MRI Flow Quantification in CCSVI

E. Mark Haacke, Ph.D.

I disclose the following financial relationships:

I have grants from the NIH and a personal interest in Magnetic Resonance Innovations, Inc.

Acknowledgements

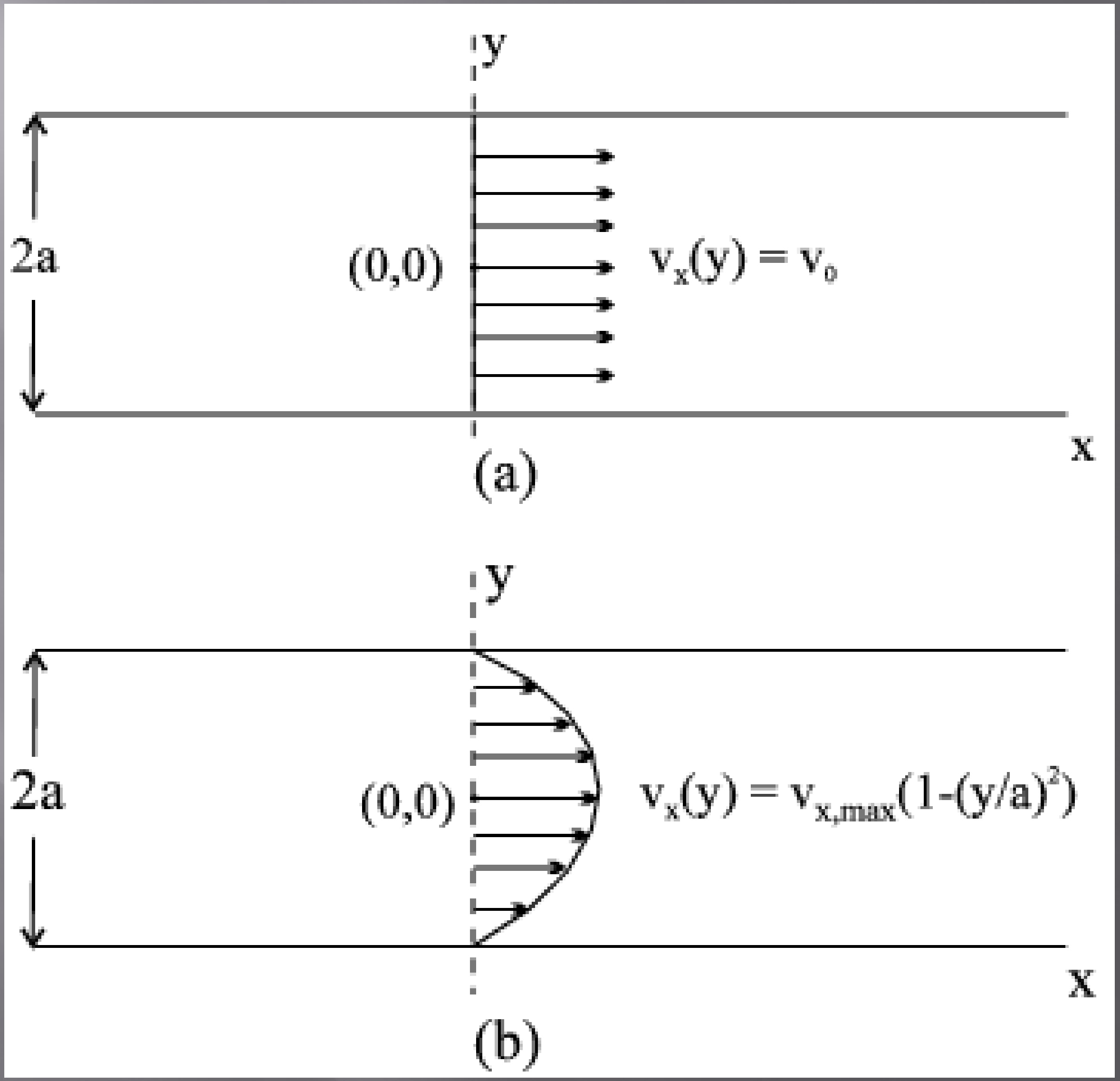
Wei Feng, PhD

David Utrianen, BS

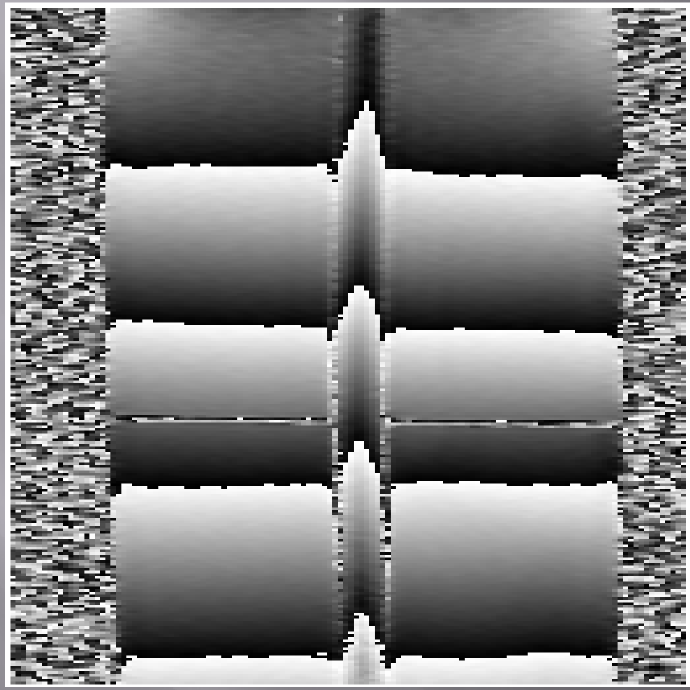
M. Marcella Laganà, PhD

Zhong Yi, MS

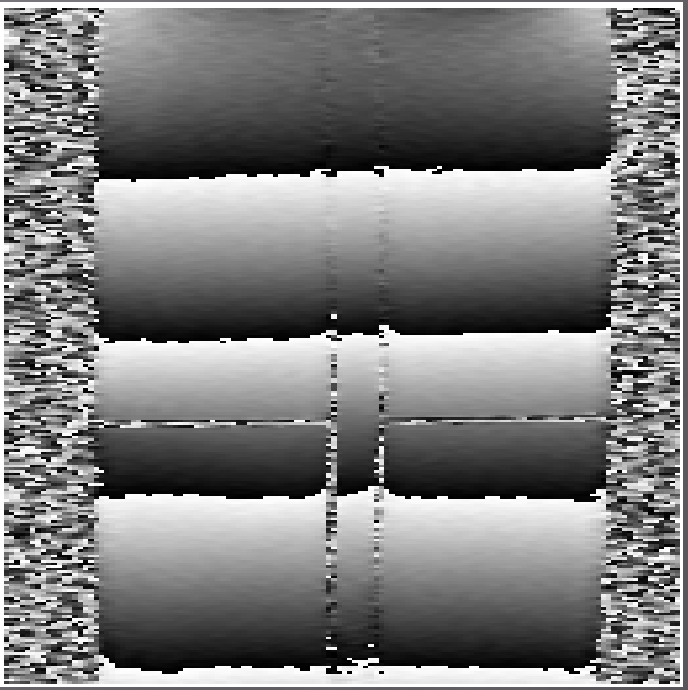
Plug flow and laminar flow



Phase as a representation of flow:
Here phase is proportional to velocity.

