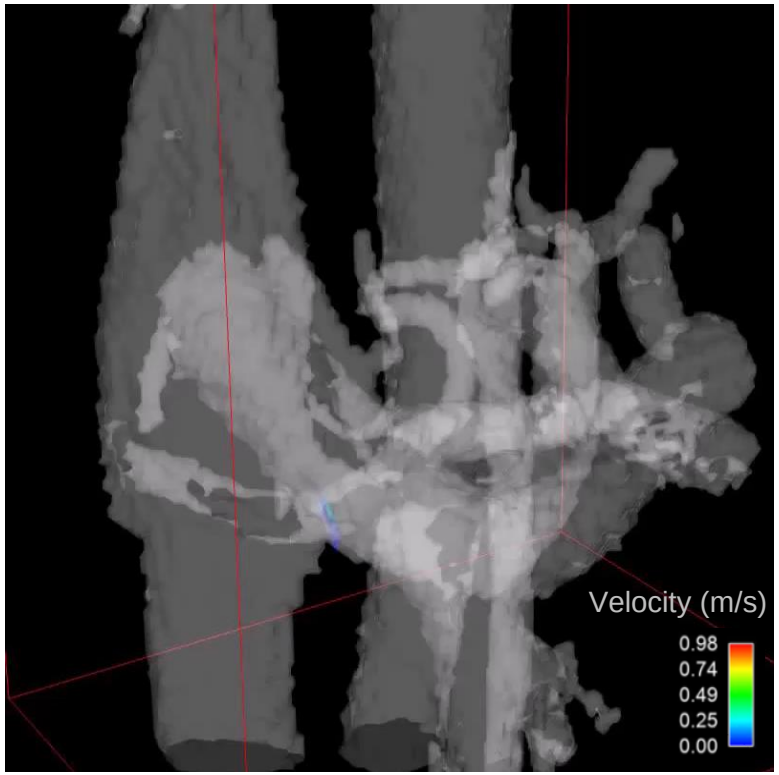
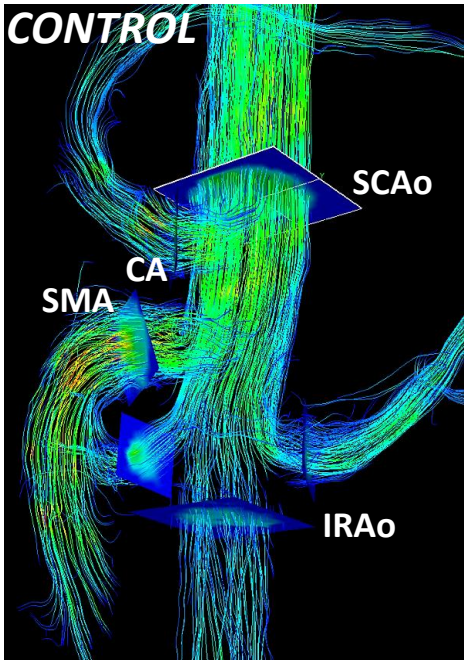
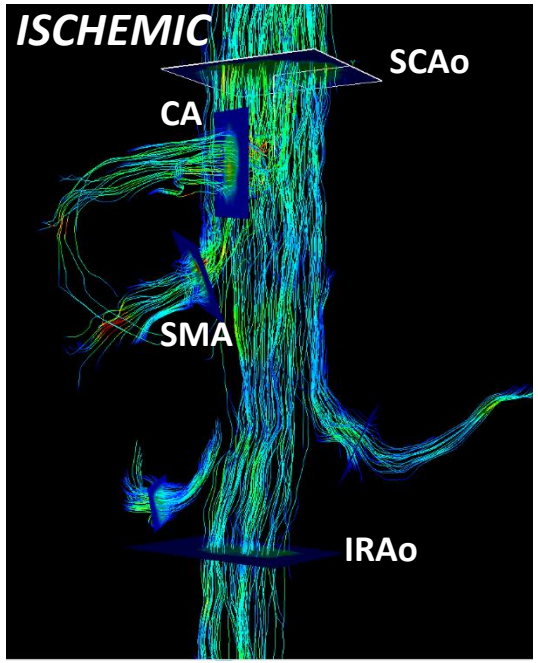
Hemodynamics of Chronic Mesenteric Ischemia Using 4D Flow MRI







