What information can 4D flow MRI provide to help in the challenging diagnosis of chronic mesenteric ischemia?

Introduction

- Chronic mesenteric ischemia (CMI) is a disease caused by inadequate blood flow to the intestines.

- Most cases are the result of atherosclerosis (95%).

- Typical symptoms include:
    - Severe postprandial abdominal pain
    - Nausea/Vomiting
    - Fear of eating
    - Weight loss

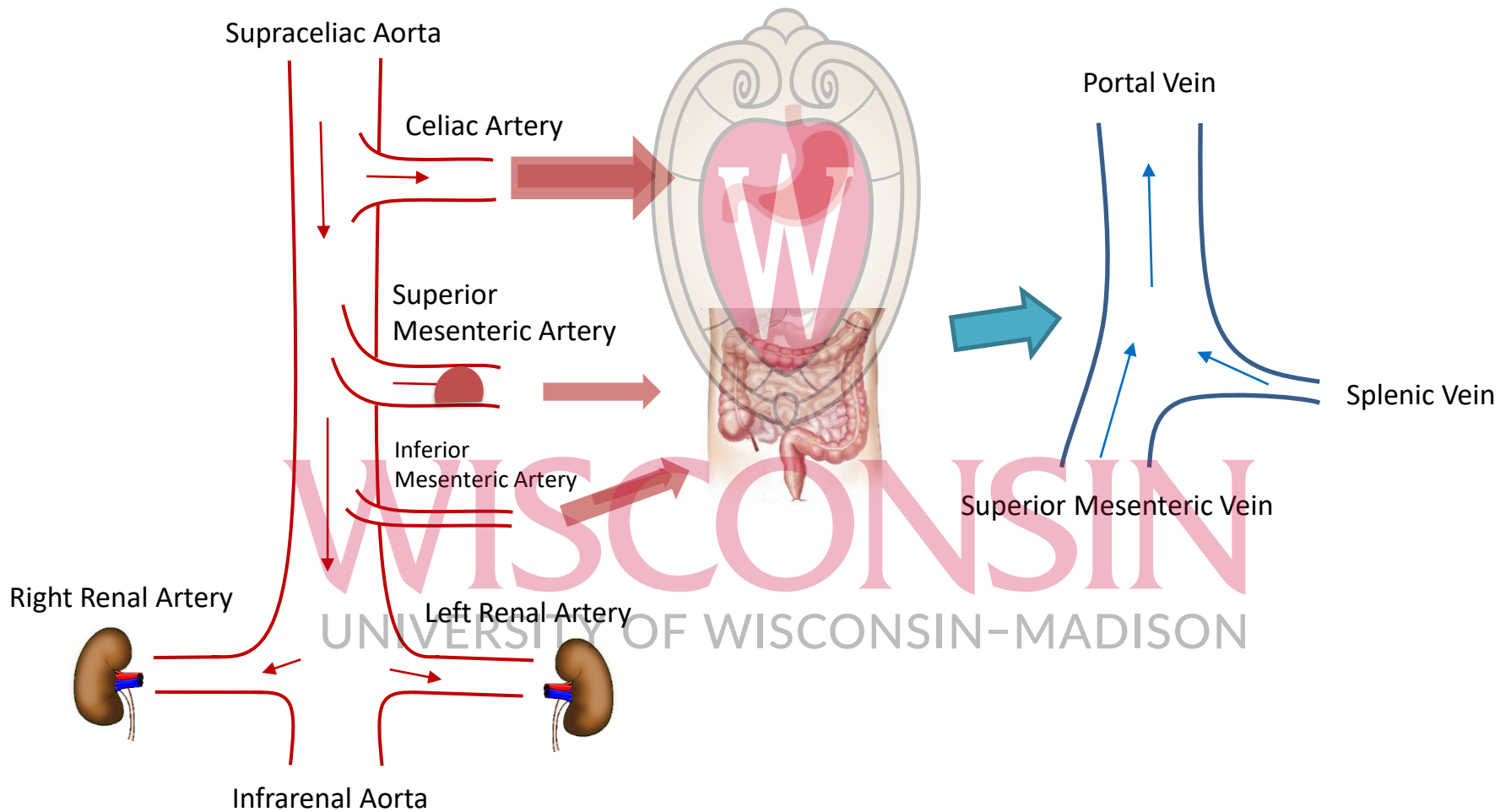- Can result in life-threatening acute ischemia.