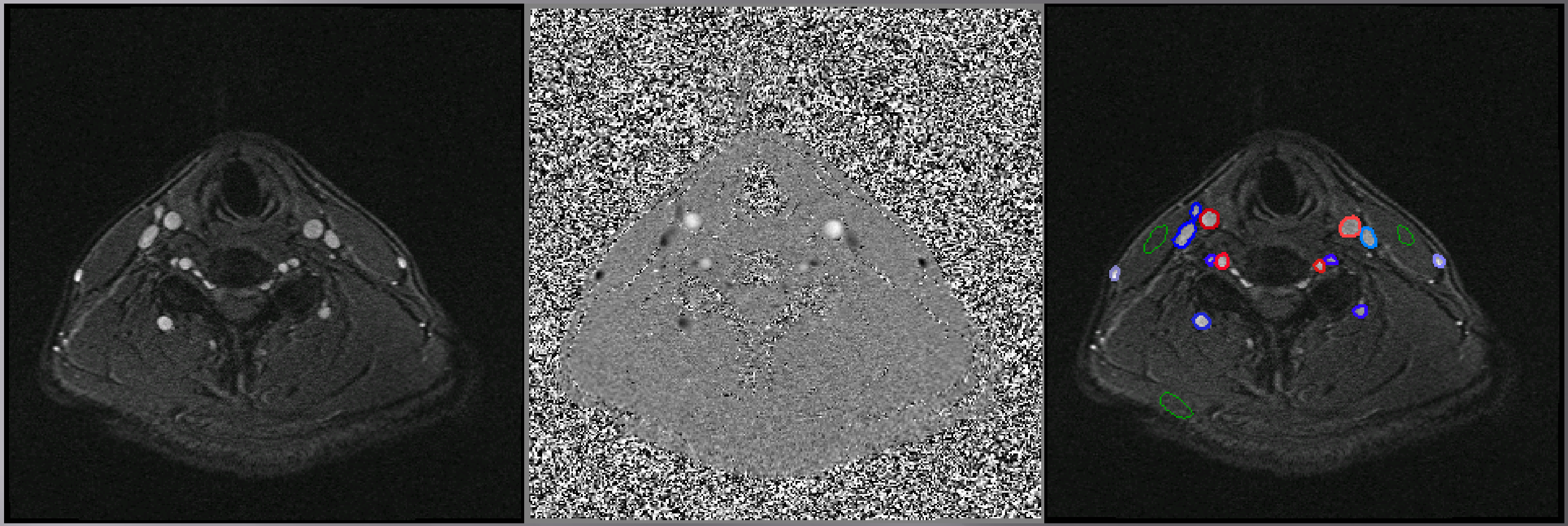


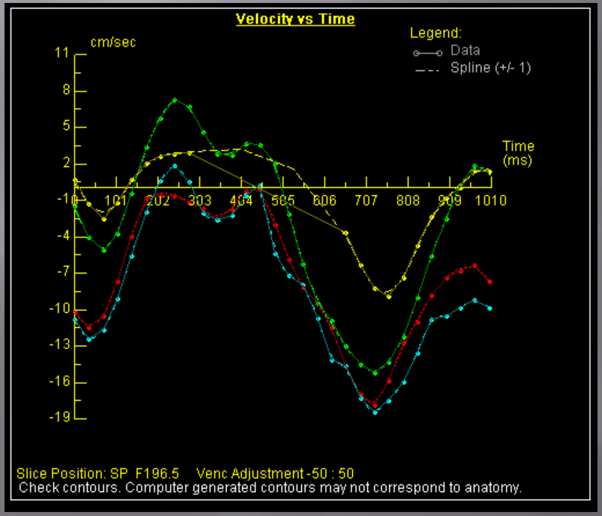
Flow encoded



Compensated

VASCULAR FUNCTION: Flow Quantification

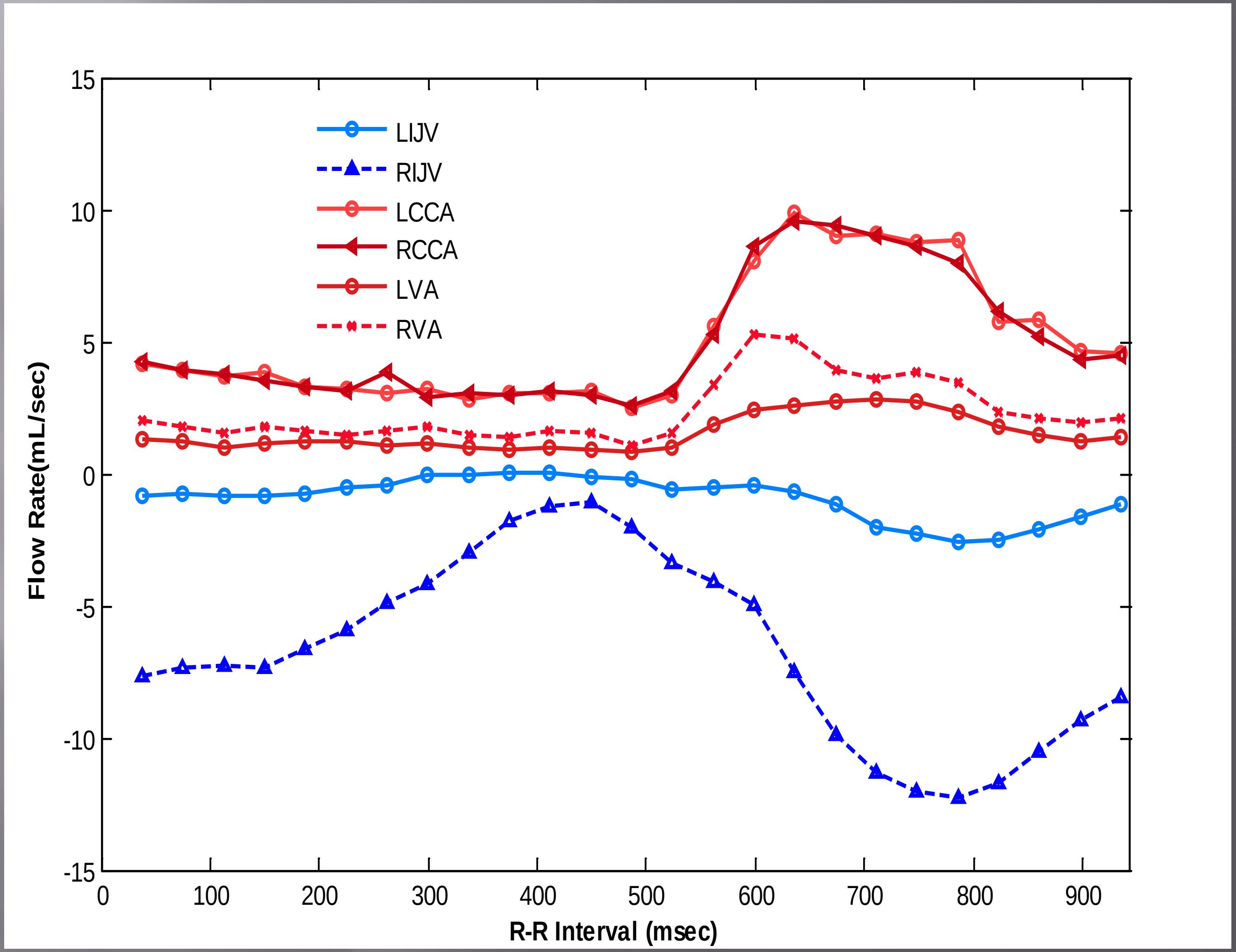




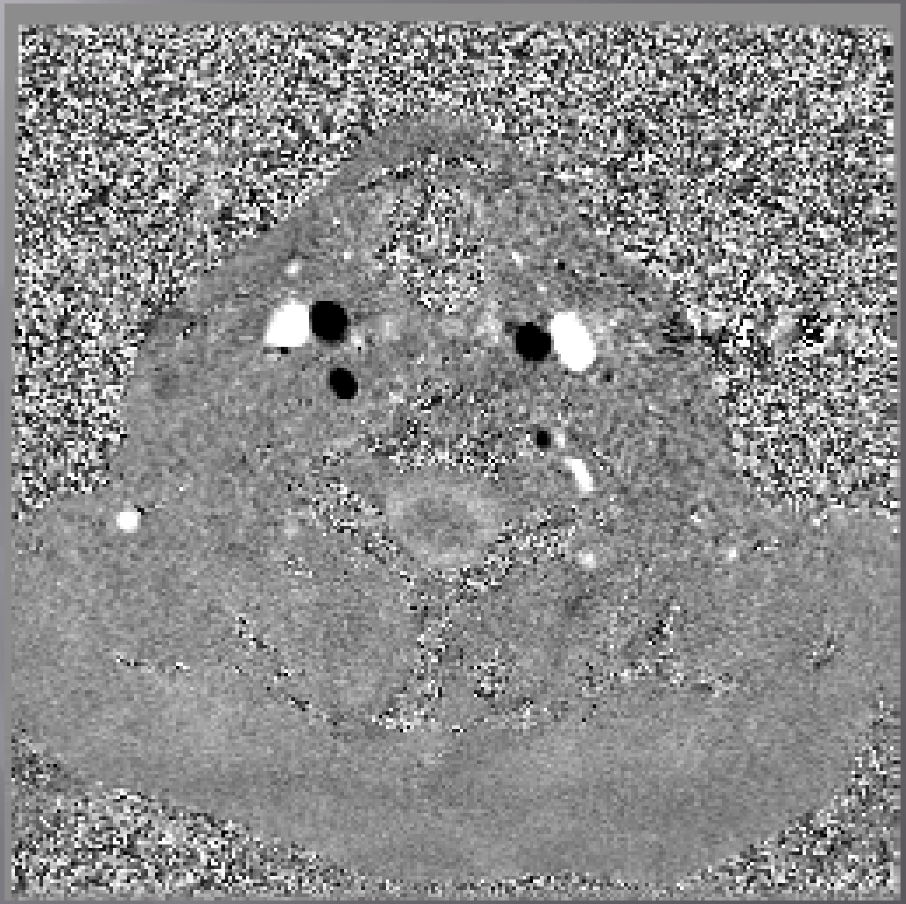
In this individual all four of the major veins in the neck showed either reflux or a reduction to nearly zero flow.

As a consequence, the speeds in the second half of the cardiac cycle had to double to get the blood out of the brain.

