Quantification of altered hepatic blood flow with 4D velocity mapping during a meal challenge provocation

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Introduction: Diagnostic assessment of the hepatic vasculature and its hemodynamics using current approaches such as Doppler ultrasound and 2D phase contrast MRI (2D PC-MRI) is challenging due to the dual blood supply to the liver and its complex and variable anatomy. Further, in the presence of advanced liver disease (ie: cirrhosis), and the resulting complication of portal hypertension (PHTN), increased resistance to flow leads to large changes in hepatic and splanchnic blood flow. Accurate non-invasive assessment of hemodynamics and morphology of the liver may improve our understanding of PHTN and potentially be useful to guide treatment. For example, portal and splanchnic blood flow before and after a meal challenge has characteristic alterations in cirrhosis [1]. Unfortunately, assessment of liver hemodynamics using time-resolved PC-MRI imaging is challenging due to the need for large volumetric coverage, with high spatial and temporal resolution and good sensitivity to a large spectrum of flow velocities in reasonable scan time. We have recently shown in qualitative studies that time resolved 3D ("4D") PC-MRI with radial undersampling holds great potential to overcome these challenges [2]. The purpose of this work was to investigate the ability of this approach to quantify blood flow changes during a meal challenge.
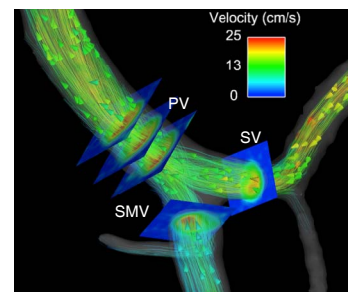

Figure 1– Conservation of mass at the portal confluence and within the main portal vein will provide indirect validation of flow measurement accuracy. PV: Portal Vein, SV: Splenic vein, SMV superior mesenteric vein.
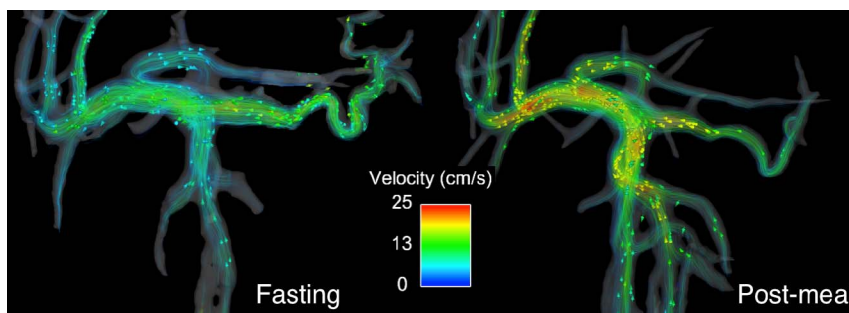
Methods: In this IRB-approved and HIPAA-compliant study, 6 volunteers with no history of liver disease (32.3 ± 10.1 years, 85.7 ± 8.7kg, 4M, 2F) were imaged after written informed consent was obtained.

MR-Imaging. Studies were conducted on a clinical 3T scanner (Discovery MR 750, GE Healthcare, Waukesha, WI) with a 32-chanel body coil (NeoCoil, Pewaukee, WI). 4D velocity mapping was achieved using a 5-point PC-VIPR for increased velocity sensitivity performance [3,4] covering the vasculature of the entire upper abdomen. PC-VIPR scanning was repeated before and after the meal. Image parameters included: imaging volume: 32x32x24cm spherical, 1.25mm acquired isotropic spatial resolution, TR/TE=6.4/2.2ms. All subjects received 0.03mmol/kg of gadofosveset trisodium (Lantheus, N. Billerica, MA), and intravascular gadolinium based contrast agent used to maximize SNR performance. Pre- and post meal challenge PC-VIPR imaging was adjusted for optimal imaging conditions and differed in the venc: pre=100cm/s, post=120cm/s and the flip angle: pre=16°, post=14°.

Meal challenge. All imaging was performed after at least 5 hours of fasting. After the first scan, subjects ingested 574mL EnSure Plus® (Abbot Laboratories, Columbus, OH; 700cal, 28% from fat, 57% from carbohydrates) orally. Scanning was resumed 20min after the meal challenge.

4D PC-VIPR data analysis consisted of vessel segmentation performed in MIMICs using PC angiograms and manual placement of cut-planes in the vessel of interest after importing the segmented masks into EnSight (CEI, Apex, NC). Those planes were then processed in a previously described MatLab-based tool for hemodynamic analysis [5].

Figure 2 – Changes in flow after a meal challenge can be visualized qualitatively. Increased flow is easily visualized in the portal and splanchnic circulation before (left) and after (right) a meal.
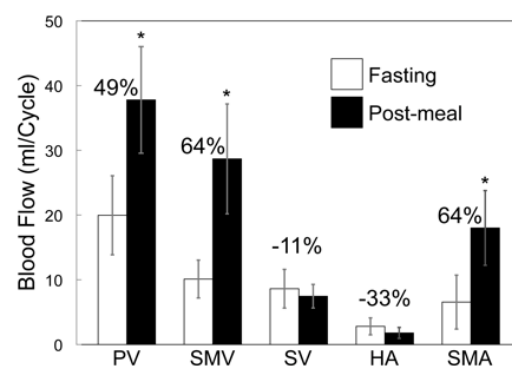
Internal validaton was performed by mass conservation at the splenomesenteric confluence ($Q_{PV}=Q_{SMV}+Q_{SV}$), as well as three planes within the portal vein for internal consistency (Fig. 1).

Statistics. Flow data were compared using paired Student t-tests. A p-value of 0.05 was chosen to indicate statistical significance.

Results and Discussion: Segmentation quality of the hepatic and splanchnic angiograms was very good with excellent vessel detail in all cases (Fig. 2). Large increases in flow were seen in the PV, SMV and SMA (Fig. 3). Also, as expected, decreases in flow were seen in the SV and HA, although these decreases were not statistically significant. This decrease in HA blood flow is likely due to the hepatic arterial buffer response (HABR) a physiological response to increased PV flow. Finally, internal validation ($Q_{PV}=Q_{SMV}+Q_{SV}$) showed an acceptable error ($5.9\pm3.4\%$ and $6.9\pm5.5\%$, p=0.7) in the flow measurements at the confluence for baseline and intervention respectively. An average error of $2.8\pm2.2\%$ was found in the three measurements within the PV.

Figure 3 – Changes in flow after a meal challenge in normal subjects (N=6). Flow measurement (right) were obtained via cut planes in vessels of interest. Flow increases in the PV, SMV and SMA, and decreases in the SV and HA as expected.

Summary: PC-VIPR allows for characterization and quantification of hemodynamics in the entire hepatic system as well as inherent anatomical co-registration from a single scan. Hemodynamic changes in portal circulation induced by the meal challenge demonstrate that PC-VIPR can successfully quantify changes in flow. Internal validation results demonstrate the validity of hepatic blood-flow measurements with PC-VIPR. These results demonstrate the potential of PC-VIPR for monitoring treatment of patients with portal hypertension using beta-blockers and TIPS.

References: [1] Zardi In Vivo 2008; [2] Frydrychowicz JMRI 2011; [3] Gu AJNR 2007; [4] Johnson MRM 2010; [5] Stalder MRM 2008