Analysis of Radially Undersampled 4D Velocity Mapping (PC VIPR) for Comprehensive Imaging in Portal Hypertension.

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Background: The hepatic and splanchnic vasculature is difficult to assess. Non-invasive methods are challenged by the complex and variable anatomy, and from alterations in flow and anatomy in pathological conditions such as portal hypertension. These challenges are compounded by the dual blood supply to the liver, the presence of complex porto-systemic shunts, and the large volume of coverage that is required. A comprehensive diagnostic approach that assesses detailed hemodynamic and morphologic information of all upper abdominal vessels in a single examination is highly desirable. Consequently, the purpose of this work was to expand previous reports on Cartesian [1] and radial [2] hepatic blood flow imaging to investigate the feasibility of PC-VIPR, a radially undersampled 4D phase contrast imaging scheme [3] for assessment of the upper abdominal vasculature in subjects with portal hypertension.

Methods: 24 subjects (55.9±10.4years, 88.4±16.7kg; 15 male, 9 female) underwent a PC-VIPR scan of the upper abdomen after obtaining IRB-approved and written informed consent. In 18 patients, the presence of chronic liver disease was confirmed by medical history and by a median MELD [4,5] score of 9.

5-point velocity encoded PC-VIPR is a radially undersampled [3] velocity mapping approach that allows for time-efficient large volume coverage with high spatial and temporal resolution and increased velocity encoding sensitivity [6]. Scans were performed on a 3T clinical scanner (Discovery MR 750, GE Healthcare, Waukesha, WI) using a 32-channel body coil (NeoCoil, Pewaukee, WI). Image parameters included: dual echo acquisition, imaging volume=32cm x 32 cm x 22 cm, acquired spatial resolution = isotropic 1.3 mm, TR/TE=6.1-7.8/2.1-3.2ms (first echo), flip angle=8-20º, venc=60cm/s, adaptive respiratory gating scheme using bellows and a 50% acceptance window, scan time: ~ 11 min. Retrospective ECG gating with temporal filtering similar to view sharing in Cartesian acquisitions was used. Data was reconstructed to 10 time frames per RR cycle. In 21 subjects, a contrast-enhanced dynamic LAVA (T1-weighted 3D-SPGR with intermittent fat saturation) series of the liver was available for comparison.

Post-Processing of the data included calculation of angiograms similar to complex difference processing [7], vessel segmentation of the vasculature from the angiograms (MIMICS, Materialise, Ann Arbor, MI, Fig. 1A), and blood flow visualization (EnSight, CEI Inc., Apex, NC) with time-resolved particle traces (Fig. 1B-D) and streamlines. To facilitate visualization for clinical assessment, a whole-volume particle emission restricted to the segmented vascular systems was also performed (Fig. 1).

Image evaluation. Segmentation quality was rated in a consensus reading with 2 radiologists on a 0-2 scale (0=poor confidence, 1=moderate quality, 2=very good image quality) and compared to image findings on clinical LAVA images with respect to vessel detection for the portal vein (PV) with both main branches (ltPV, rtPV), splenic vein (splenV), superior mesenteric vein (SMV), inferior mesenteric vein (IMV), inferior mesenteric vein (IMV), coronary vein (corV), abdominal aorta (AO), left and right renal artery (LRA< RRA), hepatic artery (HA) with both main left and right branch (LRA, RHA), and shunts. Hemodynamic visualization was evaluated with respect to presence of flow visualization quality and direction of blood flow.

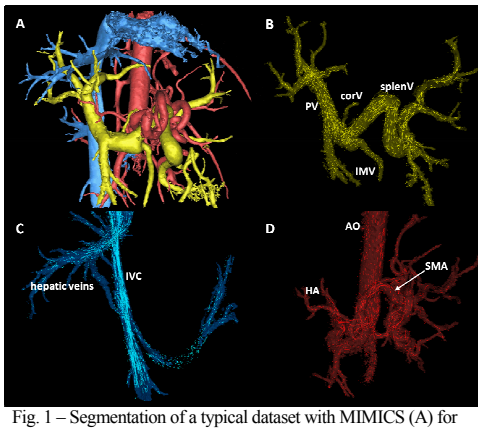
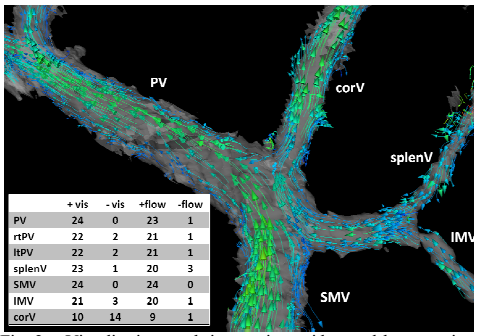