Grant Roberts

April 24, 2019

School of Medicine and Public Health
UNIVERSITY OF WISCONSIN-MADISON

Question

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*

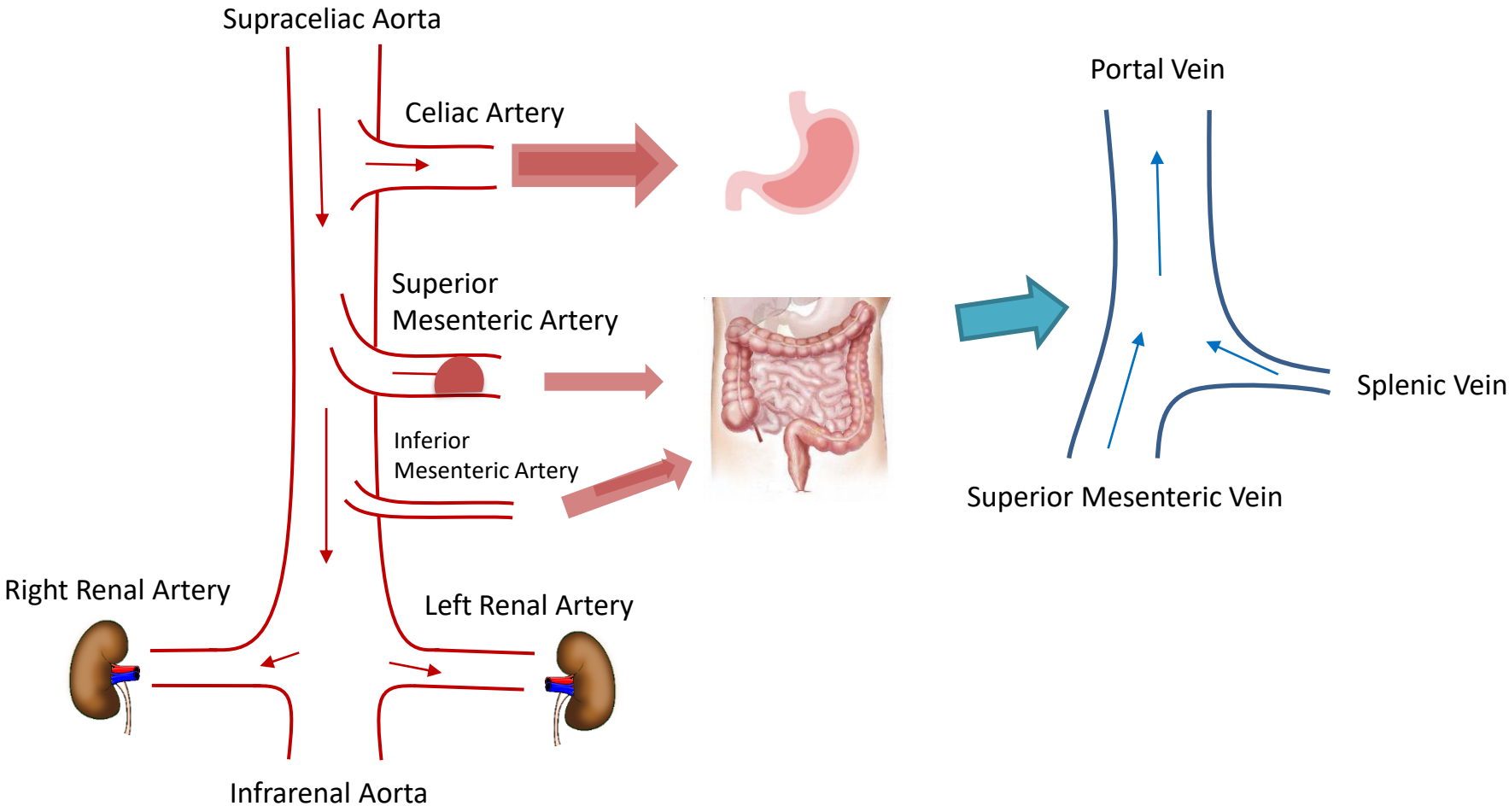
Amin MA et al. Egypt J Radiol Nucl Med 2014;45:1063–1070.

