In-vivo validation of 5-point PC-VIPR for hemodynamic assessment of the hepatic and splanchnic hemodynamics in swine

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Introduction: Hemodynamic assessment of the hepatic and splanchnic vasculature is of particular interest in the presence of liver disease such as cirrhosis and portal hypertension. However, the dual blood supply of the liver, complex and variable anatomy and dramatic changes in flow that occur with portal hypertension make hemodynamic assessment of the liver challenging. Radially undersampled 4D velocity mapping (PC-VIPR [1]) shows great promise to overcome existing limitations due to its highly time-efficient data acquisition strategy and high-resolution imaging with large volume coverage. In addition, a recently introduced 5-point velocity encoding scheme offers improved sensitivity to a wide range of velocities [2], which may be essential for hepatic flow imaging. It was the purpose of this study to validate 5-point PC-VIPR against the standard of reference (perivascular ultrasound) in swine. Comparison to 2D PC MRI was performed as a secondary endpoint.

Methods: In this validation study, results from 4D MR velocity mapping were compared to the standard of reference perivascular ultrasound. Due to the invasive nature of the procedure, examinations were conducted in a pig model.

Animal protocol. 3 swine with an approximate weight of 55kg have been scanned (IACUC approval for 14 animals). Food was withheld the morning of anesthetic procedures as per standard animal care. Anesthesia was induced with 2.2 mg/kg of Xylazine hydrochloride and 7 mg/kg of Telazol i.m. Ventilation was performed after endotracheal intubation at physiological rates using 1-5% isoflurane. Animals were sacrificed after the procedure

Ultrasound flow probe. Validation was performed using perivascular ultrasound flow probes with sizes adapted to each vascular diameter (TS420, Transonic Ithaca, NY). After open laparatomy and careful preparation of the vessels of interest (portal vein, PV; hepatic artery, HA; supra-celiac aorta, supraAO; infrarenal aorta, infraAO; both renal arteries, RRA and LRA; and splenic vein, splenV; figure 1), two ultrasound acquisitions were performed for each vessel Data were digitally recorded at 160Hz via an A/D-converted and attached PC.

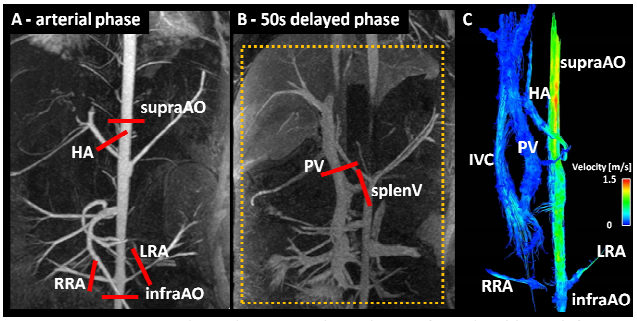

Figure 1: Contrast-enhanced MR angiography performed with gadofosveset (Ablavar) for anatomic overview and placement of 2D PC MRI planes (red). The PC VIPR acquisition volume (dashed yellow line) was prescribed such that it was centered over the liver and the locations of the 2D PC locations were covered. Hemodynamic visualization (C, 3D streamlines) are simultaneously available. HA=hepatic artery; PV = portal vein; splenV = splenic vein, supraAO = supra-celiac Aorta, infraAO = infra-renal arota; RRA = right renal artery; LRA = left renal artery.

The ***MR-imaging protocol*** included A) contrast-enhanced MR angiography using gadofosveset trisodium (Ablavar, Lantheus, Billerica, MA) for angiographic overview and improved SNR for PC imaging [3], B) multiple 2D PC-MRI scans in locations acquired by ultrasound, and C) 5-point PC-VIPR centered over central hepatic vasculature. Typical scan parameters for 5-point PC VIPR were FOV=260x260x260mm, readout=256, TR/TE=6.6-7.7/2.4-2.5; FA=14-16° resulting in an isotropic spatial resolution of 1.0x1.0x1.0mm^3. True temporal resolution was 5xTR=33-38.5ms and with heart rates of ~100-135, 11-18 time frames could be reconstructed. To correct for background phase shifts that can corrupt 2D flow measurements, phantom acquisitions were acquired according to the method of Chernobelsky et al. [4]. Studies were conducted on a clinical 3T scanner (GE Discovery MR 750, Waukesha, WI) with a 32-channel phase-array coil.

Data evaluation. 5-point PC-VIPR data was evaluated by manually placing cut-planes in the vessels of interest using EnSight (CEI, Apex, NC) which were subsequently exported into a home-built MatLab-based tool for hemodynamic analysis [5]. 2D PC MR data was analyzed with CV Flow 3.3 (MEDIS, Leiden, NL) installed on an Advanced Workstation (GE Healthcare, Waukesha, WI). Statistical evaluation included correlation and Bland-Altman analysis to compare ultrasound, 2D PC-MRI, and PC-VIPR data.

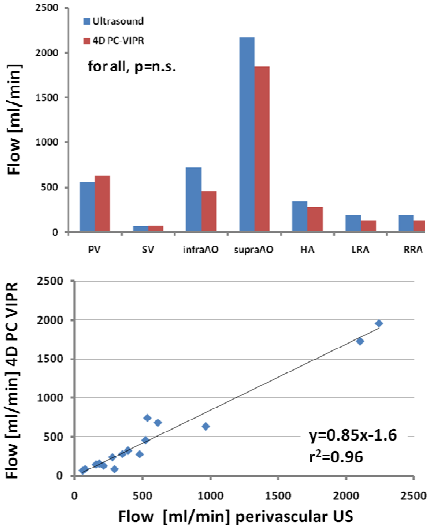

Figure 2: Good agreement between individual vessels (left) and high correlation (middle) of flows derived by perivascular ultrasound and 4D PC VIPR on basis of 16/21 abdominal vessels.

Results and Discussion: All exams were successfully completed with high image quality as shown in a typical image series in figure 1. Data were recently acquired and results are currently available for 16/21 vessels. Figure 2 shows the agreement and excellent correlation between perivascular ultrasound and 5-point 4D PC. Clinically acceptable variance between measurements as expressed by the Bland-Altman plot (bias=-92.2ml/min; 2SD limits of agreement=-398 to 214ml/min). A similar high correlation (r^2=0.87) is reached when only HA, PV and SV are studied. The correlation between 2D PC and 4D ultrasound was also very good (r^2=0.92).

Summary: Preliminary data from this validation study shows that 5-point PC VIPR is a valid tool to assess flows in regions of different velocities and volumes. By doing so, it helps overcoming limitations inherent in ultrasound. Since morphological, hemodynamic, and quantitative data are simultaneously available, 5-point PC VIPR may be well suited for use in clinical routine. Comprehensive assessment of complex flow patterns with variable and complex anatomy such as hepatic and splanchnic flow, as well as congenital heart disease, is well suited for the application of 5-point PC VIPR. Future work will include the validation of 5-point PC-VIPR in additional animals and in situations with altered flow such as under a meal challenge or pharmacological stress.

References: [1] Gu, AJNR 2005; [2] Johnson MRM 2009; [3] Bock MRM 2010; [4] Wolff JCMR 2007; [5] Stalder MRM 2008

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