From *Amin MA*

Amin MA et al. Egypt J Radiol Nucl Med 2014;45:1063–1070.

3

Study
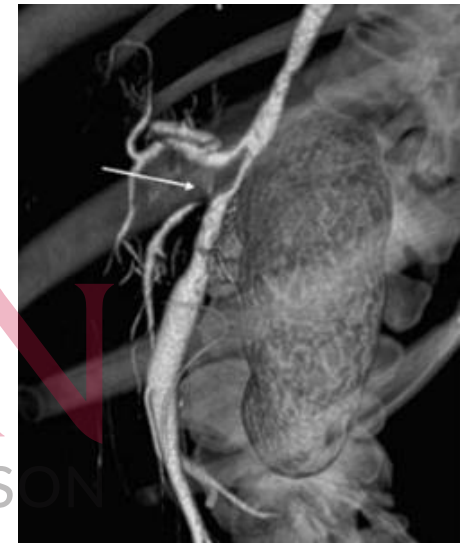
- In normal individuals, mesenteric blood flow increases after a meal.

- In patients with CMI, this postprandial blood flow response is stunted due to restricted blood flow.

- Previous CMI studies using MRI[1,2,3,4]

  - 2D CINE PC-MRI + meal challenges

  - Showed drastically reduced blood flow change after a meal in the superior mesenteric arteries/veins.

- 4D flow MRI has been proposed as a method to both functionally and anatomically evaluate mesenteric vasculature before and after a meal.

1. Li KCP, et al. Radiology 1994;190:175–179.
2. Burkart DJ, et. al. Radiology 1995;194:801–806.
3. Li KCP, et al. Radiology 1995;194:327–330.
4. Dalman RL, et al. Circulation 1996;94:206–210.

