Quantification of Hepatic Blood Flow in Obese Patients using 4D-flow MRI

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Target audience: Clinicians and scientists interested in portal hemodynamics and splanchnic blood flow in obese patients at risk for liver disease.

Introduction: Non-alcoholic fatty liver disease (NAFLD) is an increasingly prevalent condition often encountered in patients with obesity [1]. The evaluation of blood flow to the liver of obese patients may offer new insight into the pathophysiology and evolution of NAFLD, as well as its response to therapeutic intervention. However, non-invasive assessment of portal blood flow in obese patients is challenging with current imaging techniques. Therefore, ***the purpose of this study*** is to evaluate the feasibility and describe preliminary observations of 4D Flow MRI for the non-invasive assessment of portal hemodynamics in obese patients.

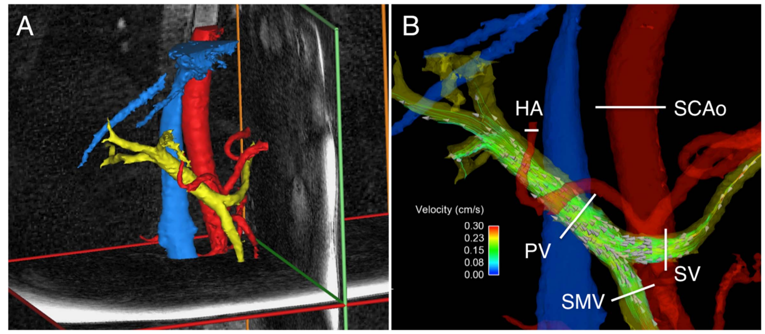

Figure 1: 4D flow MRI using PCVIPR is feasible in obese patients, as shown in the 3D visualization of the abdominal vascular anatomy in this patient with BMI=41.7±3.7kg/m^2 (**A**). Segmentation (red – systemic arterial, blue – systemic venous and yellow – portal venous systems). Axial and sagittal images as frame of reference show the high subcutaneous fat in the abdominal wall (**B**). Visualization of cut-planes for flow quantification are shown.

Methods: In this IRB-approved and HIPAA-compliant study, 7 obese (BMI = 41.7±3. 7kg/m^2) adult patients were imaged with 4D flow MRI after written informed consent was obtained.

MR-Imaging. Imaging was performed at 1.5T or 3T (GE Discovery MR450w and MR750, Waukesha, WI) using a 12-channel (1.5T) or 32-chanel (3T) body coil (NeoCoil, Pewaukee, WI). 4D velocity mapping was achieved using a radially undersampled phase contrast acquisition (5-point PC-VIPR)[2,3] and comprehensive coverage of the upper abdomen. 4D flow MRI was performed with ~10min scan time during free breathing with respiratory and retrospective ECG gating and with the following acquisition parameters: imaging volume 64x64x24cm, 1.25mm acquired isotropic spatial resolution, TR/TE=6.4/2.2ms, Venc=60cm/s. Images were reconstructed offline. Resulting velocity fields were fit to a third order polynomial to remove background phase offsets using user guided segmentation to identify static tissue.

4D flow MRI Data Analysis: Vessel segmentation was performed using MIMICs (Materialize, Leuven, Belgium) from PC angiograms. Flow measurements and visualizations were performed in EnSight (CEI, Apex, NC) using manual placement of cut-planes in the vessel of interest. *Conservation of mass* was performed to evaluate internal consistency and validation by measuring blood flow at the porto-splenic confluence ($Q_{PV} = Q_{SV} + Q_{SMV}$) (Fig.1). Flow measurements were compared to those in six healthy controls previously reported in the literature [4], acquired using a similar 4D flow MRI protocol to that described in this study.

Statistics: Flow data were acquired at the supraceliac Aorta (Ao), Hepatic Artery (HA), Portal Vein (PV), Superior Mesenteric Vein (SMV), Splenic Vein (SV), and Celiac Trunk (CT). Flow values measured in each vessel were compared between patients and controls using Wilcoxon rank sum tests (p-value of 0.05 was chosen to indicate statistical significance)

Results and Discussion: High-quality angiograms were achieved in all patients (Fig. 1). Figure 2 summarizes the flow measurements from Ao, PV, and HA, as well as the ratios between them. Blood flow through Ao was lower in obese patients (2.2 ± 0.4 L/min; range = 2.1 – 3.1 L/min) than in controls (3.4 ± 0.4 L/min; range = 2.7 – 3.6L/min) (p=0.008). Similarly PV flow was lower in obese patients (0.6 ± 0.2 L/min; range = 0.3 – 0.8 L/min) than in controls (1.1 ± 0.2 L/min; range = 0.9 – 1.3 L/min) (p=0.001). Total blood flow to the liver (Q_{PV} + Q_{HA}) was significantly lower in obese patients (0.66 ± 0.2 L/min; range = 0.42 – 0.91 L/min) than in controls 1.3 ± 0.2 L/min; range = 1.0 – 1.6 L/min) (p=0.001). The ratio of PV to Ao flow ($Q_{PV}/_{Ao}$) was not significantly different between obese patients (0.23 ± 0.1; range = 0.1 – 0.4) and controls (0.33 ± 0.03; range = 0.30 – 0.36) (p=0.07). Similarly, the ratio of PV flow to total blood flow to liver (Q_{PV} + Q_{HA}) was not significantly different between obese patients (0.23 ± 0.1; range = 0.82 – 0.08) and controls (0.33 ± 0.03; range = 0.85 – 0.05) (p=0.37). The internal validation based on conservation of mass showed a relative error of 4.1 ± 2.6 %.

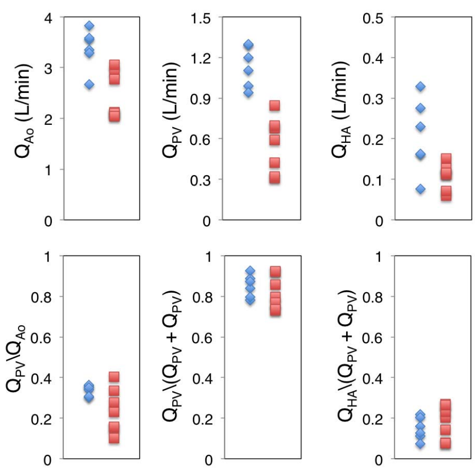

Figure 2: Obese patients (red squares) demonstrated significantly lower Ao (Q_{Ao}), PV (Q_{PV}), HA (Q_{HA}) flow than controls (blue diamonds). However the ratios, Q_{PV}/ Q_{Ao}, Q_{PV}/ (Q_{PV} + Q_{HA}) and Q_{HA}/ (Q_{PV} + Q_{HA}), were not significantly different.

Summary: Radial 4D flow MRI can characterize and quantify blood flow in the entire hepatic system with comprehensive coverage and simultaneous acquisition of high-quality angiograms in obese adult patients. The ability to non-invasively quantify mesenteric hemodynamics in these individuals suggests that 4D flow MRI may be suitable for use in future mechanistic studies of NAFLD pathogenesis, evolution, and response to therapeutic intervention.

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References: [1] Browning, Hepatology 2007; [2] Gu AJNR 2007; [3] Johnson MRM 2010; [4] Roldán-Alzate JMRI 2012.