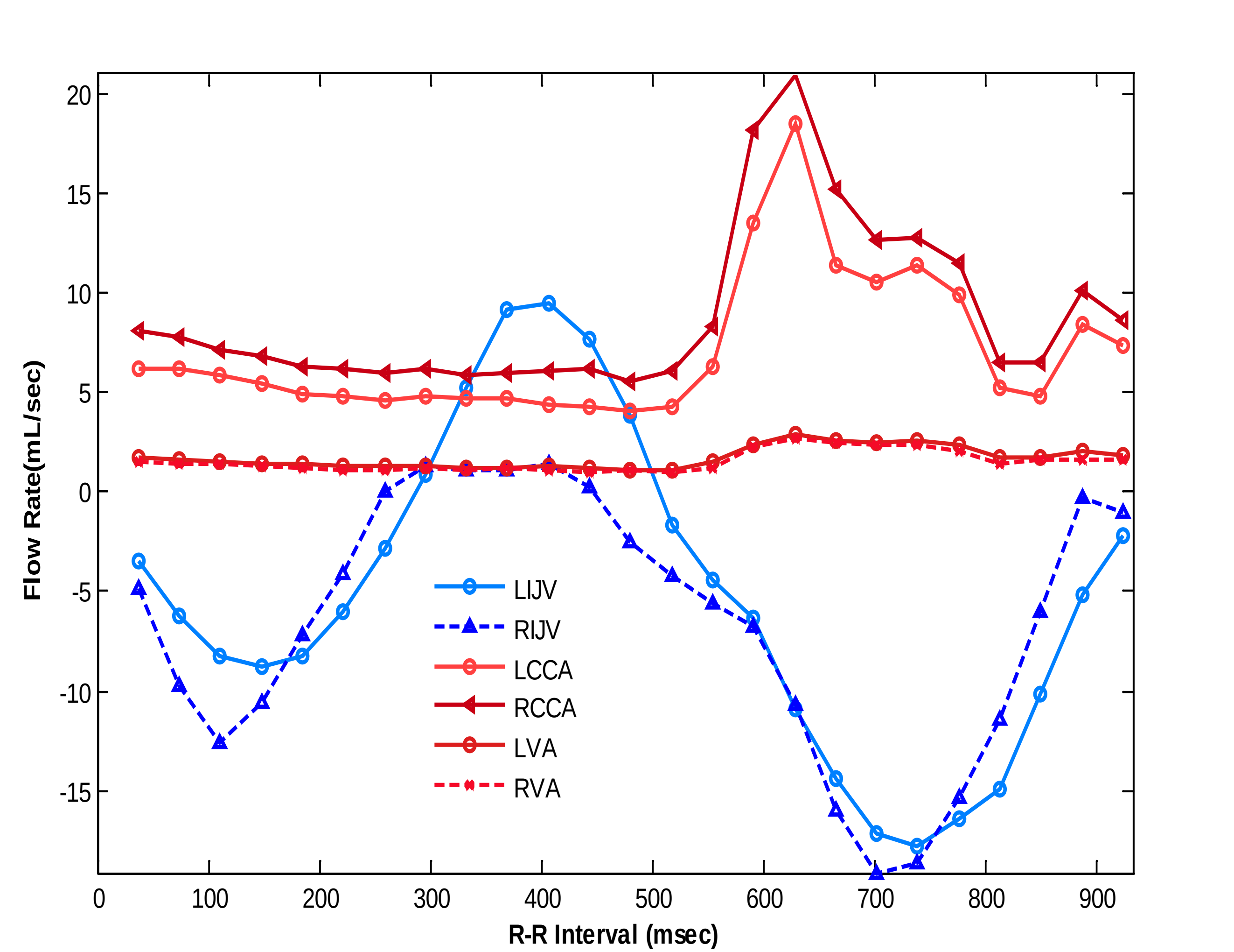
One dominant IJV



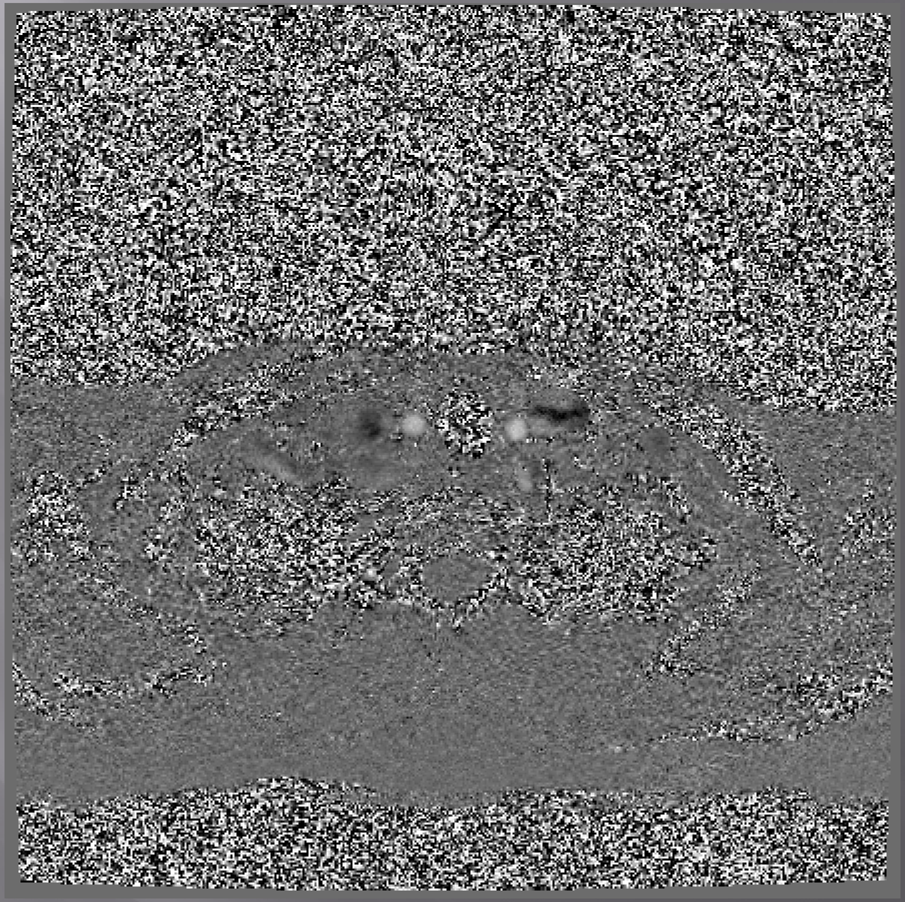
Reflux in the right IJV



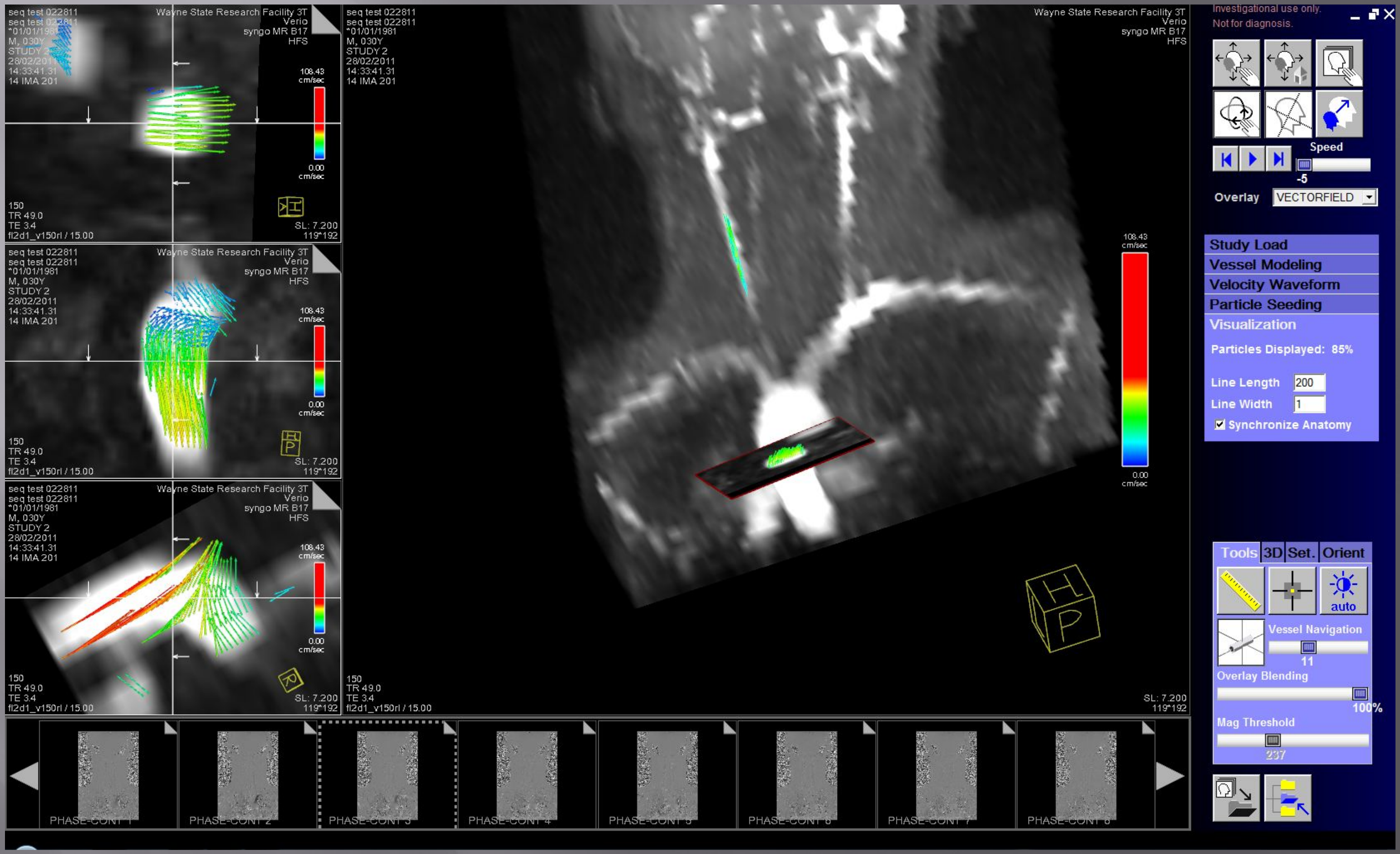
Reflux in LIJV



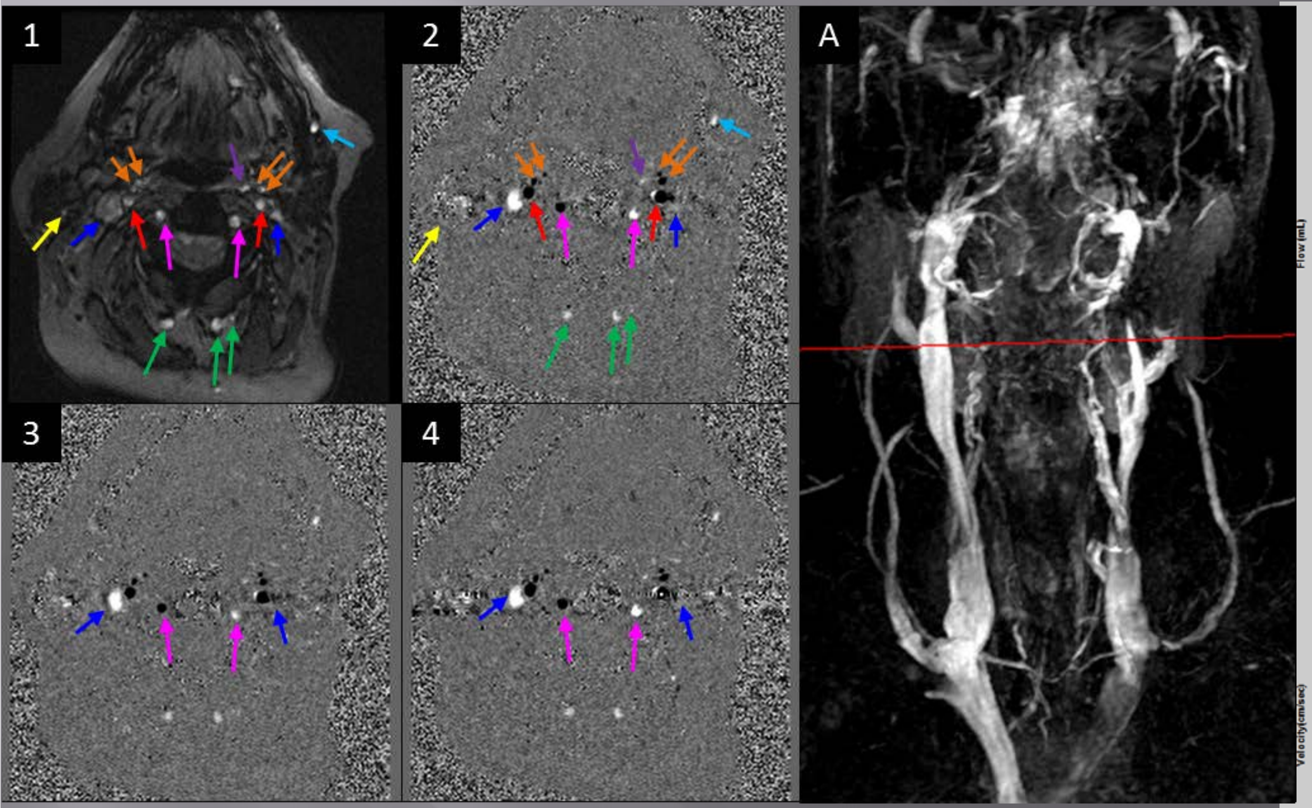
Jetting through a stuck valve?

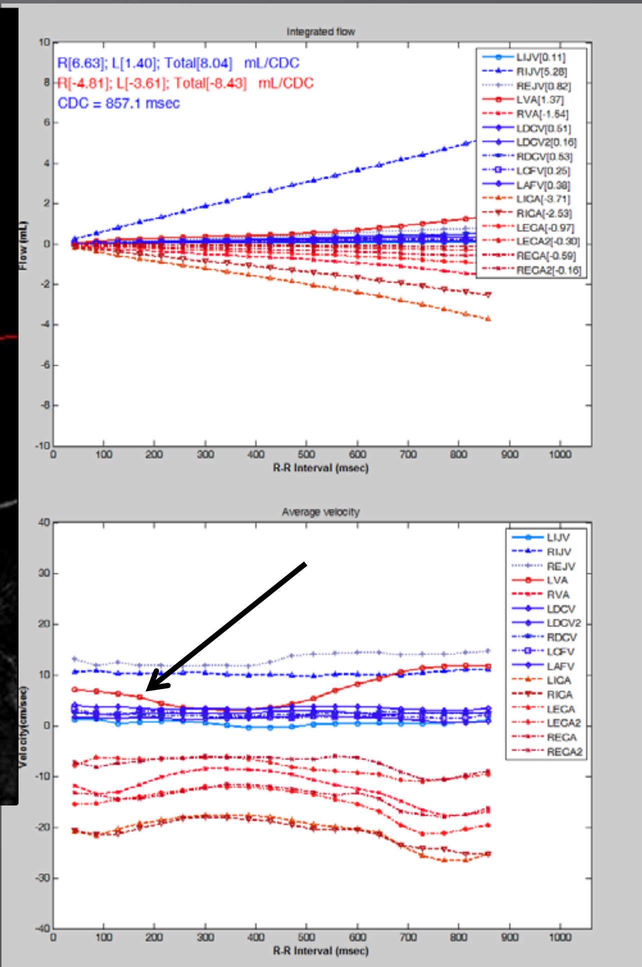


4D: New Directions in Flow



Abnormal veins and abnormal arteries: Possible blockage of the left subclavian vein.





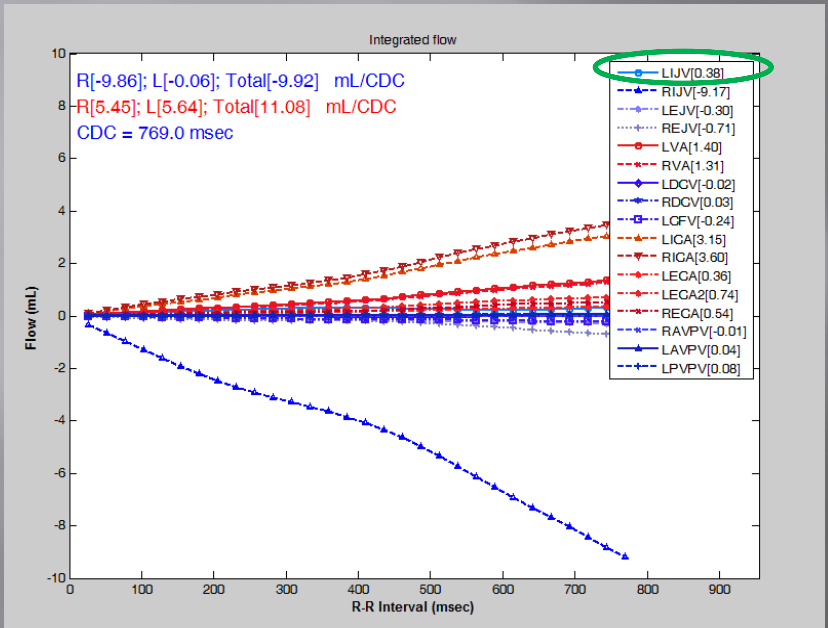
