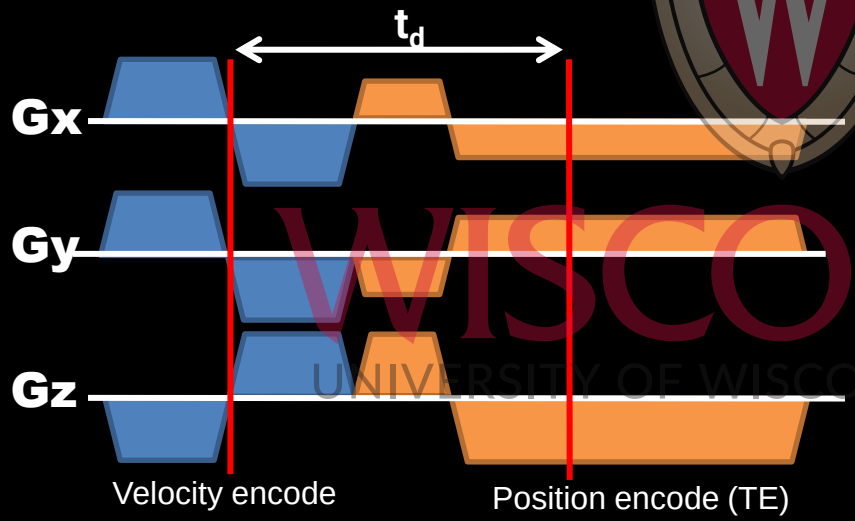
PCVIPR Sequence

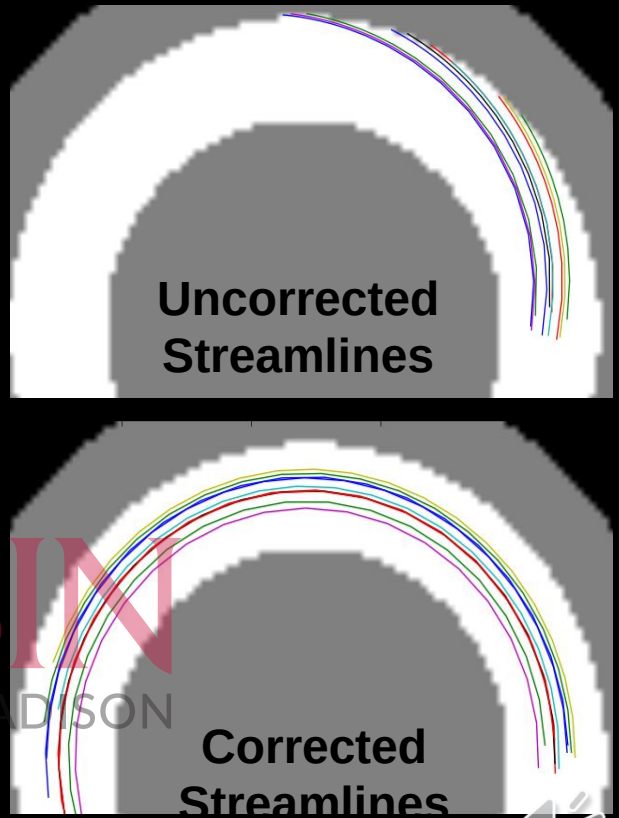


9. Gu, O, et al. *AJNR*. 2005 April; 26(4).
10. Rivera-Rivera, LA, et al. *JCBFM*. 2016 October; 36(10)
11. Chang, W, et al. *AJNR*. 2012 September; 33(1).