Anatomy

Supraceliac Aorta

Celiac Artery

Superior Mesenteric Artery

Inferior Mesenteric Artery

Right Renal Artery

Left Renal Artery

Infrarenal Aorta

Portal Vein

Splenic Vein

Superior Mesenteric Vein

Anatomy

From *Bobadilla JL*

From *Wilkins LR*
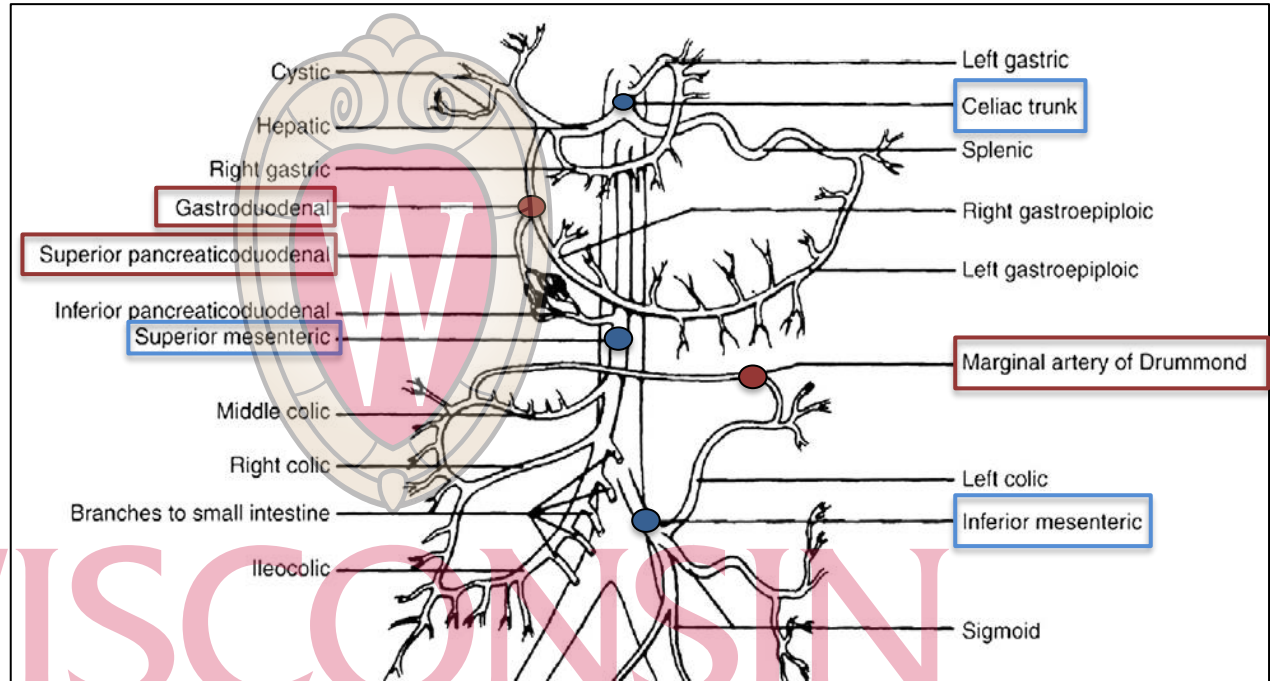
- Due to collateral circulation, patients may not experience symptoms until 2 or 3 major mesenteric vessels are involved.

Bobadilla JL. Surg Clin North Am 2013;93:925–940.
Wilkins LR, Stone JR. Tech Vasc Interv Radiol 2015;18:31–37.

Study

- **The goal of this study is to globally evaluate the hemodynamics of the mesenteric system in healthy individuals and suspected CMI patients.**

- Retrospective study
  - Patients were referred from vascular surgery from 2012 to current.
  - Multiple imaging studies, including 4D flow.
  - Diagnosis given by Radiology.

1. Li KCP, et al. Radiology 1994;190:175–179.
2. Burkart DJ, et. al. Radiology 1995;194:801–806.
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Methods

- Subjects were imaged 5 hours after fasting (preprandial) and 25 minutes after a standardized meal (postprandial).

- Scans were performed using a PCVIPR sequence.

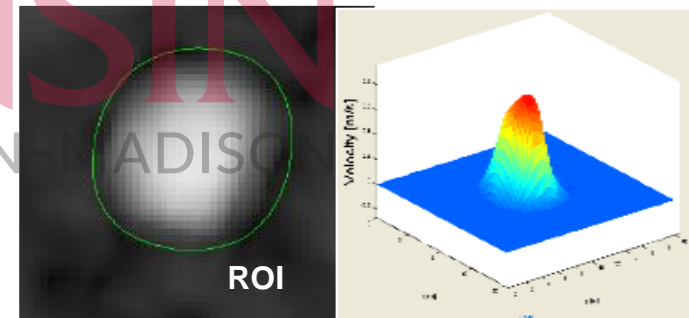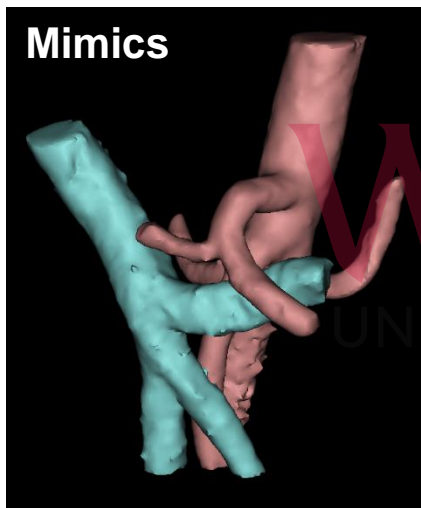| Parameters	Values
Field Strength	1.5T and 3.0T
TR/TE	6.6/2.3 ms
Flip angle	12 degrees
# Projections	11,000
VENC	100 cm/s preprandial 120 cm/s postprandial
Resolution	1.25 mm isotropic
Scan Time	10 minutes
Respiratory Gating	Retrospective
Cardiac Gating	Retrospective (14 frames)

Methods

- Patients were subcategorized based on Radiology's diagnosis into negative and positive diagnosis of CMI.