At the C2 neck level the right IJV carries the majority of the venous outflow. The left IJV carries almost no flow, the acquisition slice is positioned just below the possible atresia. The left VA carries around 1.60ml/s of flow down the neck but shares a similar but inverted flow profile with the carotid and vertebral arteries.

MIPed Coronal Image

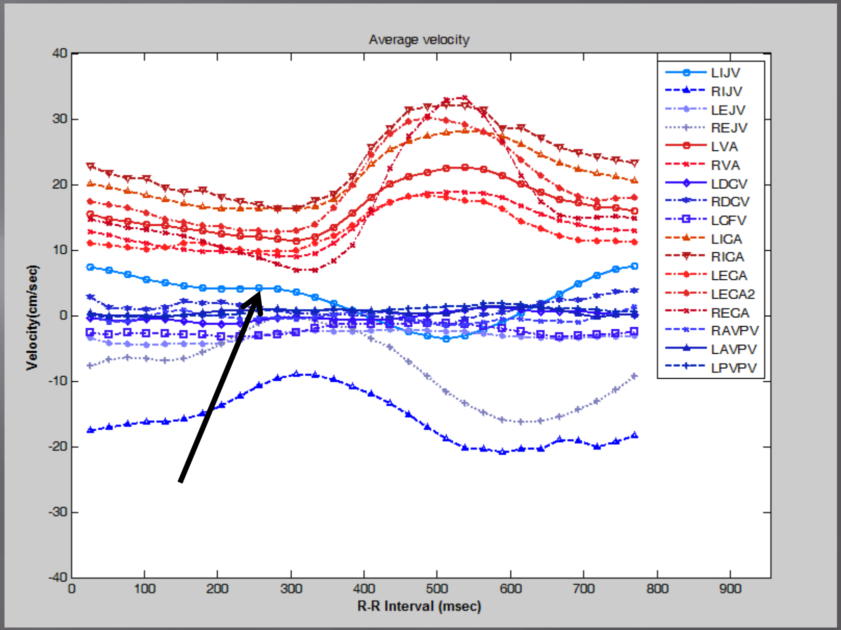
2D TOF MRV MIPed images showing the Inferior Petrosal Sinus draining into the Left IJV