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 approximated[4]

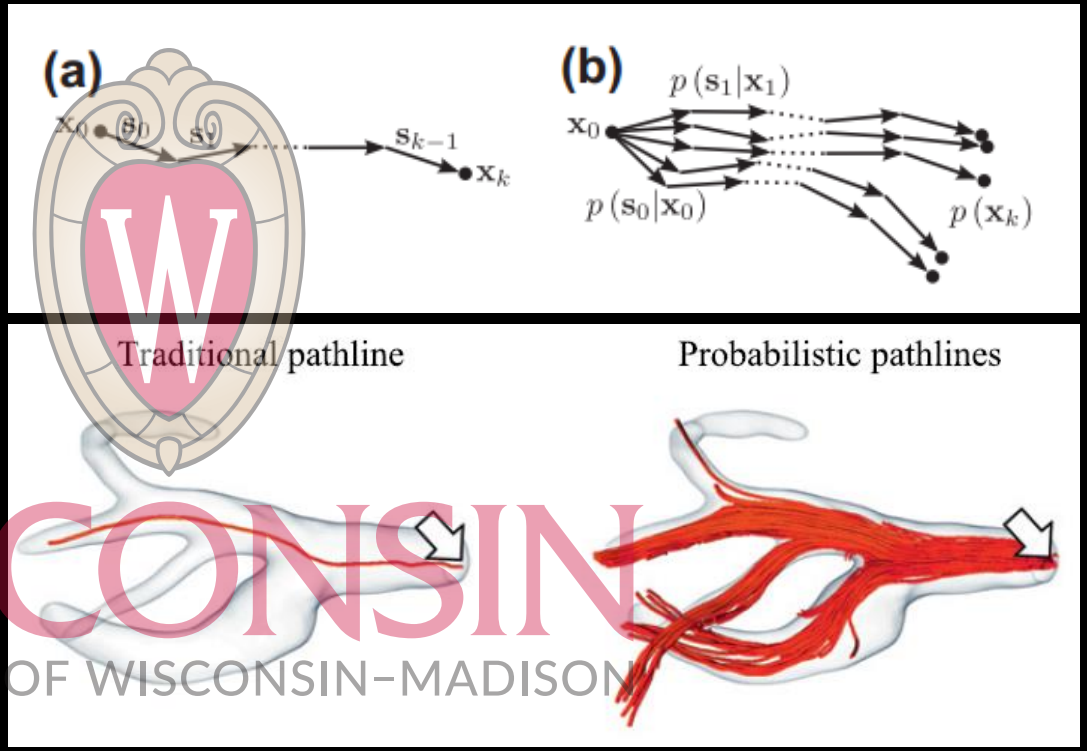




4. Thunberg, P et al. *JMRI.* 2002 November; 16(5).

Methods: Probabilistic Streamlines

- Create Gaussian distribution of noise based on local signal and variance measures[3]
- Randomly sample from this distribution at every step (Monte Carlo)
  - Create many random streamlines
- Fluid constraints
  - Minimize ΔKE
  - Non-binary vessel boundaries