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.

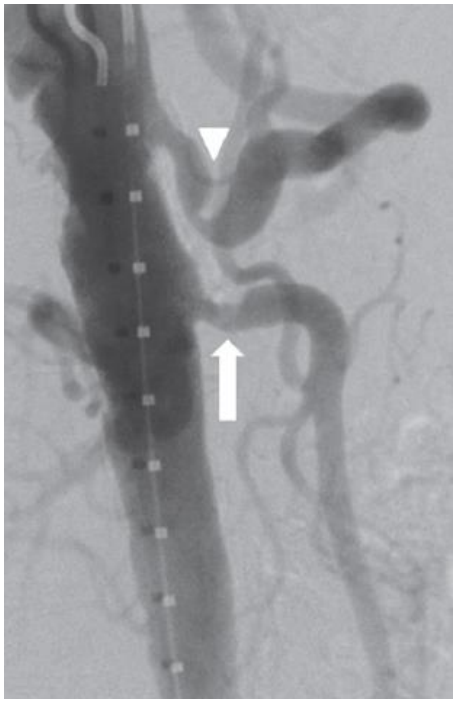
1. Li KCP, et al. Radiology 1994;190:175–179.
2. Burkart DJ, et. al. Radiology 1995;194:801–806.
3. Li KCP, et al. Radiology 1995;194:327–330.
4. Dalman RL, et al. Circulation 1996;94:206–210.

