Non-Invasive Assessment of Mesenteric Hemodynamics with 4D flow MRI

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SYNOPSIS

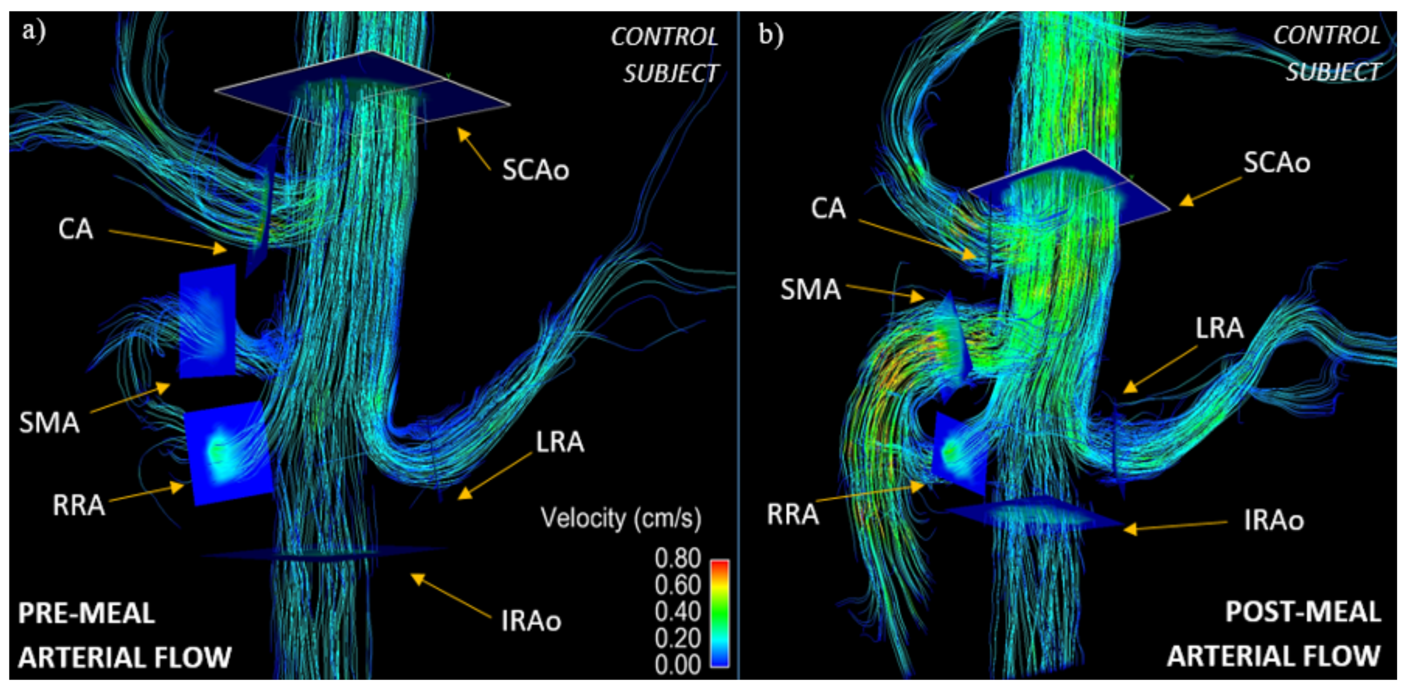
This study investigates the use of 4D flow MRI to non-invasively assess the hemodynamics of mesenteric circulation in both healthy patients and patients with chronic mesenteric ischemia.