Flow analysis at C2-C3 Level

Integrated Flow Plot

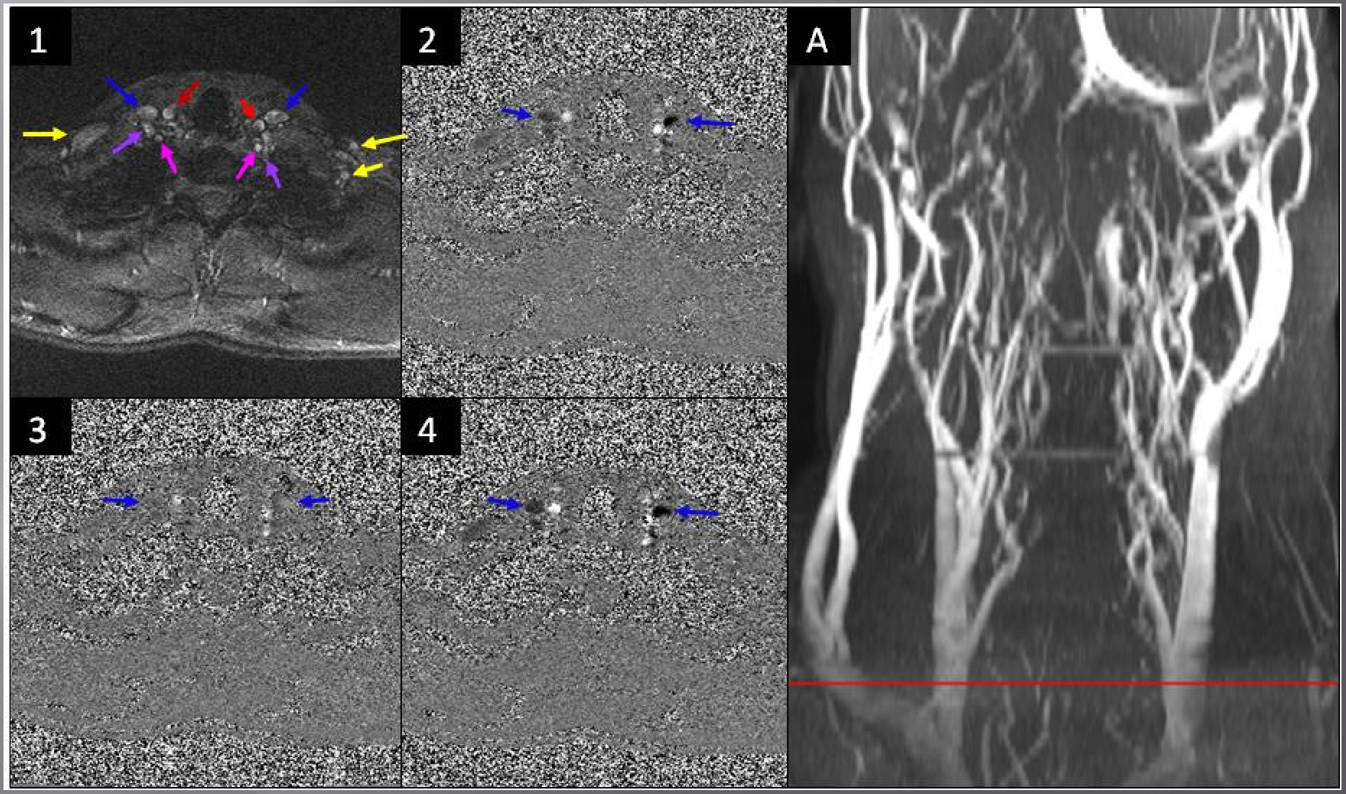


Average Velocity Plot

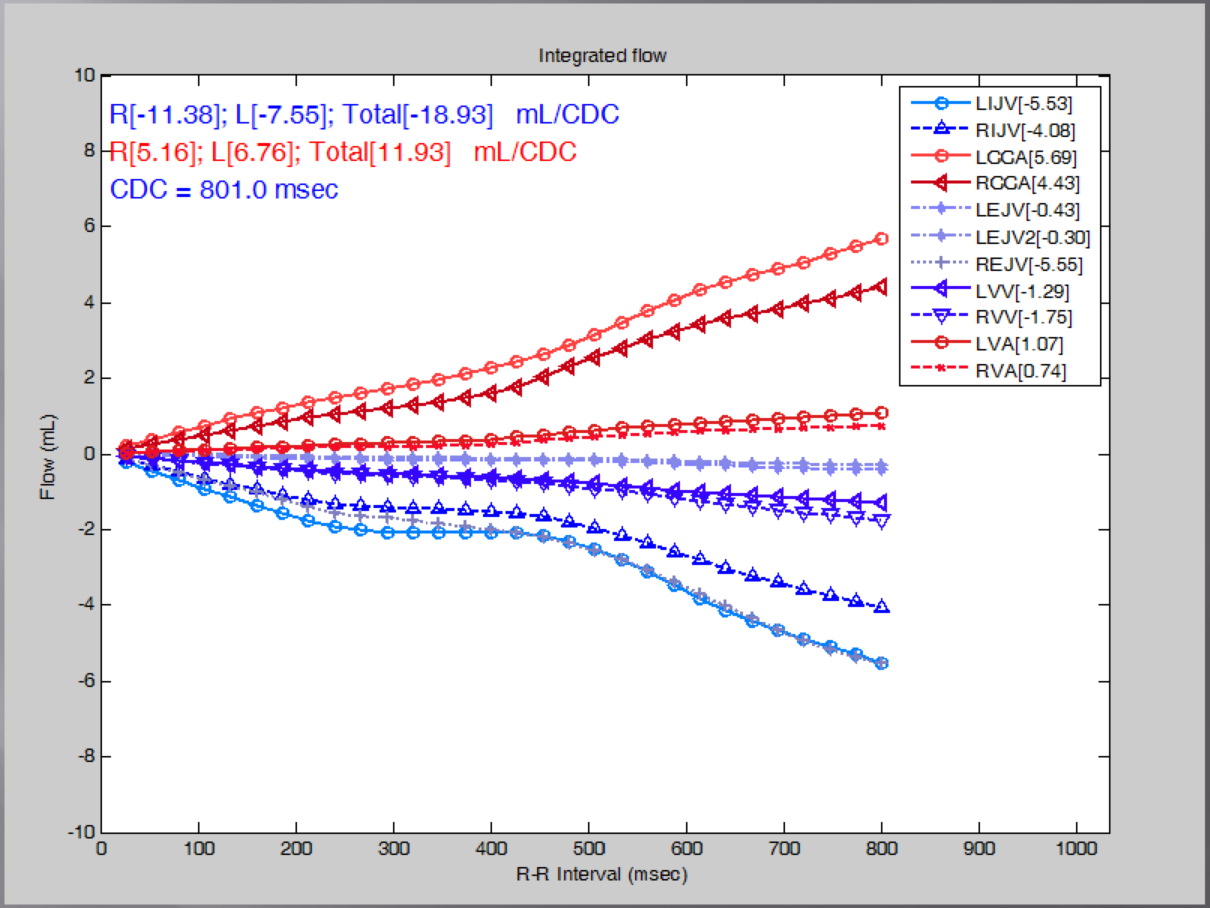


The LIJV has a reflux in its flow pattern which likely extends back to the inferior petrosal sinus.

To treat or not to treat?



Two functioning IJVs: What would be the consequence of treating one of these and causing a complete obstruction?

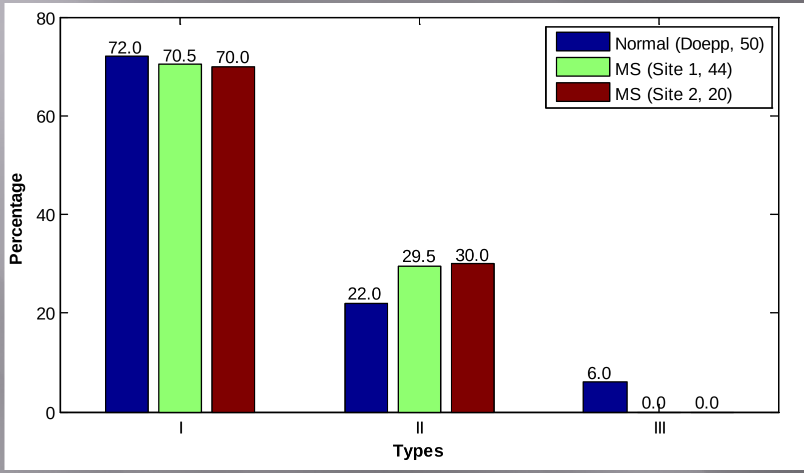


We need to understand when it is appropriate to treat and when not. We need to understand the role of the venous vasculature in brain function.

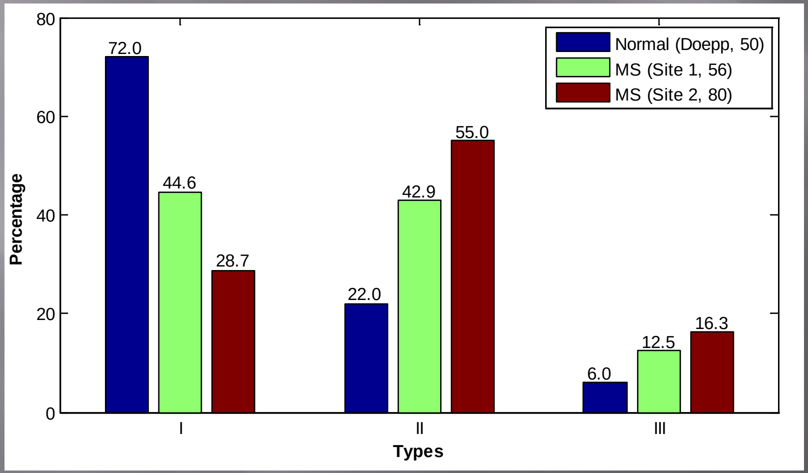
Flow and structure: Two possible guides for treatment

- If there is a severe structure abnormailty such as a stenosis great than 50% or higher then we might be tempted to treat it.
- However, what if the flow is in fact normal?
- Is it worth the risk of damaging two healthy veins that are doing their job in carrying the flow even though other aspects of the system may be compromised (such as the vertebral plexus, externals, vertebrals, etc.)?

Dominance of IJV flow in normal controls versus two MS populations: Non-Stenotic and Stenotic Patients.