- 3 Groups
  - Negative Diagnosis: 13 patients
    - 7 females, mean age: 44.3 years [21-86], mean weight: 70.1 kg
  - Positive Diagnosis (CMI): 6 patients
    - 4 females, mean age: 62.5 years [42-80], mean weight: 64.2 kg
  - Control Group: 20 individuals
    - 8 females, mean age: 44.4 years [19-73], mean weight: 80.2 kg

Stalder AF, et al. MRM 2008;60:1218–1231.

- Blood flow was measured:
  - In **controls**, **negative diagnosis**, and **CMI** patients
  - Both **preprandial** and **postprandial**
  - In 9 vessels
    - Supraceliac (SCAo), infrarenal aorta (IRAo)
    - Superior mesenteric artery (SMA)
    - Celiac artery (CA)
    - Right (RRA), left renal arteries(LRA)
    - Superior mesenteric vein (SMV)
    - Splenic vein (SV)
    - Portal Vein (PV)

SCAo

CA

SMA

RRA   LRA

IRAo

PV

SMV   SV

Methods
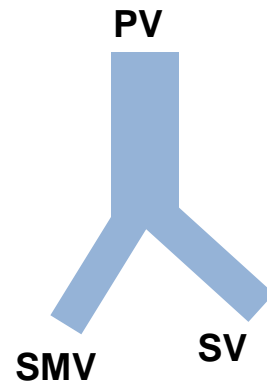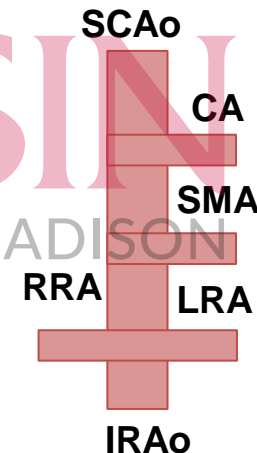
- Segmentation was performed in Mimics (Materialize, Belgium).
  - Thresholding + region-growing was applied to complex difference data