INTRODUCTION

- Chronic mesenteric ischemia (CMI) is a disease caused by inadequate blood flow to the intestines. Most cases (-90%) are casued by atherosclerosis.
- Rare conditions such as median arcuate ligament syndrome (MALS) and aortic dissection may also result in CMI[1].
- In healthy individuals, an increase in mesenteric blood flow is observed within minutes after a meal. In patients with CMI, this meal response is compromised.
- Due to collateral circulation, patients may not experience symptoms until 2 or 3 major mesenteric vessels are involved[1].
- Typical symptoms include:
  - Severe postprandial abdominal pain after a meal
  - Weight loss
  - Nausea/Vomiting
  - Fear of eating
- Functional assessment of mesenteric flow has been traditionally accomplished with invasive interventional angiography and duplex sonography.
- 4D flow MRI has previously been proposed to anatomically and functionally evaluate mesenteric vasculature[2].
- The purpose of this study is to compare the blood flow response after a meal in patients with ischemia and healthy volunteers using 4D flow MRI allowing for further assessment of the viability of 4D flow MRI as a diagnostic tool.

METHODS

- 21 patients with a suspicion of mesenteric ischemia, referred from vascular surgery, were imaged on 1.5T and 3.0T scanners (Signa Excite, GE Healthcare, Waukesha, WI).
  - Average age: 48.3 years [21 – 86 years]
- 20 healthy volunteers
  - Average age: 44.4 years [19 – 73 years]
- Hemodynamic parameters were measured before and after a meal challenge. All patients received two scans.
  - The first scan was performed after 5 hours of fasting.
  - The second scan was performed 20 minutes after ingestion of 574 mL of EnSure Plus (Abbott Laboratories, Columbus, OH)
- 4D PC MR data were acquired using 5-point PC-VIPR acquisition[3,4] with cardiac and respiratory gating.
- Complete volumetric coverage of the abdomen was acquired.
  - 32x32x24 cm spherical, 1.25 mm isotropic resolution
- 3D vessel segmentation was performed semi-automatically using Mimics (Materialize, Leuven, Belgium).
- Flow visualization and flow analysis plane placement was accomplished in EnSight (ANSYS, Canonsburg, PA) as seen in Figure 1.
- Magnitude and velocity vector data from these 9 planes were exported and analyzed in a customized software package that allowed for manual vessel segmentation over all frames of the cardiac cycle.