Fig. 1 – Segmentation of a typical dataset with MIMICS (A) for vessel overview and orientation. After segmentation, automatic whole-volume particle trace visualization facilitated the qualitative appreciation of blood flow direction. Displays color coded to origin of vessels (yellow=portal venous; blue=caval; red=arterial).



	+ vis	- vis	+flow	-flow
PV	24	0	23	1
rtPV	22	2	21	1
ltPV	22	2	21	1
splenV	23	1	20	3
SMV	24	0	24	0
IMV	21	3	20	1
corV	10	14	9	1

Fig. 2 – Visualization result in a patient with portal hypertension and summary of visualization and directionality of flows in the vessels of the portal venous circulation. Interestingly, most splenV flow is diverted in the corV whereas SMV flow contributes mostly to hepatopetal PV flow. (+/- vis) successfully/not visualized, (+/- flow) hepatopetal/hepatofugal flow. PC=portal vein; corV=coronary vein; spleenV=splenic vein; IMV=inferior mesenteric vein; SMV=superior mesenteric vein.

Results: PC-VIPR and subsequent visualization was successfully performed in all 24 participants. Segmentation quality was rated very good in 12 cases, good in 11 cases, and poor in 1 case). Figure 1 A shows the typical segmentation of the upper abdominal vasculature in a 59yo male patient. In (B-D), the wholevolume particle trace visualization of flow patterns for each vascular system is displayed, demonstrating large coverage and inclusion of segmental vessels. Figure 2 shows the detailed flow patterns in a patient with hepatofugal flow in the coronary vein (corV) ***only***. This finding is of clinical importance since it indicates portal hypertension. However, a routine ultrasound would have very likely missed this abnormality because of the size and location of the vessel associated with a limited acoustic window behind the stomach and insonation angle.

There was no association between rating quality and MELD score. In comparison to arterial phase LAVA images there was excellent detection agreement (100%) for all major vessels. Out of a total of 168 evaluated vessel segments of the portal venous circulation (24 patients, PV, rtPV, ltPV, splenV, SMV, IMV, corV) 22 were not unambiguously detected and 8 vessels showed retrograde flow (see Fig. 2 insert). Differences were found with respect to the identification of the corV and IMV. The corV was correctly identified on PC-VIPR segmentations in 11/21 cases; in 9 cases it was not identifiable; in 1 case, the corV was identified on the PC-VIPR image only. Similarly, the IMV was identified in 18/21 cases on PC-VIPR images, it was not detected in 3 cases. Fisher's exact test revealed no association between MELD score and the ability to identify corV or IMV on PC-VIPR images ($p>0.05$ for both). In 10 cases, varices and/or shunt vessel were identified by PC-VIPR which were confirmed on VIBE images.

Summary: PC-VIPR allows the depiction and hemodynamic characterization of the entire upper abdominal vasculature in a single examination. In addition, the blood flow direction can be determined, and a visualization of hemodynamic flow patterns is feasible. Furthermore, shunt and collateral flow can be analyzed in great detail, with high temporal and high spatial resolution, over the entire abdomen. Limitations regarding some very small vessels not being recognized could be related to velocity sensitivity not being set optimally or non-optimized thresholds during segmentation. Work is being done to investigate these limitations. In summary, 4D flow with radial imaging holds great potential for comprehensive vascular assessment of the abdominal circulation and more specifically for portal hypertension. Quantitative evaluation of blood flow, which is simultaneously available, is being done in parallel to this project and will be reported elsewhere.

References: [1] Stankovic JMRI 2010; [2] Verma, Proc ISMRM 2009, #561; [3] Gu, AJNR 2005; [4] Kamath Hepatology 2001; [5] http://www.mayoclinic.org/meld/mayomodel5.html; [6] Johnson MRM 2010, [7] A. Anderson et al., Proc ISMRM 2008, 934.

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