- 3D visualization, streamline generation, and cut-plane analysis was performed in Ensight (ANSYS, PA).
- Time-resolved hemodynamic analysis was performed in a customized 4D flow tool.
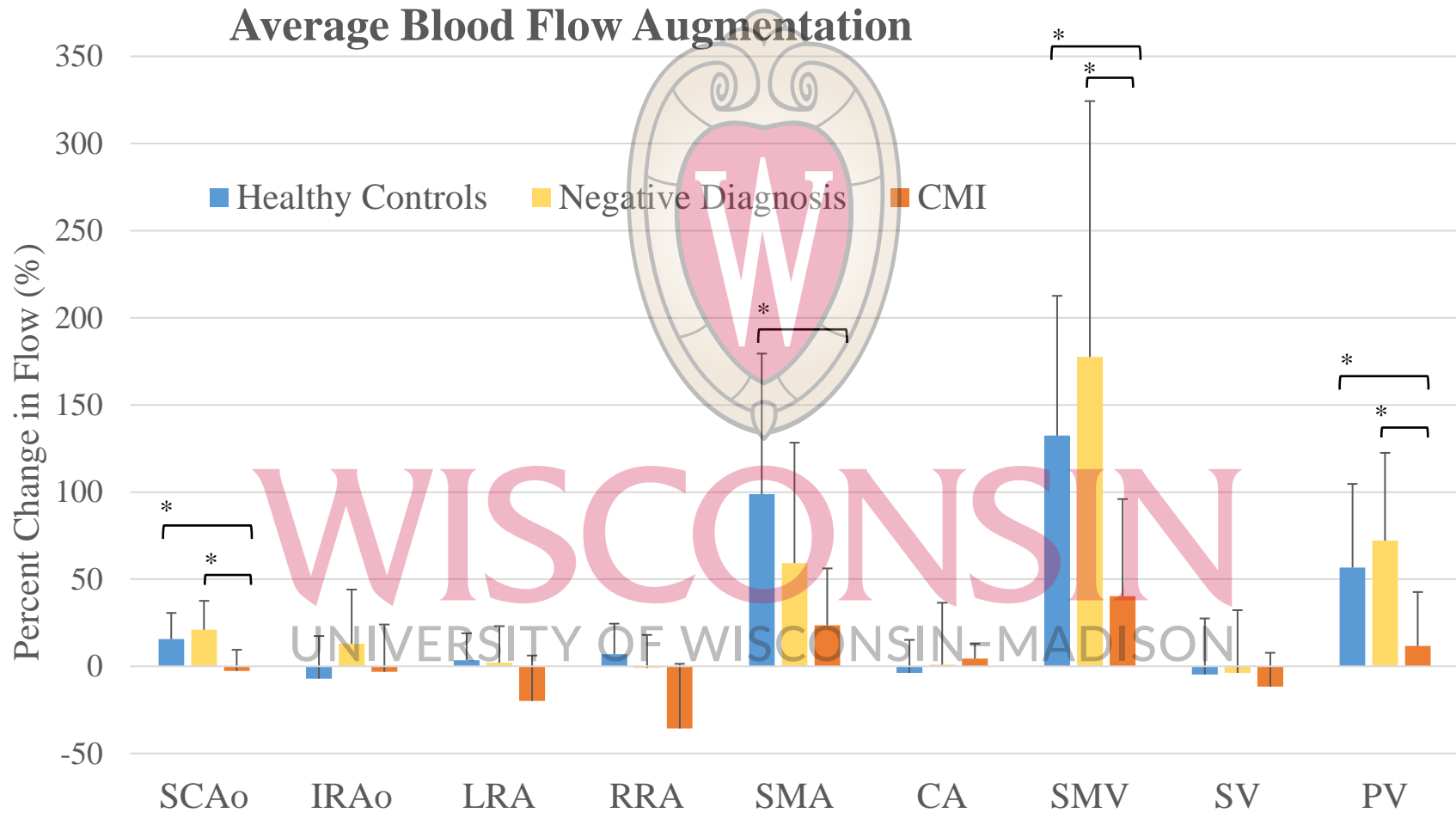
Mimics

Ensight

Velocity (m/s)
1.00
0.75
0.50
0.25
0.00

ROI

Stalder AF, et al. MRM 2008;60:1218–1231.

Average Blood Flow Augmentation

Results

Table 3: Average Percent Change in Flow (%)

	SCAo	IRAo	LRA	RRA	SMA	CA	SMV	SV	PV
Control	15.7 ± 15	-7.03 ± 24	3.58 ± 15	6.97 ± 18	98.8 ± 81	-3.73 ± 19	132 ± 81	-4.76 ± 32	56.7 ± 48
Neg. Diag.	21.1 ± 17	13.0 ± 31	2.03 ± 21	-0.95 ± 19	62.7 ± 67	0.93 ± 36	178 ± 147	-3.77 ± 36	72.1 ± 50
CMI	<u>-2.57 ± 12</u>	-3.16 ± 27	-19.9 ± 26	-35.7 ± 37	**23.5 ± 33**	4.52 ± 8.5	<u>**40.3 ± 56**</u>	-11.7 ± 19	<u>**11.7 ± 31**</u>

Percent change values are expressed as mean ± 1 standard deviation. **Bold** indicates statistical significance ($p < 0.05$) compared to controls. <u>Underline</u> indicates statistical significance ($p < 0.05$) between the CMI and Neg. Diag. group.