METHODS *(Cont.)*

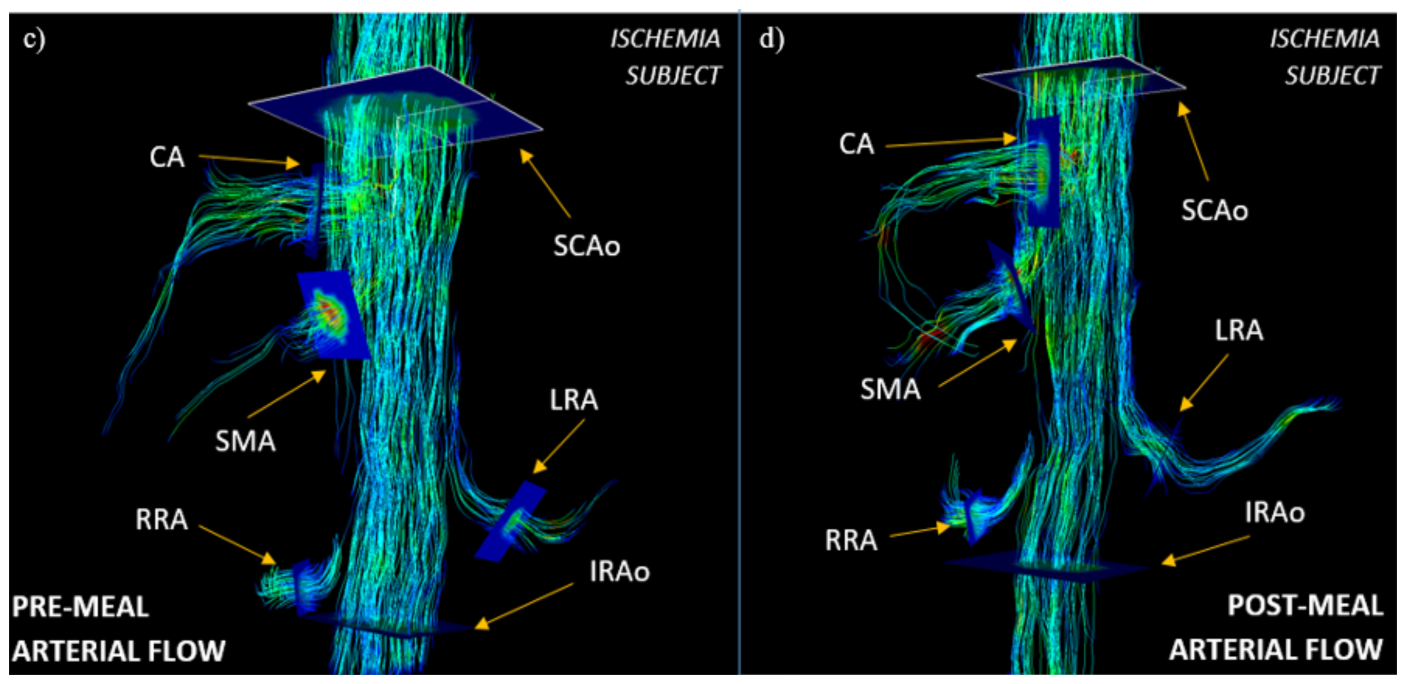


Figure 1: 4D arterial flow MRI streamline images for a control subject (figures a and b) and an ischemia subject (figures c and d) both before (figures a and c) and after a meal challenge (figures b and d)

- Flow analysis was conducted in 6 arterial and 3 portal vessel segments.
  - Arterial vessels: supraceliac aorta (SCAo), infrarenal aorta (IRAo), superior mesenteric artery (SMA), celiac artery (CA), right renal artery (RRA), and left renal artery (LRA).
  - Portal Vessels: portal vein (PV), splenic vein (SV), and superior mesenteric vein (SMV).
- After flow analysis, the clinical diagnosis for each patient was provided and the suspected ischemia group was further subcategorized into 2 groups.
  - Ischemia (positive diagnosis of ischemia)
  - Negative Diagnosis

RESULTS

- 4D flow data were successfully obtained for all 82 scans.
- Flow changes between pre- and post-meal are shown in Figure 2 and Table 1.