Anatomy

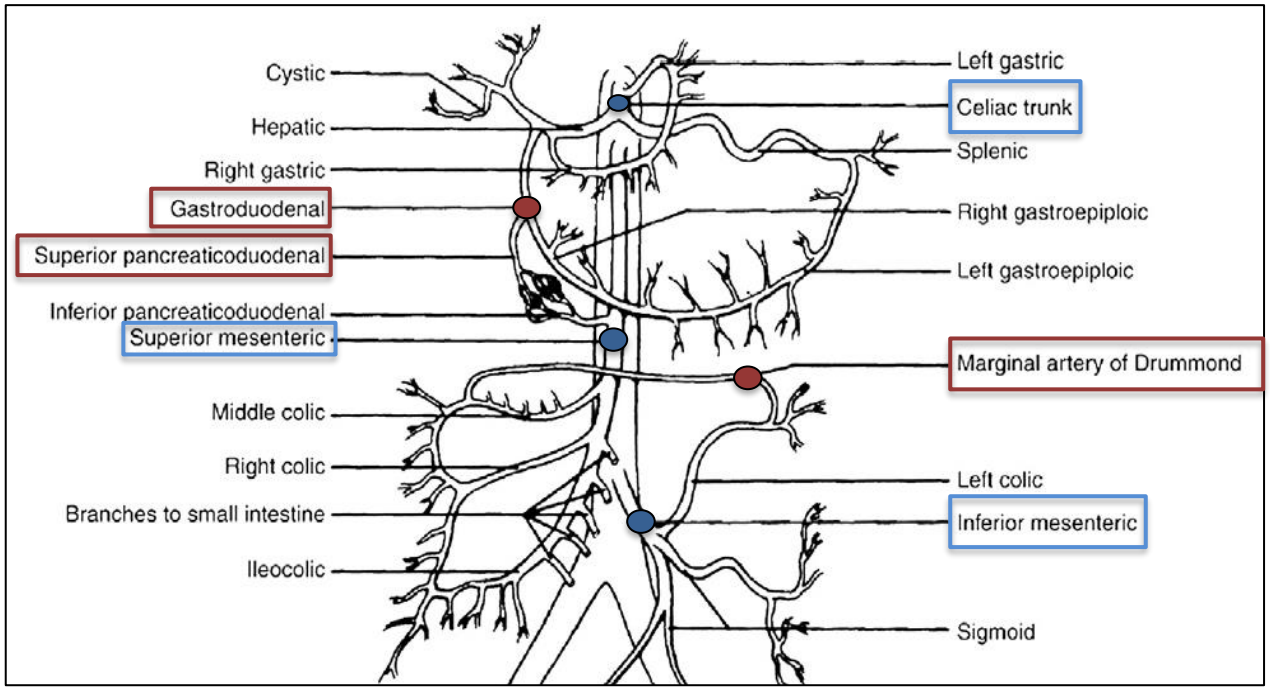

Supraceliac Aorta
Celiac Artery
Superior
Mesenteric Artery
Inferior
Mesenteric Artery
Right Renal Artery
Left Renal Artery
Infrarenal Aorta
Portal Vein
Splenic Vein
Superior Mesenteric Vein

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.
3. Li KCP, et al. Radiology 1995;194:327–330.
4. Dalman RL, et al. Circulation 1996;94:206–210.

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)

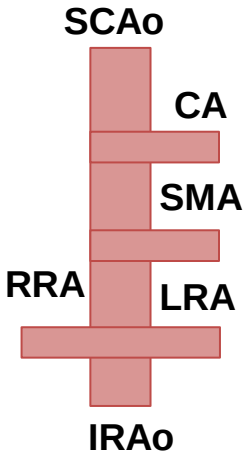
Methods

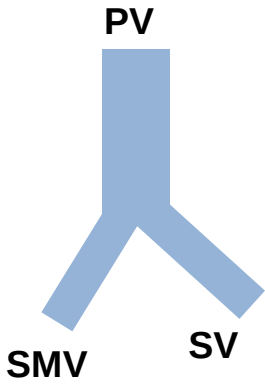
- Patients were subcategorized based on Radiology's diagnosis into negative and positive diagnosis of CMI.
- 3 Groups
  - Negative Diagnosis: 13 patients
    - 7 females, mean age: 44.3 years [21-86], mean weight: 70.1 kg
  - Positive Diagnosis (CMI): 6 patients
    - 4 females, mean age: 62.5 years [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.

Methods

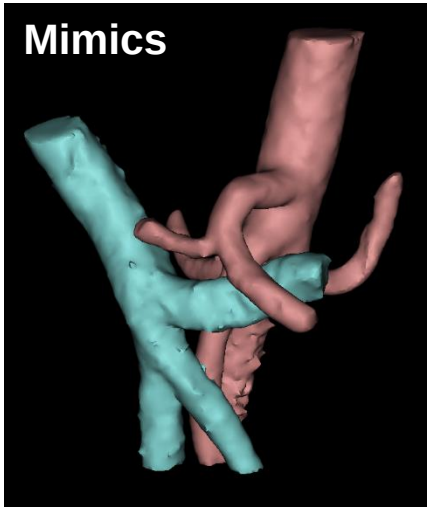
- Blood flow was measured:
  - In **controls**, **negative diagnosis**, and **CMI** patients
  - Both **preprandial** and **postprandial**
  - In 9 vessels
    - Supraceliac (SCAo), infrarenal aorta (IRAo)
    - Superior mesenteric artery (SMA)
    - Celiac artery (CA)
    - Right (RRA), left renal arteries(LRA)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

