Repeatability of 4D flow MRI Quantification of Venous and Arterial flow in the Abdomen

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Target audience: Researchers and clinicians interested in 4D MR flow for non-invasive quantification of splanchnic hemodynamics

Introduction: Hemodynamic assessment of mesenteric circulation in patients with portal hypertension is challenging due to the complex and variable anatomy. In recent years, four-dimensional (4D) phase contrast (PC) magnetic resonance imaging (MRI) has become available as a research tool to investigate vascular anatomy and flow (1-3) for comprehensive hemodynamic analysis. Several studies have been conducted to validate in vivo 4D PC flow measurements (4-5). However, further evaluation is needed to assess the performance of 4D PC techniques in the abdomen where there is interest in arterial and venous flow as well as the potential for artifacts arising from respiratory and peristaltic motion in abdominal exams. This is particularly true when quantifying blood flow as for example in the analysis of meal challenges (6). The purpose of this study was to evaluate the repeatability of 4D PC flow measurements in both arteries and veins of the abdominal circulation.

Methods: In this IRB-approved and HIPAA-compliant study, 10 subjects, 3 patients with portal hypertension and 7 controls (42±13 years, 90±9 kg), were imaged after written informed consent. MR Imaging: Two consecutive MR scans were performed before 10 am after at least 5 hours of fasting to control for potential diurnal variations. Studies were conducted on a clinical 3T scanner (Discovery MR 750, GE Healthcare, Waukesha, WI) with a 32-channel body coil (NeoCoil, Pewaukee, WI). 4D velocity mapping was achieved using a radially undersampled phase contrast acquisition (5-point PC-VIPR) with increased velocity sensitivity performance (7) and comprehensive coverage of the upper abdomen. Radial 4D flow MRI image parameters included: imaging volume: 32x32x24cm, 1.25mm acquired isotropic spatial resolution, TR/TE=6.4/2.2 ms. All subjects received 0.03mmol/kg of gadofosveset trisodium (Lantheus, N. Billerica, MA), an intravascular contrast agent used to maximize SNR performance. The entire protocol was repeated at a second visit within one week of the first imaging exam.

4D flow MRI Data Analysis: Vessel segmentation was performed in MIMICS (Materialize, Leuven, Belgium) from PC angiograms and manual placement of oblique cut-planes in the vessel of interest was performed interactively in EnSight (CEI, Apex, NC) were flow measurements and visualizations were conducted. Flow was analyzed at the supraceliac Aorta (Ao), Portal Vein (PV), Superior Mesenteric Vein (SMV) and Splenic Vein (SV) (Fig 1).

Statistics: Percent differences of repeated measurements were computed as the absolute value of the difference between the first and second flow measurements. Linear regressions of the repeated measurements were performed separately for aorta (Fig 1) and the veins (Fig 2). A paired Student’s t-test (P < 0.05) was performed to compare repeated measurements. Similarly, the back-to-back measurements at each day were averaged and subsequently a paired Student’s t-test (P < 0.05) was performed to compare day-to-day variations. Additionally Bland-Altman analysis was performed to evaluate repeatability of flow measurements.

Results and Discussion: Mean ±1SD percent differences of repeated measurements were 8.3 ± 5.0, 8.5 ± 8.1, 13.9 ± 6.9 and 12.3 ± 7.8 % for the Ao, PV, SMV and SV respectively. No significant difference were found between repeated measurements in any of the vessels. Figure 2 displays arterial flow (Ao) from scan 1 vs scan 2 (left), demonstrating excellent correlation (r²=0.95) and Ao flow from day 1 vs day 2 (right), also demonstrating good agreement between the repeated measurements (r=0.79). Similarly Figure 3 plots venous flow (PV, SMV and SV) from scan 1 vs scan 2 (left), and day 1 vs day 2 (right) showing excellent correlation (r²=0.94) and (r²=0.80) respectively.

Summary: Excellent correlation and low percent difference between repeated measurements within the same day for both arterial and venous circulation demonstrates the repeatability of radial 4D flow MRI for comprehensively quantifying blood flow in the abdominal circulation. Similarly comparison of day-to-day variation show that radial 4D flow MRI is repeatable for assessing mesenteric hemodynamics in controlled fasting states.

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Figure 1 – 4D flow visualization of the abdominal circulation. Flow measurements were done at the supraceliac Aorta (Ao), Portal Vein (PV), Superior Mesenteric Vein (SMV) and Splenic Vein (SV).

Figure 2 – Linear correlation of 4D flow repeated measurements in the supraceliac Aorta (Ao), \( Q_1 \) is the flow measured from scan 1 and \( Q_2 \) is the flow measured from scan 2 (left). Results from Bland-Altman analysis are shown in each plot.

Figure 3 – Linear correlation of 4D flow repeated measurements in the PV (○), SMV (■) and SV (□). \( Q_1 \) is the flow measured from scan 1 and \( Q_2 \) is the flow measured from scan 2 (left). Results from Bland-Altman analysis are shown in the plots.