	SCAo	SMA	SMV	PV
CMI - Control	p=0.022, d=0.956	p=0.003, d=0.865	p=0.008, d=0.944	p=0.006, d=1.023
CMI – Neg. Diagn.	p=0.008, d=1.150		p=0.009, d=0.875	p=0.018, d=0.788

Results

Paired T-Test p-values

	SCAo	IRAo	LRA	RRA	SMA	CA	SMV	SV	PV
Control	5.62E-05	0.170	0.716	0.103	5.20E-06	0.187	2.51E-08	0.129	1.17E-05
Neg. Diag.	0.0049	0.468	0.980	0.913	0.003	0.535	3.05E-06	0.367	1.60E-05
CMI	0.592	0.868	0.097	0.122	0.193	0.290	0.120	0.221	0.255

Effect Sizes (Cohen's D)

	SCAo	IRAo	LRA	RRA	SMA	CA	SMV	SV	PV
Control	0.381	-0.215	-0.019	0.139	1.256	-0.107	2.101	-0.216	1.137
Neg. Diag.	0.507	0.180	-0.004	0.014	0.703	0.088	1.665	-0.109	1.690
CMI	-0.107	-0.080	-0.316	-0.416	0.465	0.101	0.777	-0.417	0.379

- Increase in mesenteric blood flow after meal
  - *Immediate* increase in celiac artery (CA)
  - *Delayed* increase in superior mesenteric artery (SMA)
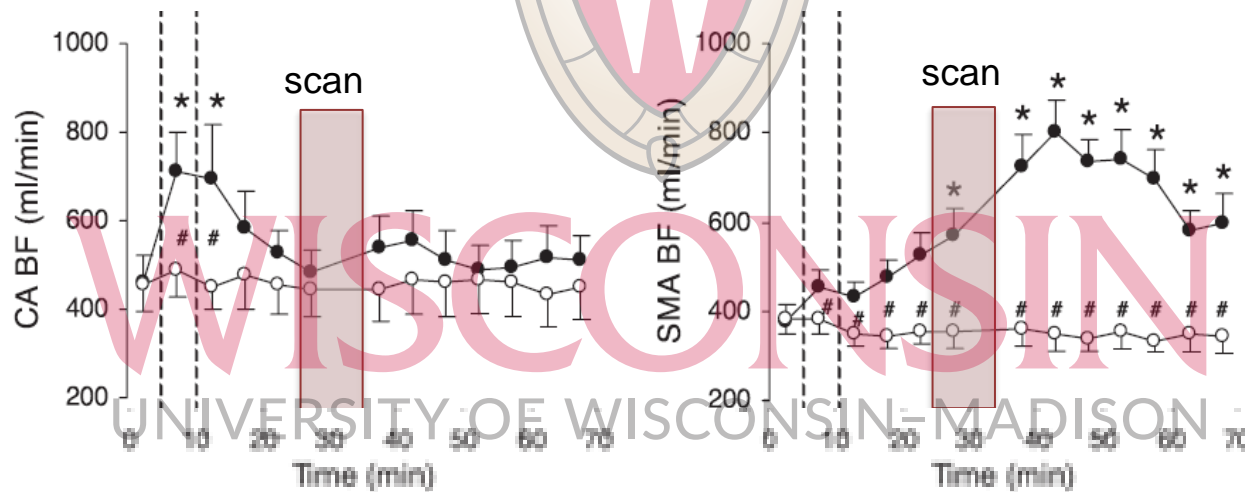
Blood flow response after standardized meal is shown in black. From *Someya et al.*
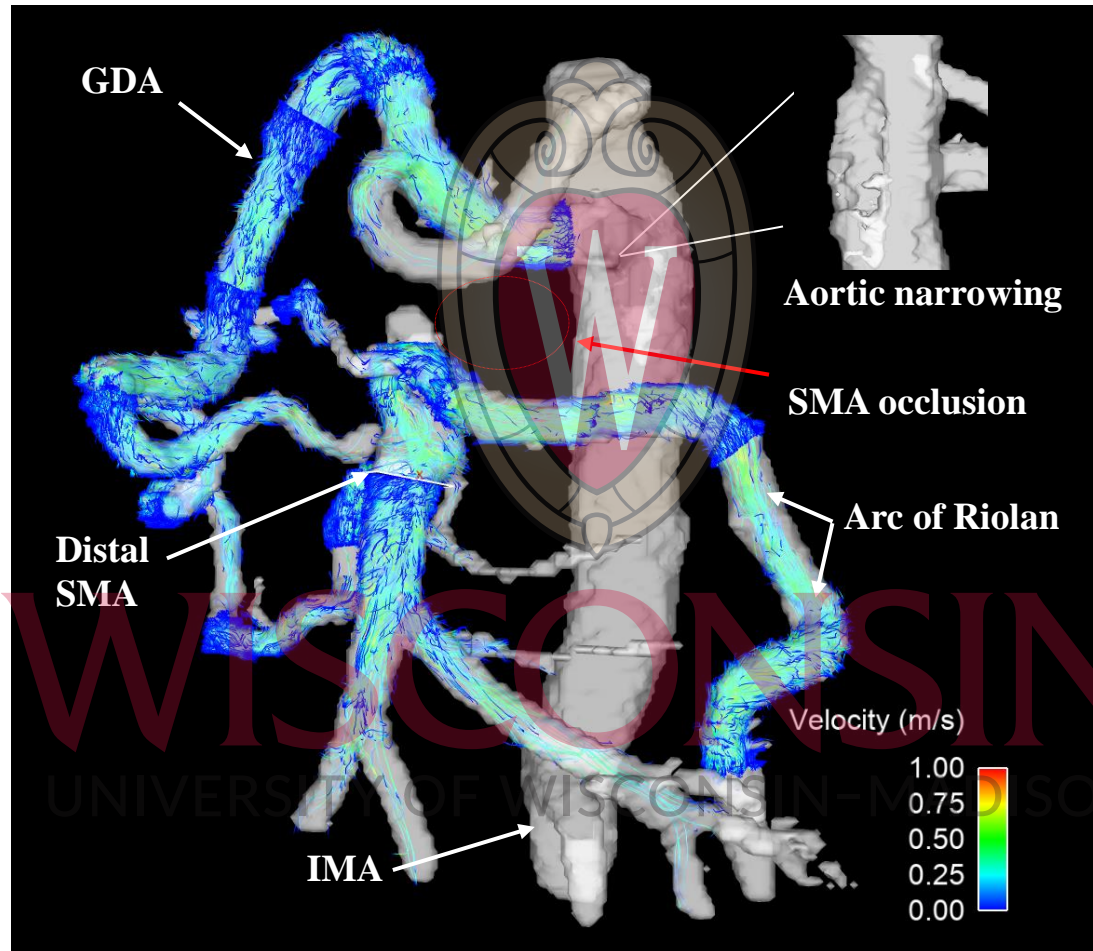
Someya N, et al. Am J Physiol Regul Integr Comp Physiol 2008;294:1790–1796.