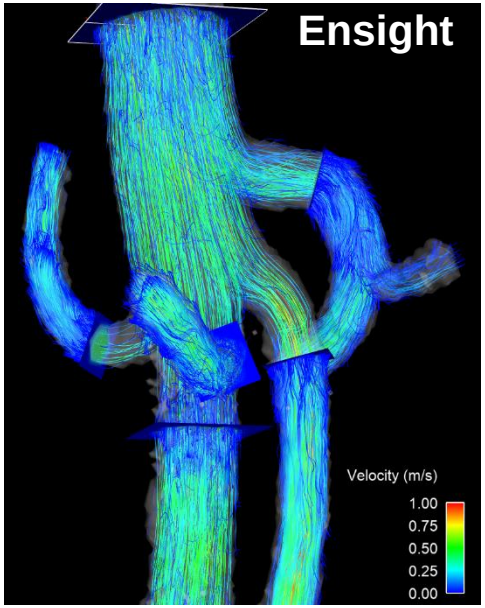


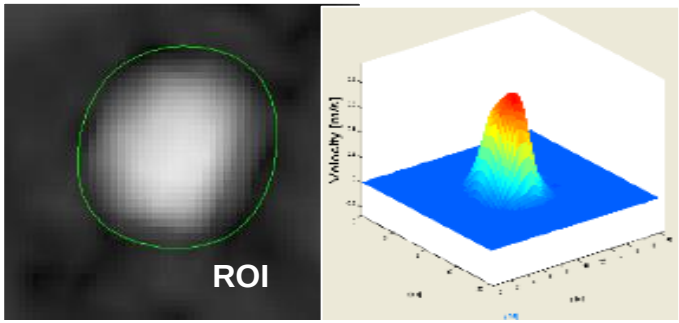


Methods

- 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.