Non-Stenotic MS
vs normal

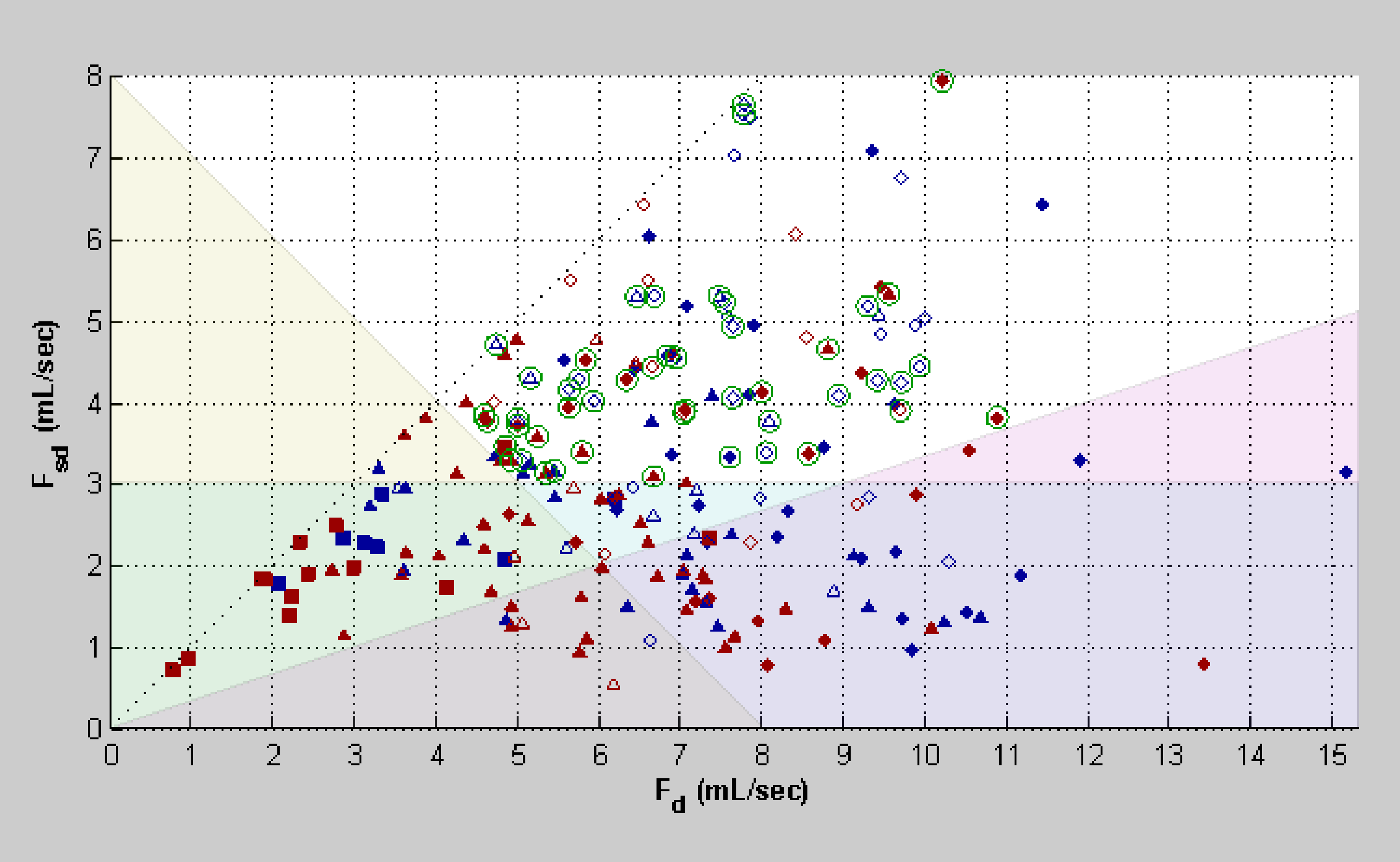


Stenotic MS
vs normal

Comparison of non-stenotic MS patients out of the 200 MS patients and 50 normals using the ratio of IJV flow diivided by total arterial flow: F(IJV)/F(tA). (Doepp et al., Neuroradiology, 2004).

(Type I: F(IJV)/F(tA)>=2/3; Type II: 2/3>F(IJV)/F(tA)>=1/3; Type III: F(IJV)/F(tA)<1/3)

Results: Dominant vs. Sub-dominant Venous Flow Rates



Flow rate scatter plots of sub-dominant vein vs. dominant vein for 100 MS patients each site symbol-coded by Doepp categorization criterion. Red and blue correspond to Site 1 and Site 2. Diamonds, triangles and squares correspond to Types I, II and III. Solid symbols are stenotic MS cases (UL and LL stenosis, bilateral stenosis, diffused stenosis and TVM). Green circles represent patients with abnormal valves.

Quantitative Flow Measurements Flow Rate (Site 1 vs. Site 2, N=125)

	Site 1		Site 2	
	Mean	Std	Mean	Std
Age (years)	47.50	10.04	49.08	10.42
HR (/sec)	70.41	9.93	70.70	12.65
Flow Rate (mL/sec)				
LCCA	6.29	1.36	-5.72	1.30
RCCA	6.40	1.36	-5.89	1.43
LVA	1.73	0.74	-1.37	0.71
RVA	1.48	0.61	-1.21	0.60
LIJV	-4.06	2.72	3.34	2.56
RIJV	-6.35	2.95	4.90	2.90
tIJV	-10.42	3.43	8.23	3.79
tLA	8.02	1.74	-7.10	1.58
tRA	7.89	1.49	-7.10	1.64
tA	15.90	2.87	-14.20	2.91
tLV	-5.98	2.60	5.15	2.64
tRV	-8.83	2.74	6.95	2.86
tV	-14.81	2.74	12.10	3.63

Flow Distributions (Site 1 vs. Site 2, N=125)

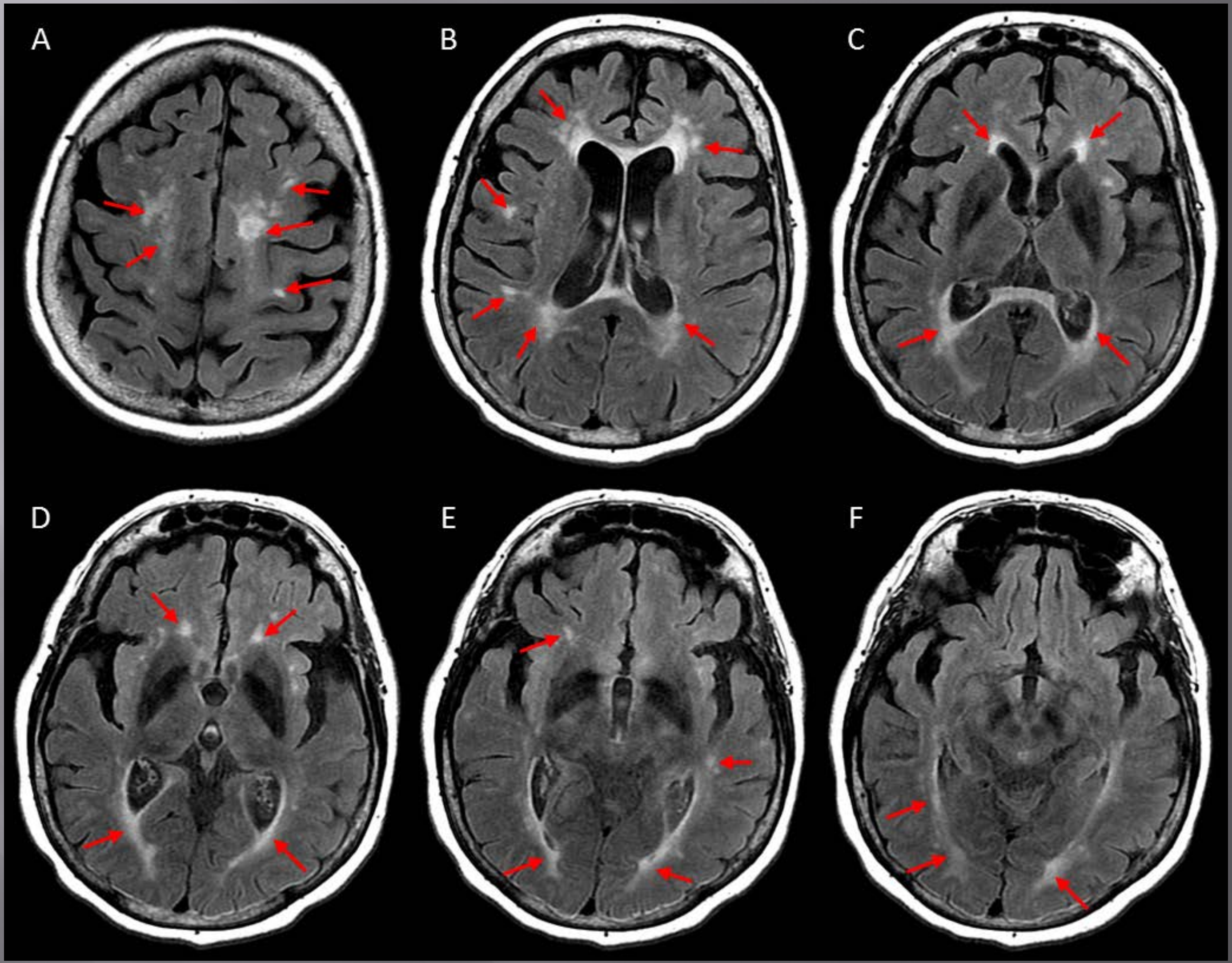
Flow Distribution (%)	Site 1		Site 2	
	Mean	Std	Mean	Std
LCCA/tA	39.43	3.72	40.38	4.56
RCCA/tA	40.20	4.24	41.43	4.35
LIJV/tV	27.42	17.13	27.11	18.60
RIJV/tV	42.83	18.28	39.38	20.73
tLA/tA	50.28	4.80	50.00	5.08
tRA/tA	49.72	4.80	50.00	5.08
IJV/tV	70.24	19.08	66.49	22.60
IJV/tA	-66.29	20.64	-58.64	27.47
A-V mismatch (%)	6.21	12.30	14.37	21.51
Fsd/Fd	0.51	0.25	0.52	0.25
Fd/Fsd	2.64	1.76	2.71	2.22

Vessel Cross-Sectional Area (Site 1 vs. Site 2, N=125)

