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.

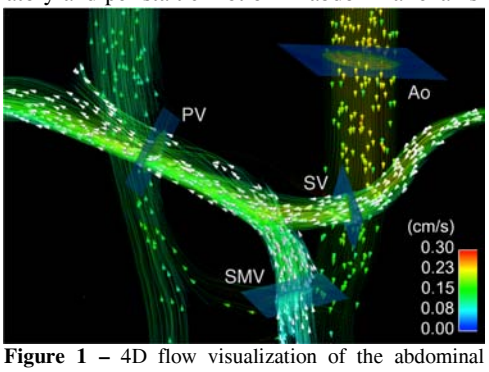

Figure 1 – 4D flow visualization of the abdominal circulation. Flow measurements were done at the supraceliac Aorta (Ao), Portal Vein (PV), Superior Mesenteric Vein (SMV) and Splenic Vein (SV).

Methods: In this IRB-approved and HIPAA-compliant study, 10 subjects, 3 patients with portal hypertension and 7 controls (42±13years, 90±9kg), 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-chanel 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 () 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=6.4/2.2ms. 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) (Fig1).

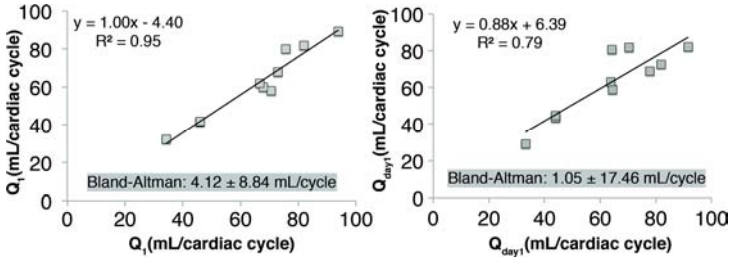

Figure 2 – Linear correlation of 4D flow repeated measurements in the supraceliac Aorta (Ao). Q_1 is the flow measured from scan 1 and Q_2 is the flow measured from scan 2 (left). Q_{day1} is the average between Q_1 and Q_2 and Q_{day2} is the flow from day 2 (right). Results from Bland-Altman analysis are shown in each plot.

Statistics: Percent differences of repeated measurements were computed as the absolute value of the difference between the first and second flow measurements in each vessel, divided by the mean of the two flow measurements. Linear regressions of the repeated measurements were performed separately for aorta (Fig1) and the veins (Fig2). 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. plots arterial flow (Ao) from scan1 vs scan2 (left), demonstrating excellent correlation (r^2=0.95) and Ao flow from day1 vs day2 (right), also demonstrating good agreement between the repeated measurements (r^2=0.79). Similarly Figure 3 plots venous flow (PV, SMV and SV) from scan 1 vs scan2 (left), and day1 vs day2 (right) showing excellent correlation (r^2=0.94) and (r^2=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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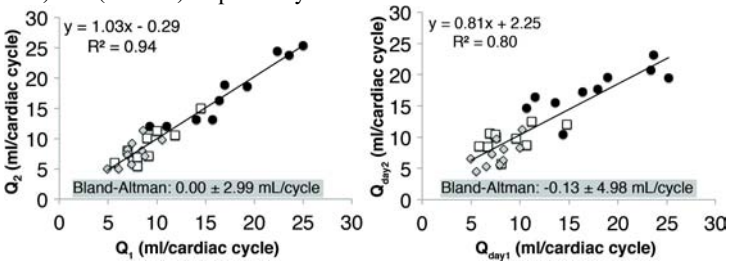

Figure 3 – Linear correlation of 4D flow repeated measurements in the PV (●), SMV(□) and SV(◇). Q_1 is the flow measured from scan 1 and Q_2 is the flow measured from scan 2 (left). Q_{day1} is the average between Q_1 and Q_2 and Q_{day2} is the flow from day 2 (right). Results from Bland-Altman analysis are shown in the plots.

References: [1] Stankovic JMRI 2010; [2] Frydrychowicz JMRI 2011; [3] Roldán-Alzate JMRI 2012; [4] Gu AJNR 2005; [5] Nett L JMRI 2012; [6] Roldán-Alzate IRMRM 2013; [7] Johnson MRM 2010