(Submitting as Original Research to JMRI)

TITLE PAGE

# Title:

Non-invasive Assessment of Mesenteric Hemodynamics in Patients with Suspected Chronic Mesenteric Ischemia using 4D flow MRI

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# Acknowledgments:

# Grant Support:

# Running Title:

Assessing Mesenteric Blood Flow with 4D PC MRI

# Abstract:

## Background:

Chronic mesenteric ischemia (CMI) is a rare disease often caused by atherosclerosis, resulting in inadequate blood flow to the small intestine.

## Purpose:

To quantitatively compare hemodynamic parameters before and after a standardized meal challenge in patients suspected of having CMI and healthy individuals.

## Study Type:

Retrospective.

## Subjects:

Twenty-five patients suspected of CMI and twenty healthy controls.

## Field Strength/Sequence:

Subjects were scanned at either 1.5T or 3.0T using a radially-undersampled 4D flow MR sequence (PC-VIPR).

## Assessment:

Volumetric flow rates were obtained in the supraceliac and infrarenal aorta (SCAo/IRAo), celiac artery (CA), superior mesenteric artery (SMA), left and right renal arteries (LRA/RRA), superior mesenteric vein (SMV), splenic vein (SV), and portal vein (PV) in a fasting state and 20 minutes after a 700 kcal meal. Patients were subcategorized into CMI-positive (N=6) and CMI-negative (N=19) based on clinical findings.

## Statistical Tests:

Preprandial and postprandial flow rates for each subject were compared using a paired t-test. Hemodynamic parameters were compared between subgroups using a Welch t-test. P<0.05 reflected statistical significance.

## Results:

In controls and CMI-negative patients, SCAo, SMA, SMV, and PV flow increased significantly after meal ingestion (p<0.005 for all). No significant flow increases were observed in CMI-positive patients. Percent changes in SCAo (p=0.022), SMA (p=0.003), SMV (p=0.008), and PV (p=0.018) flow were significantly greater in controls compared to CMI-positive patients. The only significant difference between controls and CMI-negative patients was preprandial CA flow (p=0.023). SMA flow responses decreased with increasing atherosclerotic severity. Additionally, percent changes in flow in the SCAo (p=0.008), SMV (p=0.009), and PV (p=0.006) were significantly greater in CMI-negative patients compared to CMI-positive patients. However, percent change in SMA flow was not.

## Data Conclusion:

4D flow MRI can assist in diagnosing CMI by providing a PC angiogram for 3D anatomical assessment and quantitative information in measuring hemodynamics in the SCAo, SMA, SMV, and PV.

## Level of Evidence:

3

## Technical Efficacy:

Stage 3

# Key Words:

4D flow MRI; phase contrast; radial undersampling; hemodynamics; atherosclerosis; chronic mesenteric ischemia

# Introduction:

Chronic mesenteric ischemia (CMI) is a disease caused by inadequate blood flow to the small intestine due to underlying stenotic and occlusive diseases affecting mesenteric vasculature. The primary etiology of CMI is atherosclerotic lesions (greater than 95% of cases), often originating in proximal segments of the celiac artery (CA), superior mesenteric artery (SMA), and inferior mesenteric artery (IMA) (1). It is commonly recognized that at least 2 of the 3 main mesenteric arteries must be occluded to result in symptomatic CMI due to a rich collateral network that can compensate for chronically reduced blood flow (2). In normal individuals, an increase in mesenteric blood flow is necessary for satisfying the increased metabolic demands of the gastrointestinal tract after meal consumption. In patients with CMI, this normal blood flow response is disrupted by inherent pathophysiology. This causes dull, postprandial abdominal pain 15-60 minutes after meal ingestion with pain continuing up to 4 hours, subsequently leading to fear of food, severe weight loss, and malnutrition (3). This can eventually progress to acute-on-chronic mesenteric ischemia, which is associated with a high mortality rate (4).

Computed tomography (CT) and contrast-enhanced CT angiography (CTA) of the abdomen are usually the first diagnostic exams of choice because they have been successful in both identifying and locating regions of stenosis and occlusion, as well as simultaneously excluding other abdominal pathologies (5, 6). Contrast-enhanced magnetic resonance angiography (CE-MRA) is another commonly used imaging technique that is highly sensitive and specific in detecting proximal mesenteric lesions (7, 8). However, neither CTA nor CE-MRA provide functional information regarding blood velocity and blood flow, a crucial physiological component of the disease. Currently, there are no well-established functional studies that non-invasively evaluate mesenteric hemodynamics in patients with suspected CMI. Duplex sonography has shown some success in characterizing the extent of stenoses in patients suspected of CMI and has even demonstrated that evaluating blood hemodynamics before and after a meal challenge can provide additional diagnostic information (9–11). However, sonography is not always feasible due to technical limitations (bowel gas overlying vessels of interest), excess adipose tissue, and operator dependence (12).

Previous studies have suggested that two-dimensional time-resolved phase-contrast magnetic resonance imaging (2D CINE PC-MRI) may be an effective method to non-invasively screen patients with suspected ischemia by measuring volumetric blood flow rates in mesenteric vasculature before and after meal consumption (13–16). Using 2D CINE PC-MR flow measurement techniques, it was first shown by Li et al. (14) that postprandial flow augmentation in the SMA was reduced proportionally to the severity of atherosclerosis in the mesenteric vessels. A subsequent study by Burkart et al. (13) used 2D CINE PC-MR to prospectively evaluate patients suspected of having CMI by measuring volumetric blood flow rates in the SMV before and after a meal. The results showed that there was drastically reduced blood flow augmentation in the SMV in patients with true CMI compared to those who were symptomatic but did not have CMI (as determined by angiography and clinical follow-up studies). A second study by Li et al. (15) reinforced these findings by showing that there is reduced postprandial flow augmentation in both the SMV and SMA in patients with CMI.

Time-resolved PC-MR with three-dimensional velocity encoding (4D flow MRI) is a novel diagnostic tool that has been developed to provide simultaneous anatomical and temporally-resolved hemodynamic information within a three-dimensional (3D) imaging volume. It has recently been proposed that 4D flow MRI may assist in the challenging diagnosis of CMI by allowing for functional assessment of volumetric blood flow rates before and after a meal challenge while also providing a volume-rendered PC angiogram, allowing for visualization of pathology (17, 18). To date, 4D flow MRI has not been thoroughly tested as a potential screening tool in CMI diagnosis. In this study, the diagnostic capability of 4D flow MRI will be assessed and hemodynamic parameters of various arterial and venous mesenteric vessels will be compared before and after a meal in patients suspected of mesenteric ischemia and healthy volunteers.

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