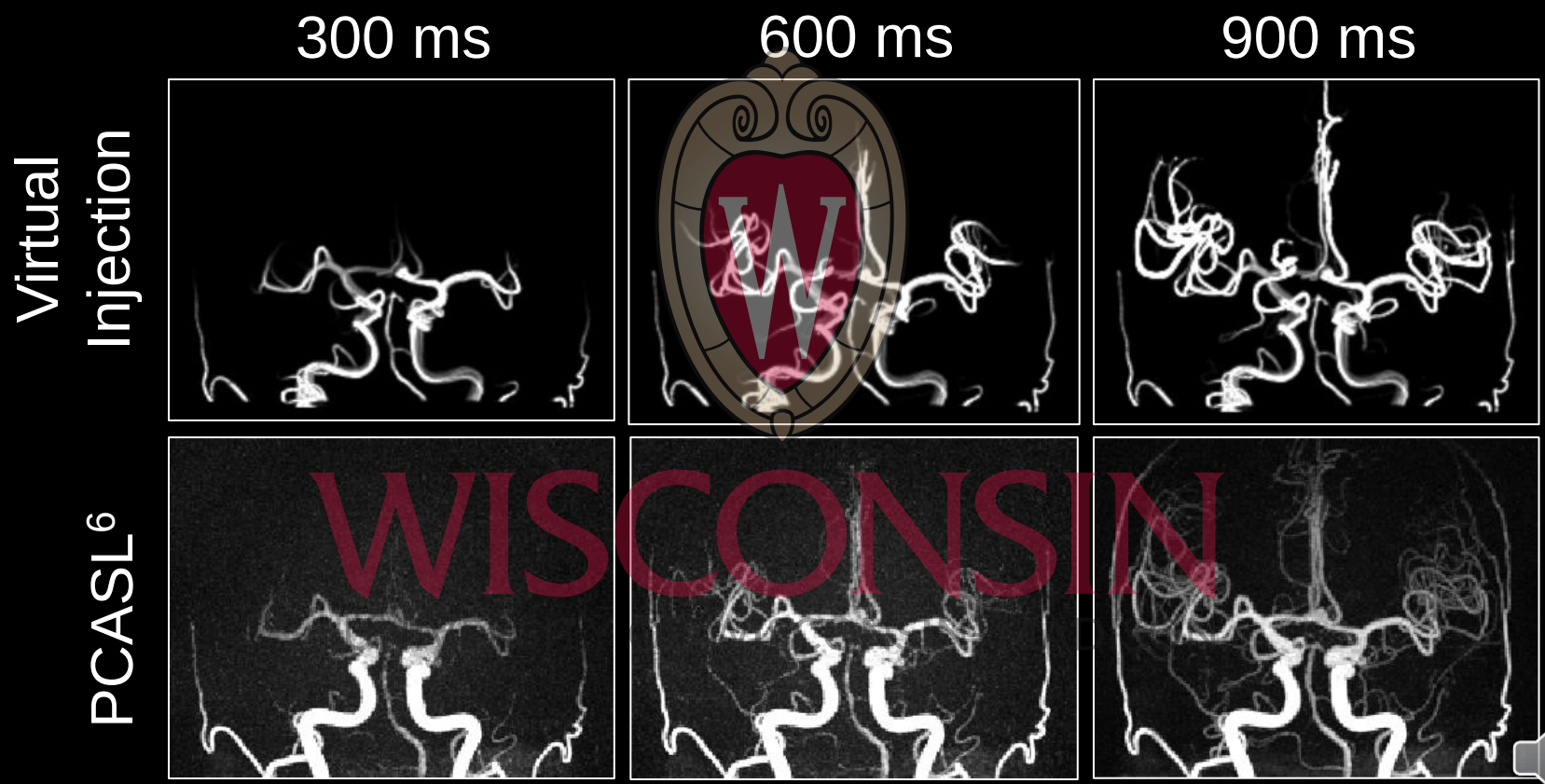
3. Friman, O et al. *Med Image Anal.* 2011 October; 15(5)

Methods: In-Vivo Experiments

- Virtual injection methodology[5]:
  - 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