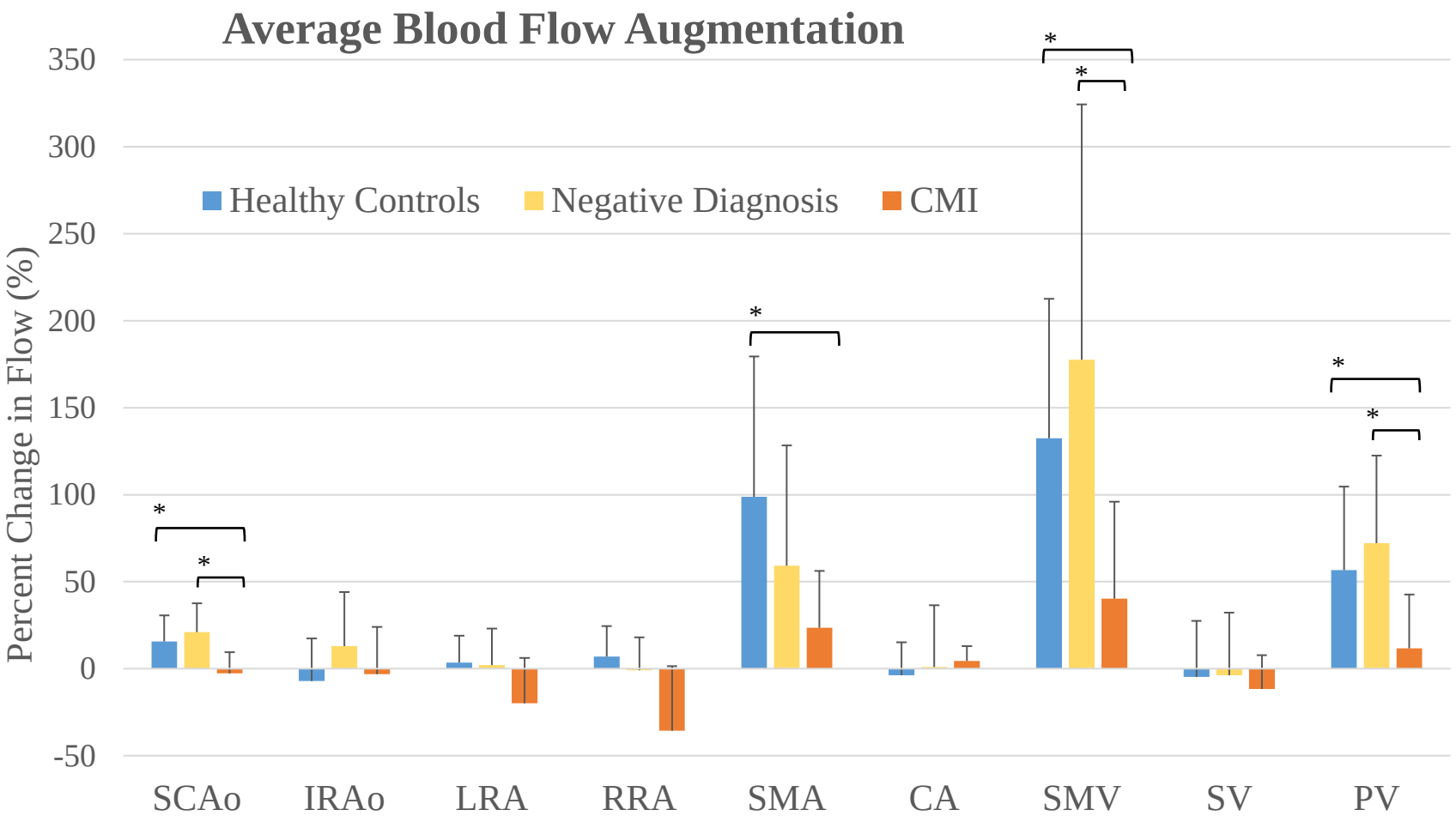






Stalder AF, et al. MRM 2008;60:1218–1231.

Results


Average Blood Flow Augmentation
Healthy Controls
Negative Diagnosis
CMI
Percent Change in Flow (%)
350
300
250
200
150
100
50
0
-50
SCAo
IRAo
LRA
RRA
SMA
CA
SMV
SV
PV
*

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	**-2.57 ± 12**	-3.16 ± 27	-19.9 ± 26	-35.7 ± 37	**23.5 ± 33**	4.52 ± 8.5	**40.3 ± 56**	-11.7 ± 19	**11.7 ± 31**

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

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

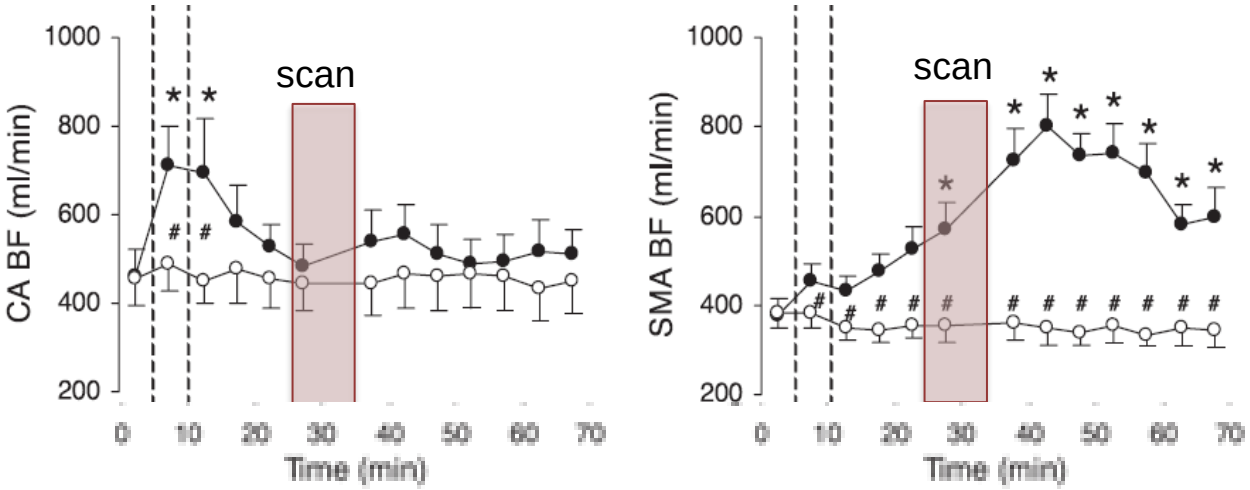
	SCAo	IRAo	LRA	RRA	SMA	CA	SMV	SV	PV
Control	5.62E-05	0.170	0.716	0.103	5.20E-06	0.187	2.51E-08	0.129	1.17E-05
Neg. Diag.	0.0049	0.468	0.980	0.913	0.003	0.535	3.05E-06	0.367	1.60E-05
CMI	0.592	0.868	0.097	0.122	0.193	0.290	0.120	0.221	0.255