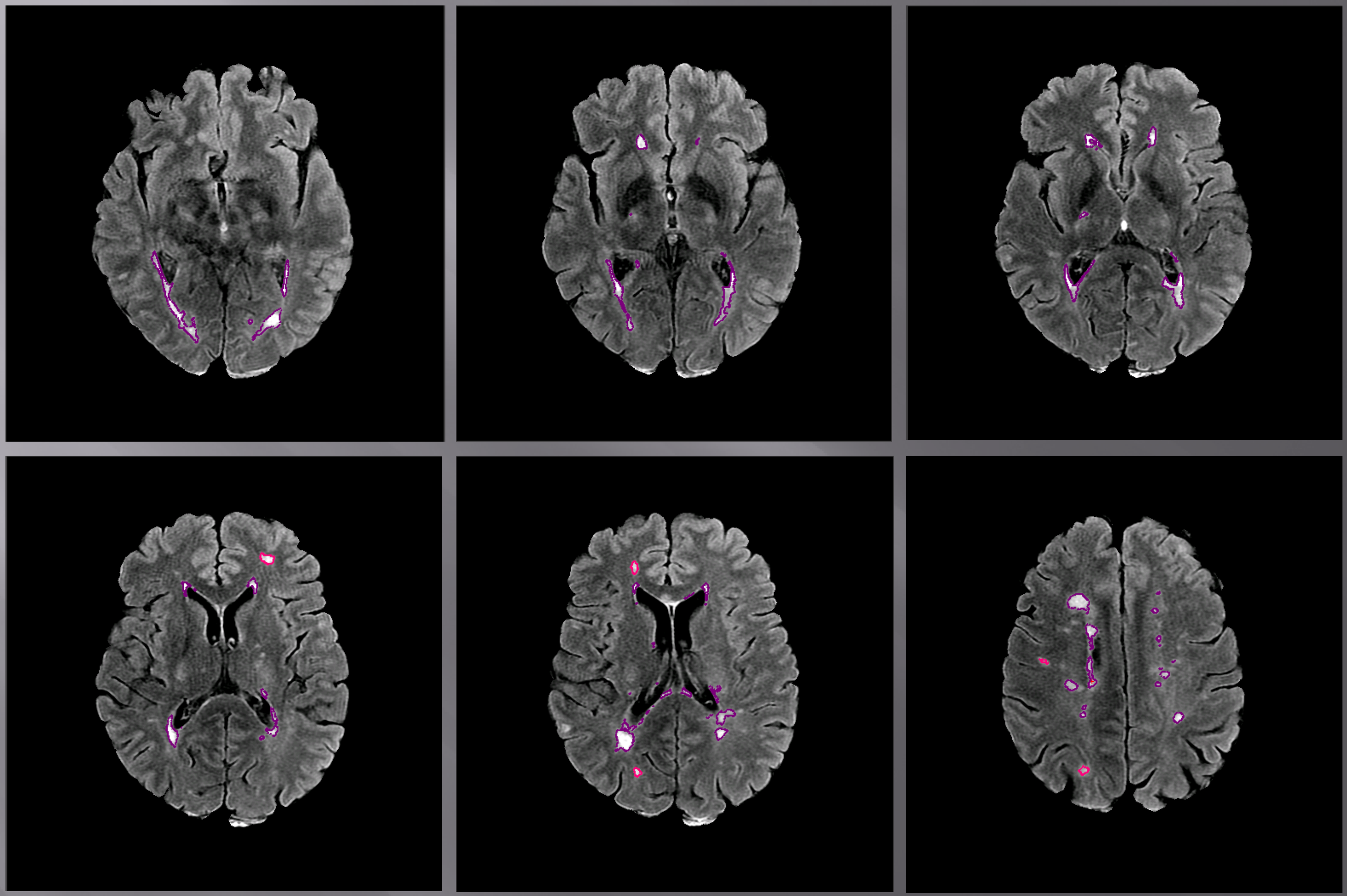
Vessel CS Area (mm^2)	Site 1		Site 2	
	Mean	Std	Mean	Std
LCCA	31.74	7.12	36.12	11.69
RCCA	33.72	7.36	35.41	10.17
LVA	13.23	4.58	13.55	5.75
RVA	12.30	4.34	12.89	5.42
LIJV	57.34	37.76	49.29	41.52
RIJV	75.40	45.63	60.68	56.32
tLA	45.00	9.73	49.76	13.86
tRA	46.05	9.10	48.46	12.68
tA	91.05	16.77	98.23	24.03
tLV	98.77	43.48	98.05	50.38
tRV	120.00	49.44	108.88	63.68
tV	218.78	79.12	206.93	102.51

NEURO-ANATOMICAL INFORMATION:

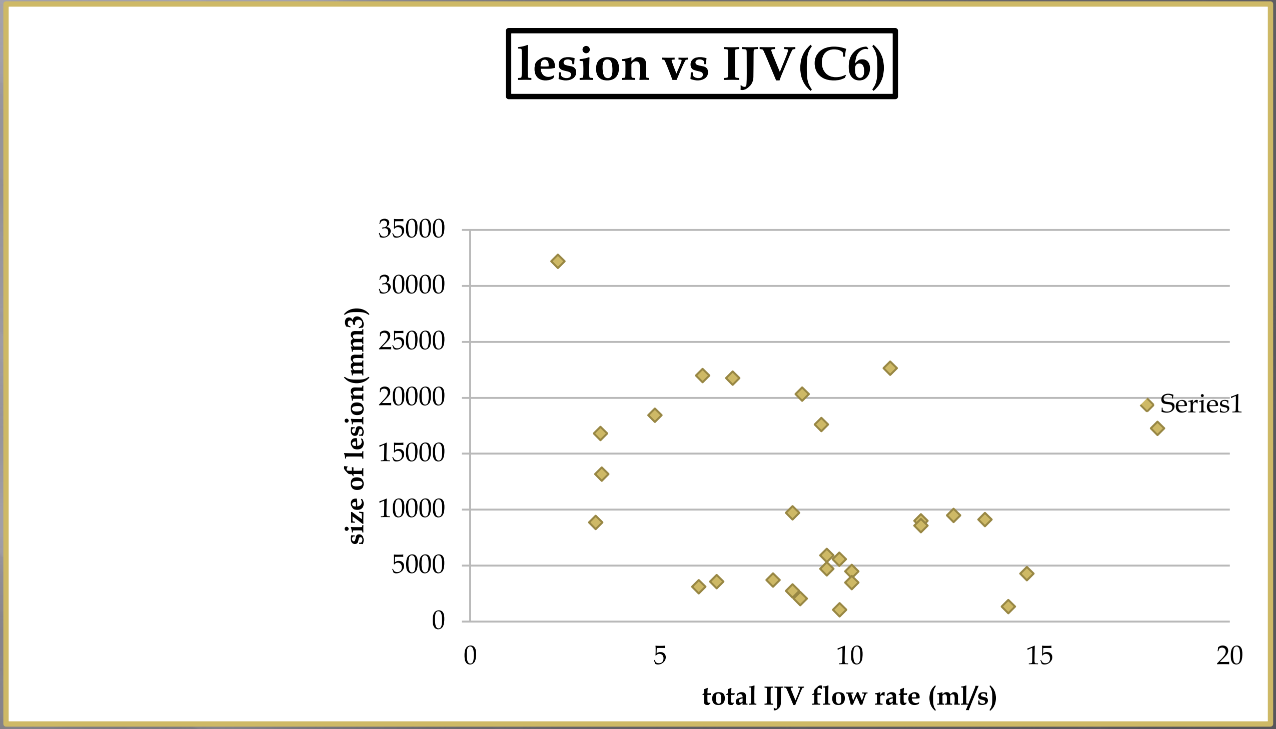
This individual shows multiple white matter lesions from high resolution 3D FLAIR including diffuse hyper-intensities.



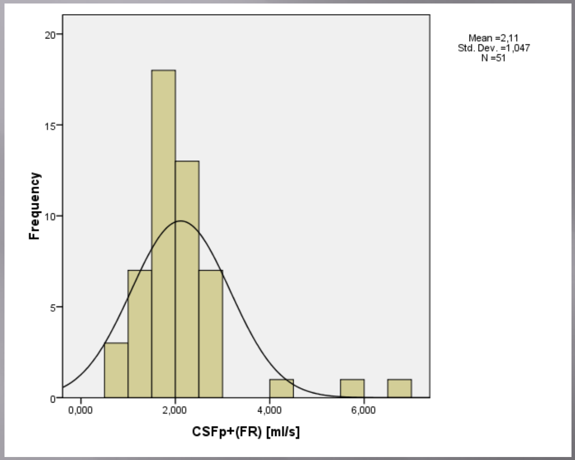
Automatic detection of FLAIR lesions

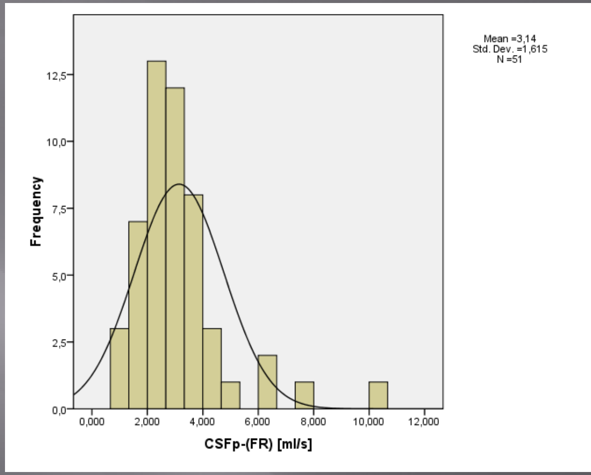


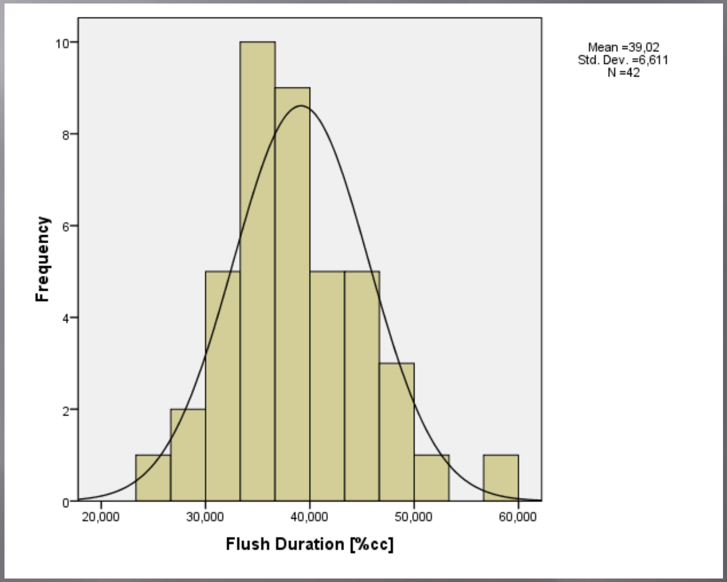
Lesion load vs IJV flow



Comparison of CSF Flow Rates (ml/s)