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

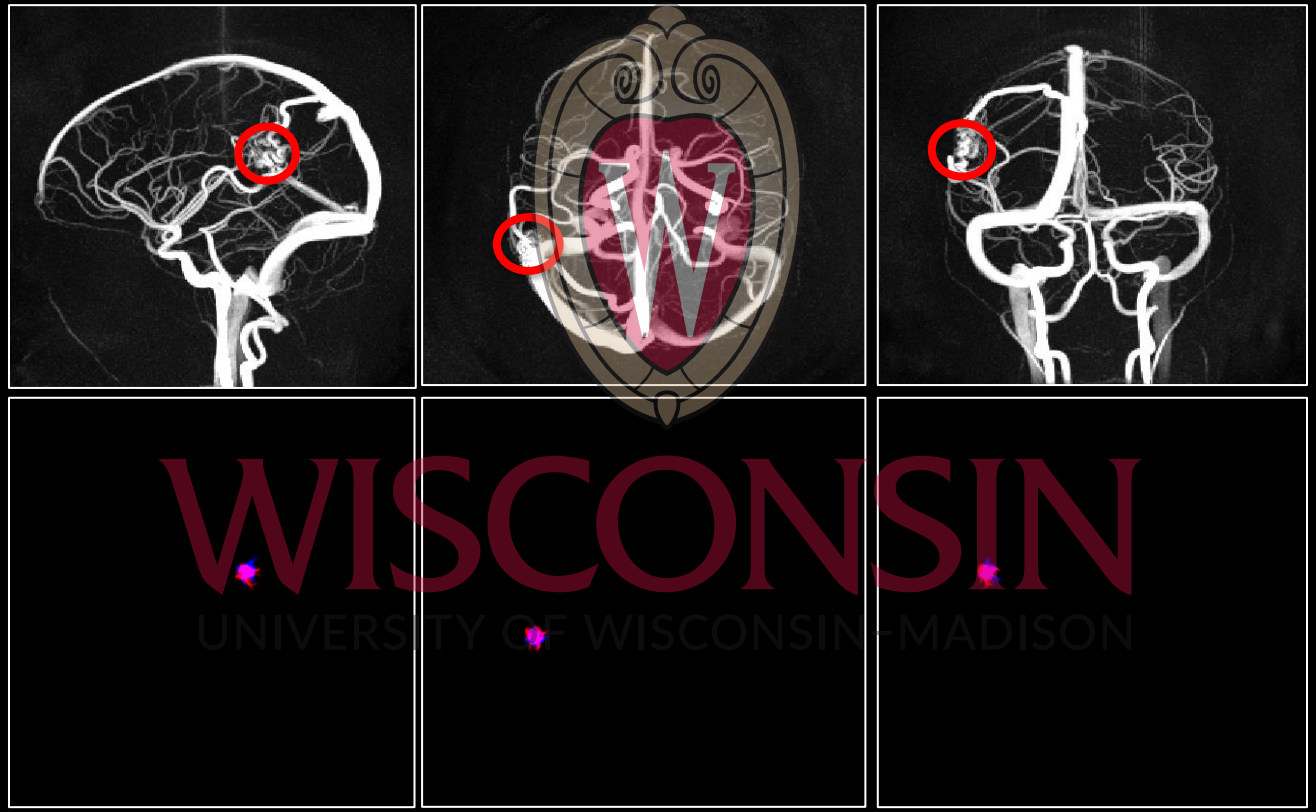
Results: Comparison to PCASL



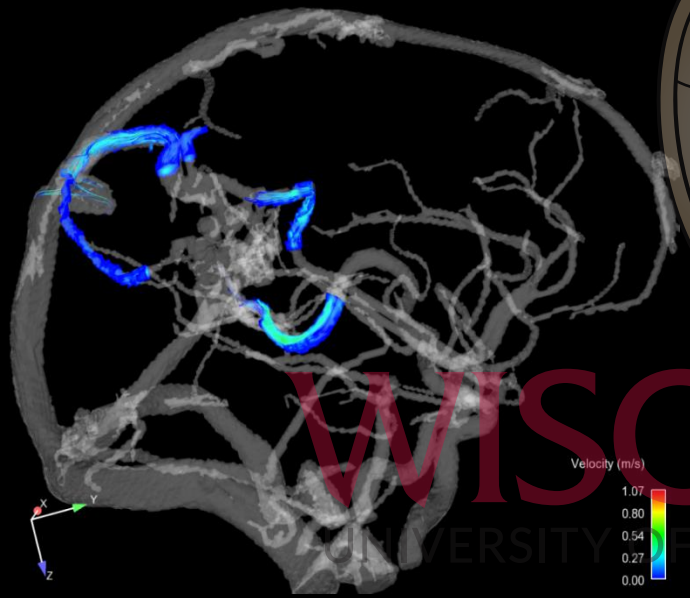
6. Wu, H et al. *MRM.* 2012 March; 69 (3)