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

Physiology

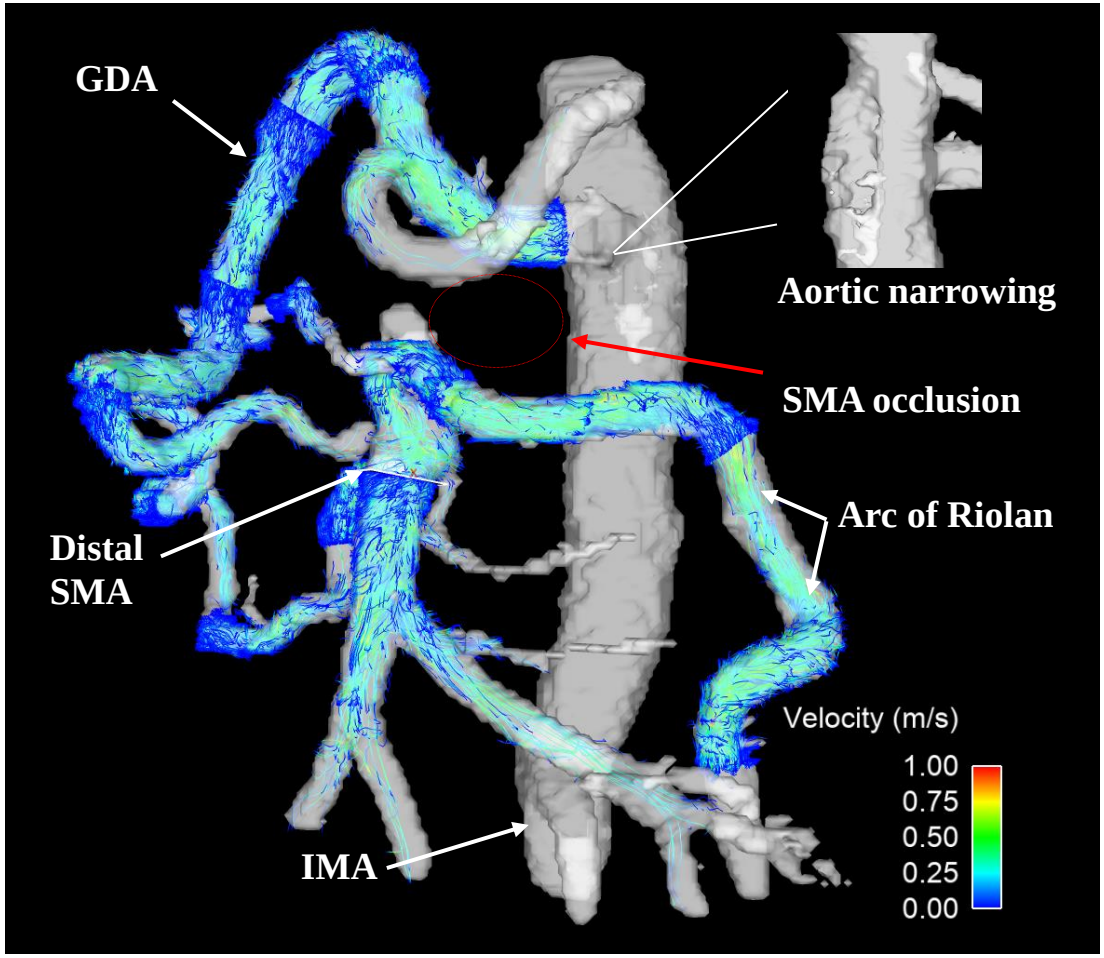
- Increase in mesenteric blood flow after meal
  - *Immediate* increase in celiac artery (CA)
  - *Delayed* increase in superior mesenteric artery (SMA)