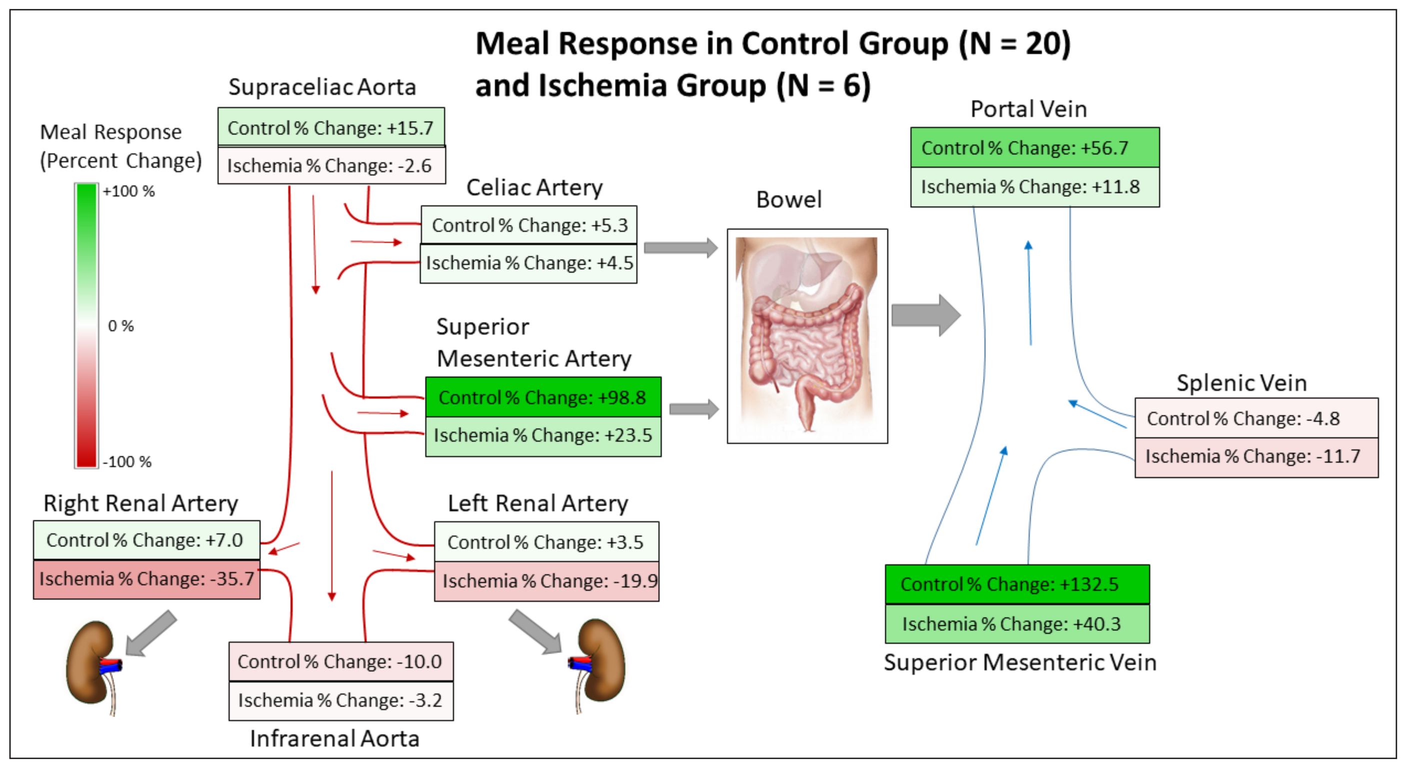


Figure 2: Comparison of meal challenge response between the control group and the ischemia group.

	Vessel	Avg. % Change in Blood Flow after Meal Challenge: CONTROL (N = 20)	NEGATIVE DIAGNOSIS (N = 15)	ISCHEMIA (N = 6)
Arterial	SCAo	15.7 ± 14.8	31.9 ± 38.5	-2.57 ± 12.1
	IRAo	-10.0 ± 27.0	27.1 ± 72.4	-3.16 ± 27.1
	LRA	3.58 ± 15.4	9.75 ± 38.8	-19.9 ± 26.1
	RRA	7.00 ± 17.5	6.45 ± 33.2	-35.7 ± 37.1
	SMA	98.8 ± 80.7	116 ± 163	23.5 ± 32.7
	CA	5.25 ± 52.3	19.0 ± 124	4.52 ± 8.52
Venous	SMV	132 ± 80.2	254 ± 267	40.3 ± 55.6
	SV	-4.75 ± 32.3	4.21 ± 48.2	-11.7 ± 19.4
	PV	56.7 ± 47.9	120 ± 153	11.8 ± 30.9

Table 1: Average percent change of blood flow in response to a meal challenge is shown for all three cohorts for each vessel. The negative diagnosis group and ischemia group were compared to the control data set using a t-test. Yellow indicates statistical significance ($p < 0.05$).

RESULTS *(Cont.)*

- One subject with MALS was studied before and after median arcuate ligament release surgery