Results: Virtual Injection in AVM

Anterograde + Retrograde Nidus Seeding

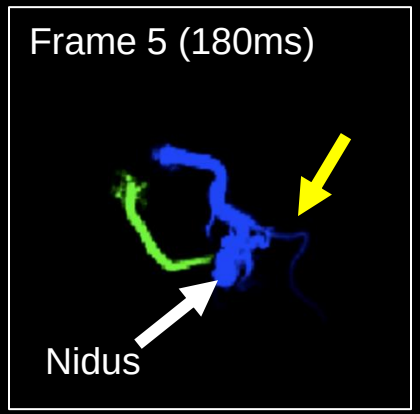


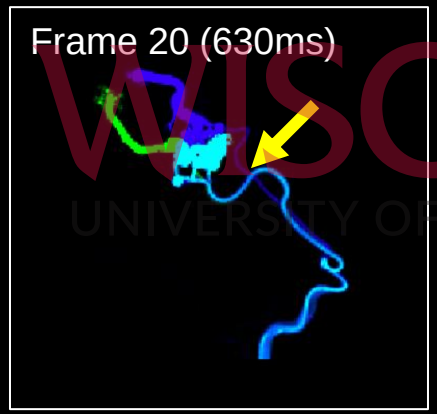
Results: Venous Mapping in AVM

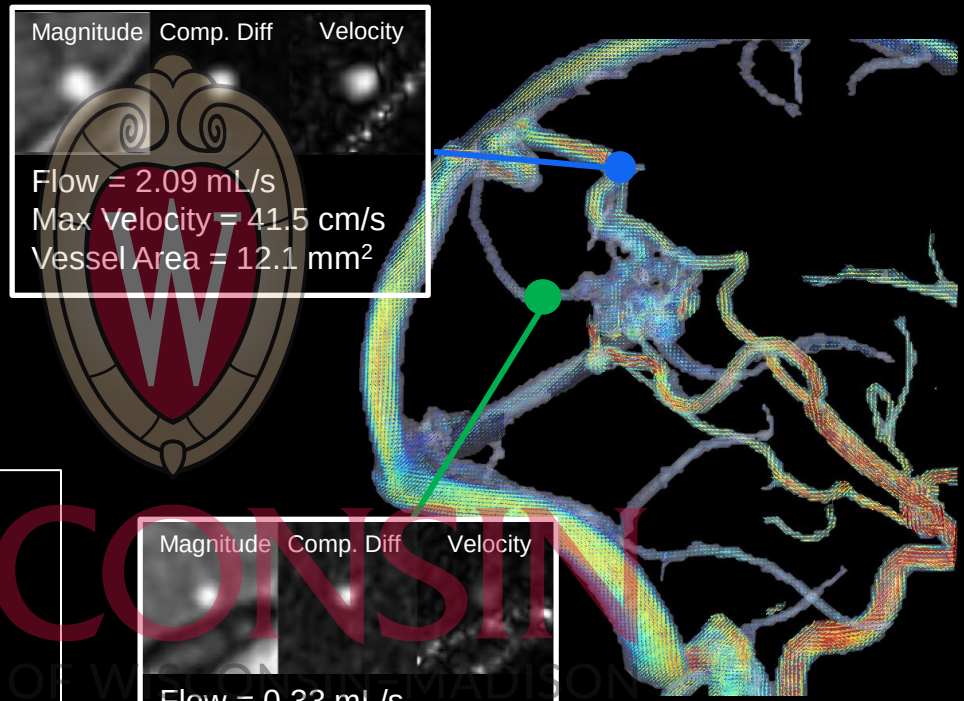


Results: Venous Mapping in AVM

Venous Mapping (GIF)