Case 2
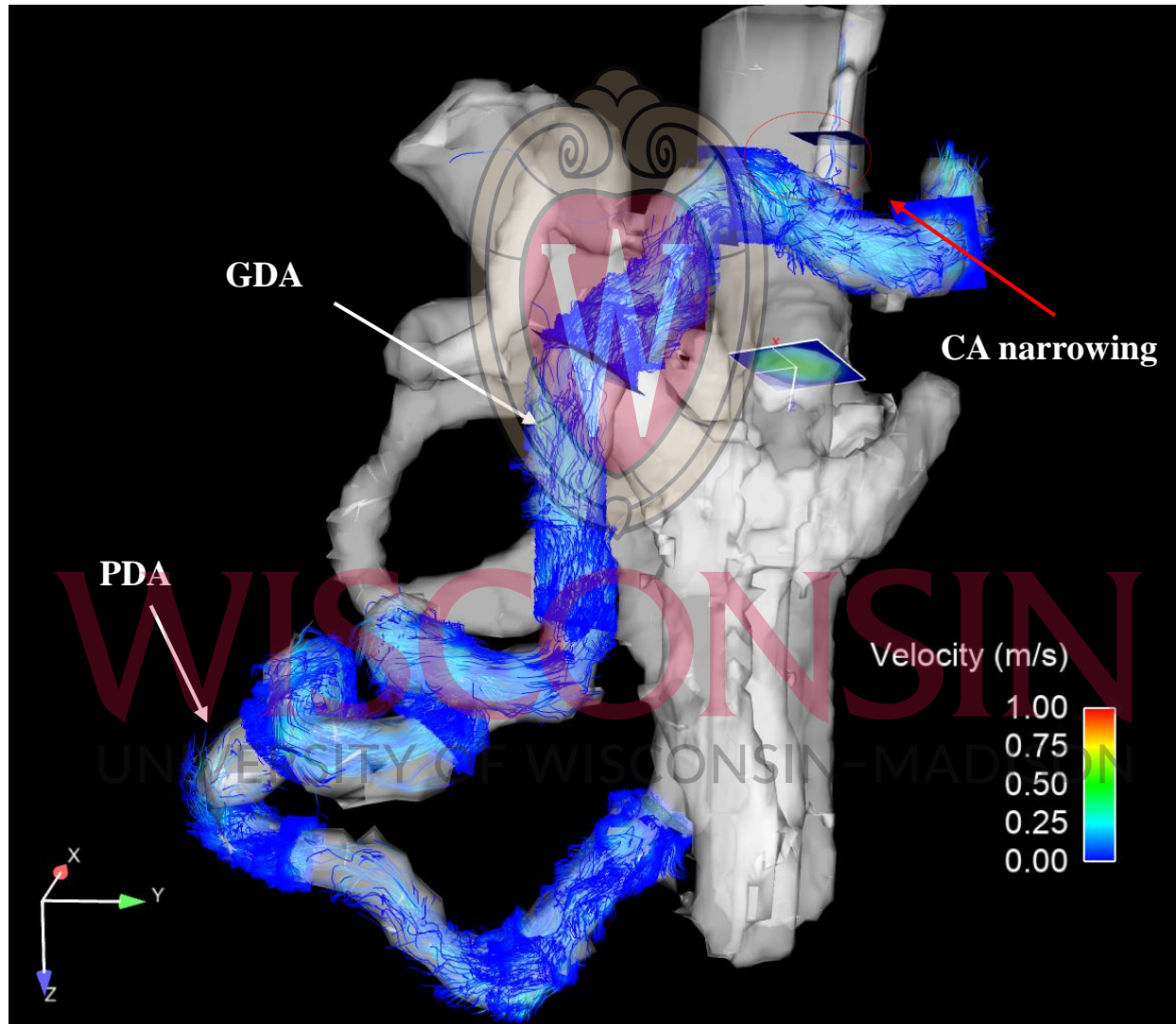
Future Directions

- Imaging controls and patients with the same field strength and body coil types.

- Larger patient cohort for stronger statistics.

- More automated image processing pipeline
  - One case took ~40 minutes for experienced user

- Acquiring an additional scan immediately after meal ingestion may show insight in CA flow.

- Measuring flow in IMA would provide a more comprehensive evaluation of mesenteric flow.

Conclusion

- There is strong evidence that quantifiable differences in blood flow patterns exist in CMI patients.

- 4D flow MRI possesses the unique capability of obtaining complete volumetric hemodynamic information in one scan.
    - Allowing for retrospective flow analysis in any vessel

- PC angiogram to morphologically assess stenoses and occlusions

- **4D flow MRI is a promising non-invasive diagnostic technique that can functionally and anatomically evaluate mesenteric vasculature.**

Acknowledgements

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