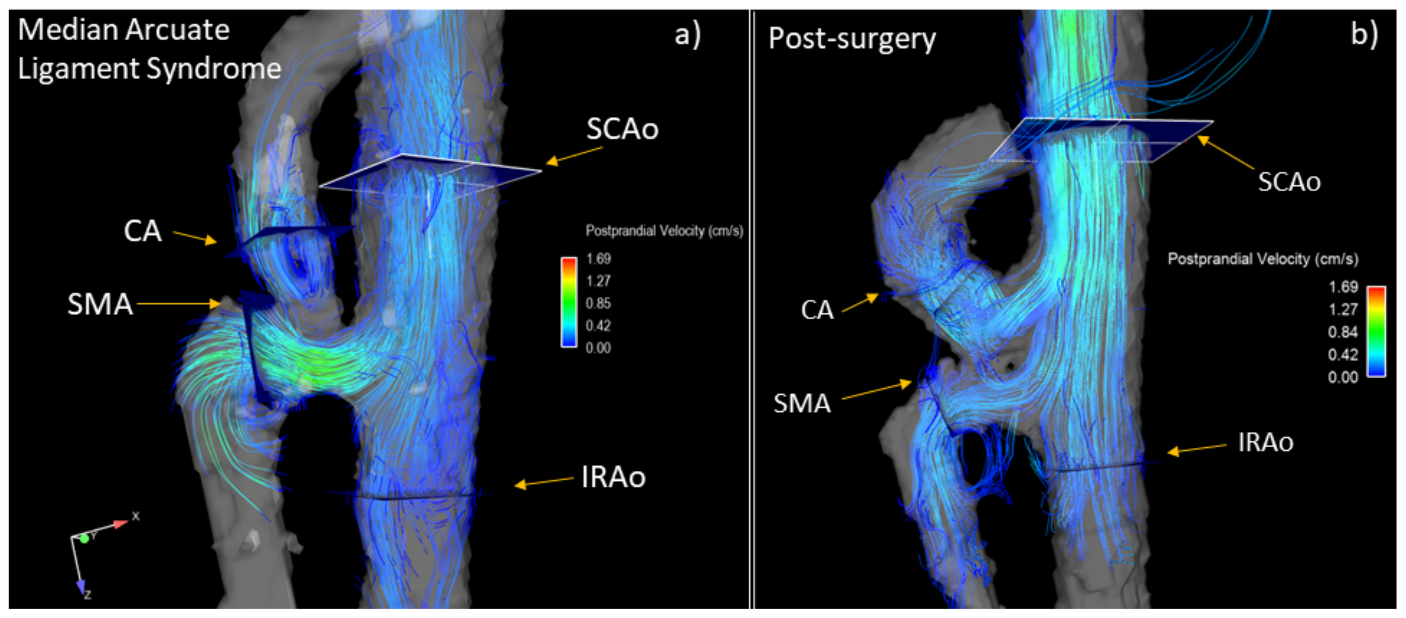


Figure 3: Patient diagnosed with MALS. Images are shown before a) and after b) median arcuate ligament release surgery. Image b) shows greatly improved flow after surgery (CA flow increase of 156%).

- Using a paired t-test, the SCAo, SMA, SMV, and SV showed a statistically significant flow response (p-values < 0.01) in both the control and negative diagnosis group. No vessels in the ischemia group showed a statistically significant flow response after a meal.
- Cross comparing the percent flow change between the control group and the ischemic group shows a statistically significant difference in the SCAo (p=0.022), SMA (p=0.003), SMV (p=0.008), and PV (p=0.018) as seen in Table 1. The RRA (p=0.080) and LRA (p=0.060) also showed a notable difference, but not significant. There was no statistically significant difference in percent flow change between the negative diagnosis group and the controls.
- Additionally, both the pre- and post-prandial flow values in the SCAo for the ischemia group were less than that of the controls (p=0.034 and p=0.001 respectively).
- Interestingly, the pre- and post-prandial flow values in the CA for the negative diagnosis group were less than that of the controls (p=0.003 and p=0.008 respectively).

DISCUSSION & CONCLUSION

- The ischemia group showed overall lower flow values than the control group in the supraceliac aorta (SCAo) and splenic vein (SV). This is most likely due to globally compromised cardiovascular health.
- The ischemia group showed a stunted flow response after a meal challenge, particularly in the SCAo, SMA, SMV, and PV. This is most likely due to the intrinsic pathology preventing mesenteric vessels from fulfilling demand for increased blood flow to the abdomen.
- The flow values in the CA for the negative diagnosis group is likely lower due to narrowing of the CA present in some patients.
- Visualization of anatomy and flow patterns can further aid in diagnosis by identifying patient-specific pathology (Figure 3).
- This study demonstrates a quantifiable difference in change in blood flow between ischemic and healthy patients after a meal challenge. This further supports 4D flow as a feasible diagnostic tool in the challenging diagnosis of CMI.

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