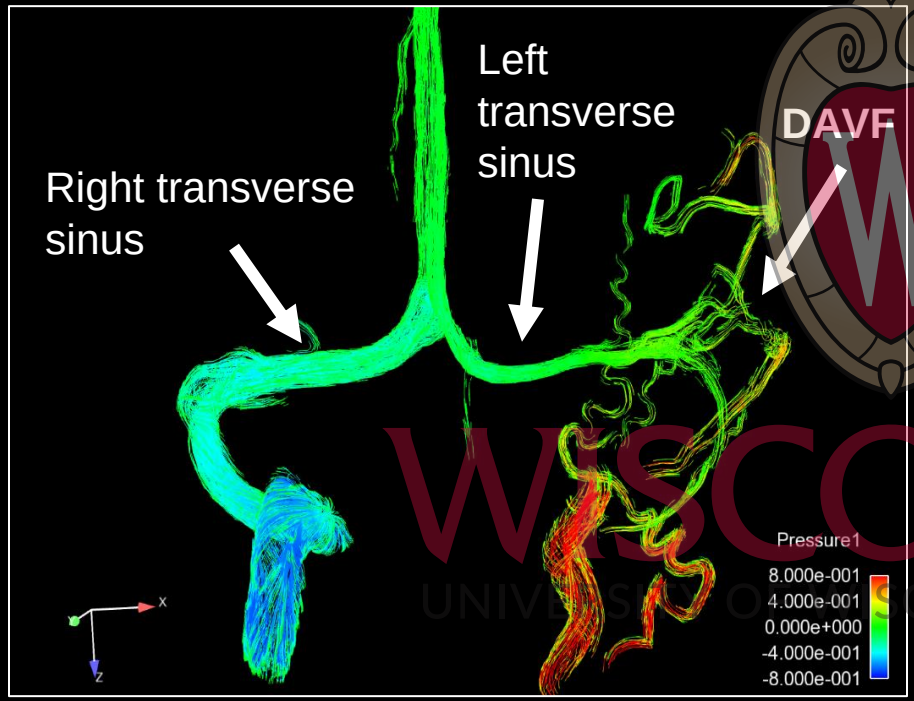




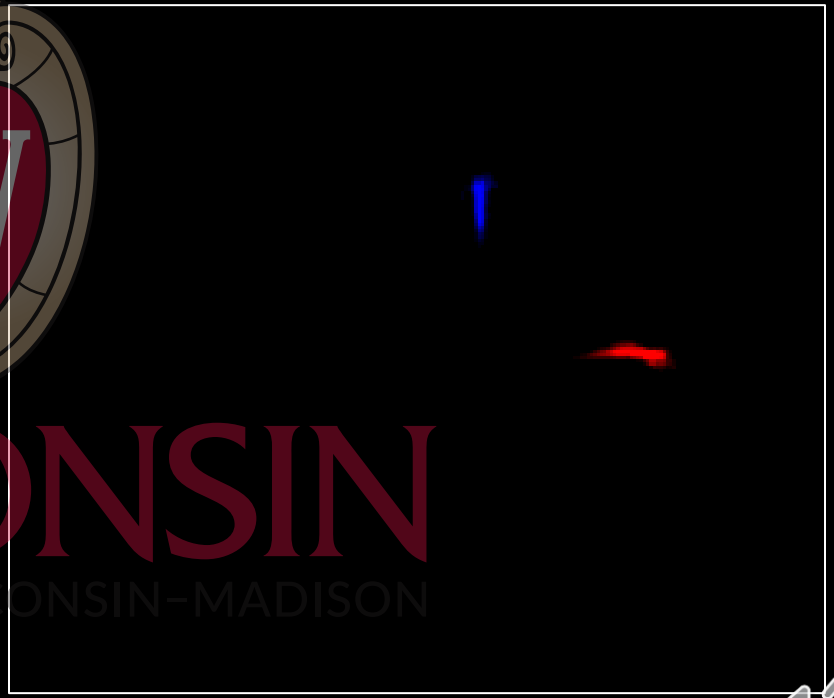


Results: Venous Mapping in DAVF

Pressure Mapping



Virtual Injection



12. Rivera-Rivera, LA, et al. *AJNR*. 2018 March; 39(3)

Discussion

- 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

Conclusion

- 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.

Acknowledgements

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