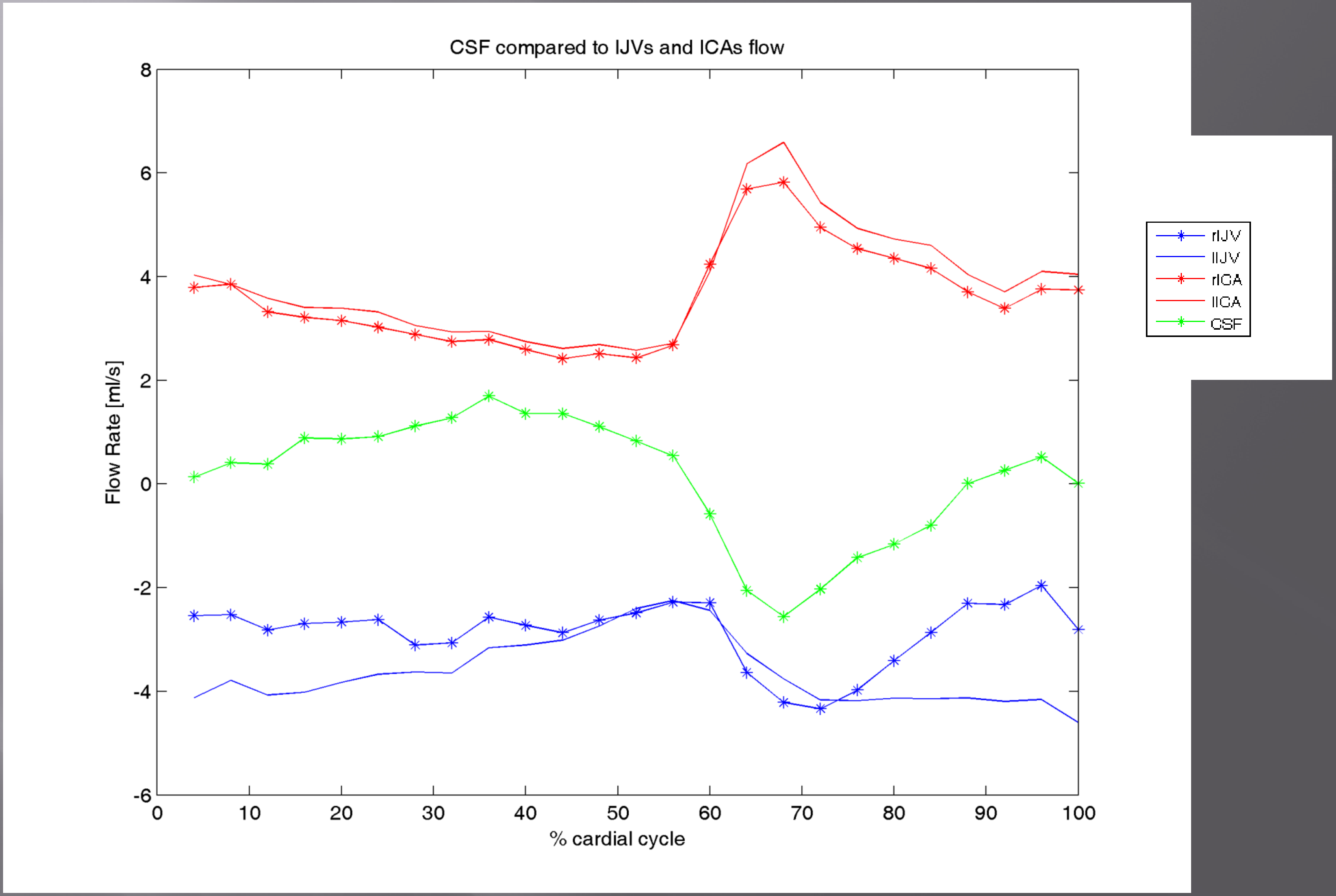


Comparison with Baledent et al., 2001

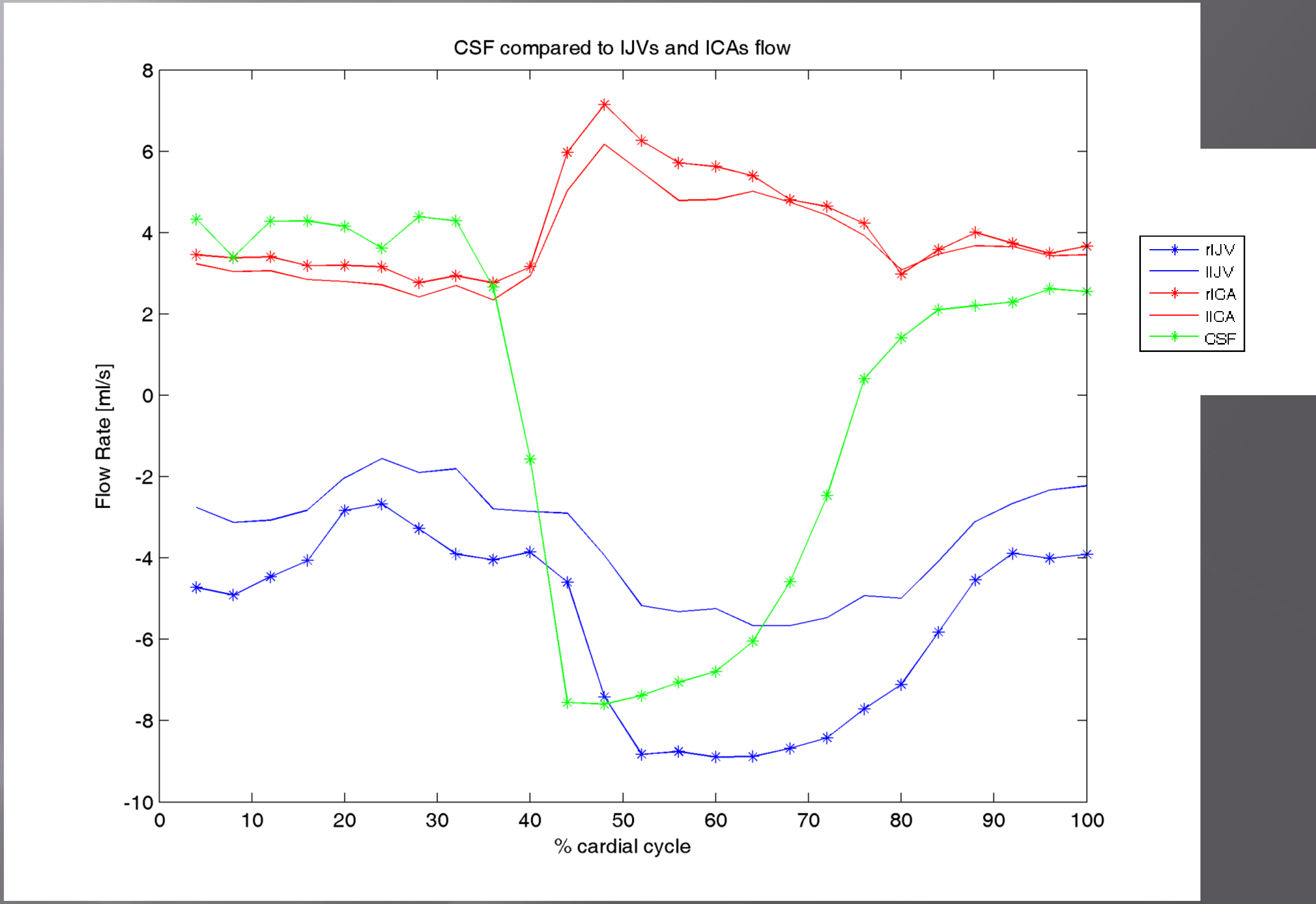
16 healthy subjects
Flush Duration = (40±10) % cc

Balédent O, et al. Cerebrospinal fluid dynamics and relation with blood flow: a magnetic resonance study with semiautomated cerebrospinal fluid segmentation. Invest Radiol. 2001,36:368-377.

Example of normal CSF flow



Example of high negative peak CSF flow



Why perform MR imaging before and after treatment? We need to:

- monitor lesions and iron content quantitatively
- monitor arterial, venous and CSF flow changes
  - Use normal flow in both IJVs as a marker not to treat
- use the 3D vascular data to plan the intervention
  - Beware of situations which may not be treatable
- categorize different types of MS populations
- serve as a baseline to study the anatomy and flow after treatment if complications develop

Conclusions

- *We need to understand the hemodynamics and fluid dynamics of the human brain.*
- Patients should be imaged before and after treatment and IRs should participate in IRB driven studies for full data documentation.
- We should then create an international database to better understand the vascular system and its role in neurological diseases such as MS.

Conclusions

- We need to image as many normals as possible. Currently, the number of patients being imaged and/or treated is in the 1000s; we need age matched normal controls to compare to this patient population.
- Please visit www.ms-mri.com for updates in MR imaging protocols, publications, educational material and new quantification results.