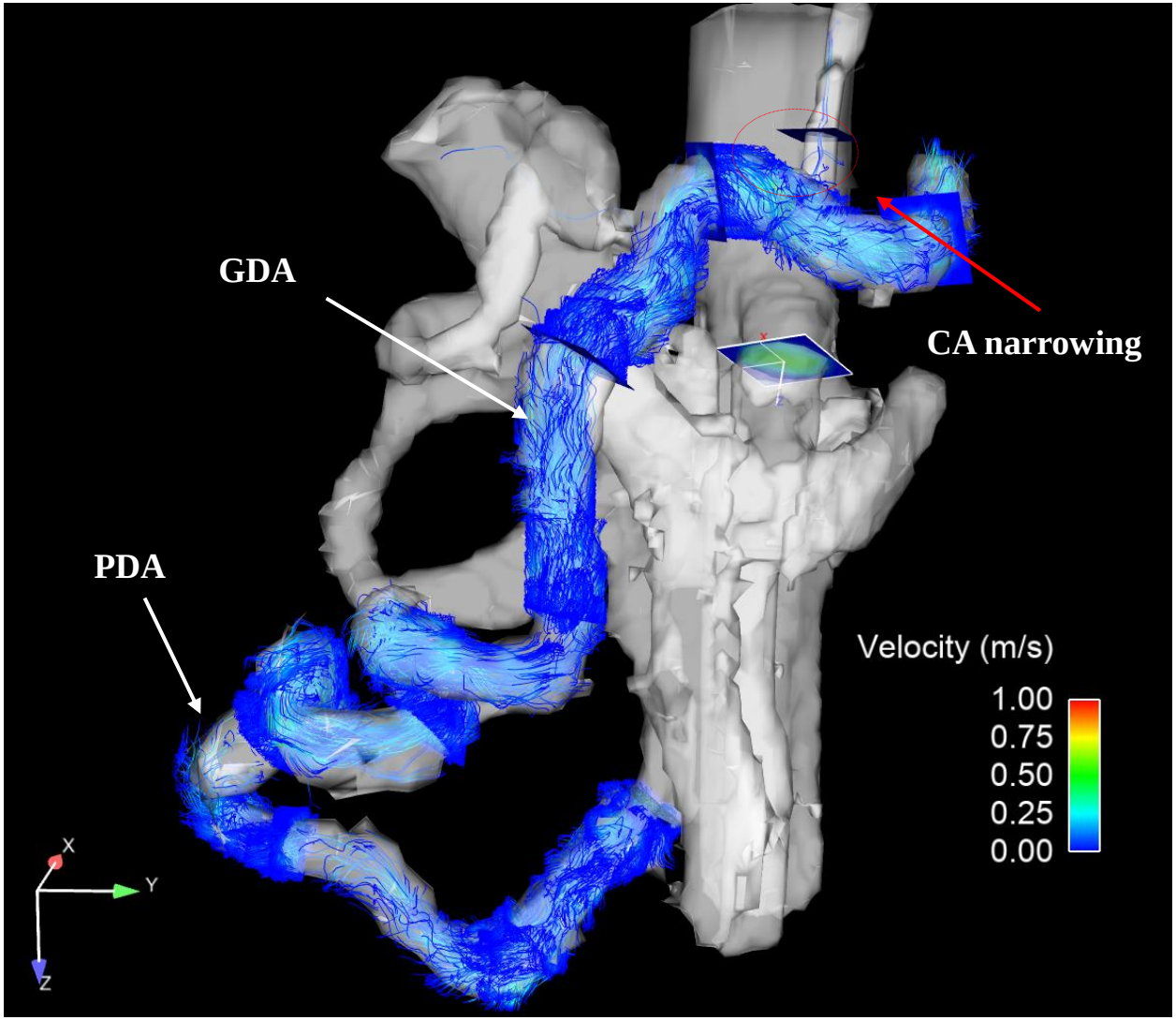
Blood flow response after standardized meal is shown in black. From *Someya et al.*

Someya N, et al. Am J Physiol Regul Integr Comp Physiol 2008;294:1790–1796.

Case 1


GDA
Aortic narrowing
SMA occlusion
Arc of Riolan
Distal SMA
IMA
Velocity (m/s)
1.00
0.75
0.50
0.25
0.00

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

MR Flow Group

Oliver Wieben
Leonardo Rivera-Rivera
Carson Hoffman
Dahan Kim
Phil Corrado
Grant Roberts
Dan Seiter
Archana Dhyani
Eric Schrauben
Mike Loecher

UW MR Support Staff

Kelli Hellenbrand
Sara John
Jenelle Fuller

CFD Lab

Alejandro Roldán-Alzate
Sylvana Garcia
Katrina Ruedinger
David Rutkowski
Rafael Medero
Timothy Ruesink

Radiology

Christopher Francois

School of Medicine and Public Health
UNIVERSITY OF WISCONSIN–MADISON