Longitudinal Monitoring of Hepatic Blood Flow in patients with portal hypertension before and after TIPS implantation with 4D Flow MRI

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Target Audience: Physicists and clinicians interested in cirrhosis, portal hypertension and 4D-flow MRI.

Purpose: To demonstrate the feasibility of 4D-flow MRI for non-invasive longitudinal qualitative and quantitative hemodynamic monitoring of patients before as well as 2 and 12 weeks after TIPS placement.

Methods: In this IRB-approved study, 7 patients (52±8 years, 6M, 1F) with portal hypertension and refractory ascites were imaged before and then 2 and 12 weeks after placement of 10mm ø Viatorr TIPS-stents (Gore, Flagstaff, AZ). Imaging was performed on a 3T scanner (MR750, GE Healthcare, Waukesha, WI) with a 32-channel body coil (NeoCoil, Pewaukee, WI).

4D-flow MRI was performed using a radially undersampled phase contrast acquisition (5-point PC-VIPR) with increased velocity sensitivity performance [1,2,3,4]. Imaging parameters included: 32x32x24cm spherical volume, 1.25mm isotropic resolution, TR/TE= 6.4/2.2ms, flip angle=16º. All subjects received 0.03mmol/kg of gadofosveset trisodium (Lantheus, N. Billerica, MA) to improve SNR performance. Velocity encoding (venc) was adjusted for pre-TIPS at 60cm/s for optimal imaging of slow blood flow due to portal hypertension. For post-TIPS imaging at 2 and 12 weeks, the 4D velocity mapping was repeated back-to-back with a venc of 80cm/s and 120cm/s imaging for optimal imaging conditions of low flow in the portal vein and increased flow in the TIPS-stent.

Vessel segmentation was performed in MIMICs (Materialize, Leuven, Belgium) from PC angiograms and manual placement of cut-planes in the vessel of interest after importing the segmented masks into EnSight (CEI, Apex, NC) where flow measurements and visualizations were conducted. Flow data were acquired in the superior mesenteric vein (SMV), splenic vein (SV), portal vein (PV), and the TIPS-stent. Flow values measured in each vessel were compared pre- and post-TIPS using paired t-tests. The ratio of blood flow in the TIPS-stent versus the PV was calculated and changes in ascites volume and the need for paracentesis were recorded.

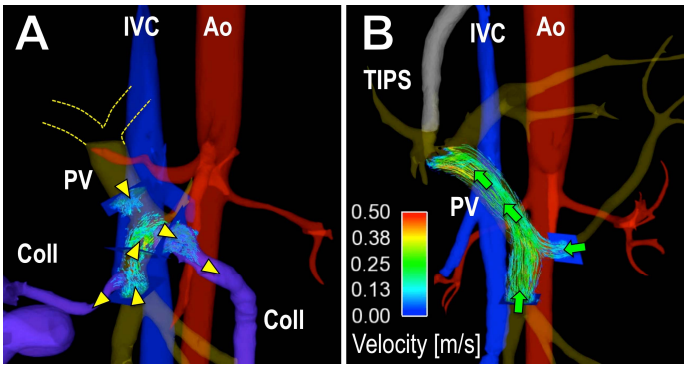

***Figure 1**: 4D-flow MRI visualization of hemodynamics in the portal vein before and after TIPS placement in a patient with portal hypertension. **(A)** Retrograde hepatofugal flow (arrow heads) into collaterals (Coll) is seen in the portal vein (PV) pre-TIPS. There was no detectable flow in the right and left portal vein (indicated by dotted lines). **(B)** Post-TIPS the flow reversed, now hepatopetal (arrows) in the portal vein, whereas no flow was detectable in collaterals. Ao=Aorta, IVC=inferior vena cava.*

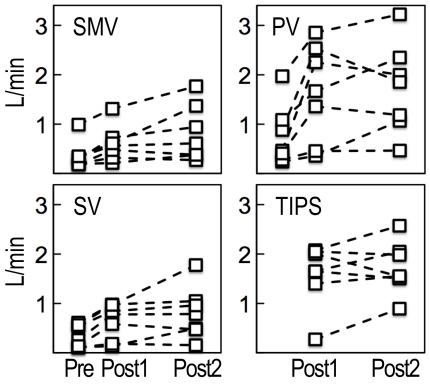

***Figure 2**: 4D-flow MRI-based quantification of blood flow before vs. 2 and 12 weeks post-TIPS. Flow was measured in the superior mesenteric vein (SMV), portal vein (PV), splenic vein, (SV) and TIPS-stent.*

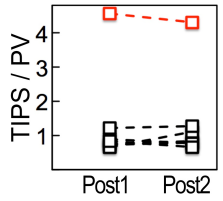

***Figure 3**: Ratio of flow in TIPS-stent vs. portal vein. The ratio in 6 of 7 patients was 0.8±0.2 and 0.9±0.2 on days 1 and 2. In one patient (red) with refractory ascites post-TIPS, a higher ratio was detected (4.6 / 4.3). This patient had an arterio-portal-venous fistula draining into the TIPS.*

Results: In 6 of 7 patients TIPS-implantation reduced ascites and rendered paracentesis unnecessary. In 1 patient ascites remained unchanged and paracentesis was still required post-TIPS. ***Figure 1*** shows a segmented angiogram in a patient with slow hepatofugal flow before TIPS and increased hepatopetal flow after TIPS, with a massive reduction in ascites. The blood flow volume increased on average significantly in all three vessels (SMV, SV, PV; all $p<0.05$) on both post-TIPS scans as compared to pre-TIPS. There was no significant difference between post-TIPS1 and post-TIPS2. However, the behavior of blood flow changes was non-uniform in the individual subjects as illustrated in ***Figure 2***. The TIPS/PV blood flow-ratio in the 6 patients with reduced ascites was on average <1 as illustrated in ***Figure 3***. In the one patient where ascites remained unchanged post-TIPS implantation, the TIPS/PV ratio was ~4 (*indicated in red Figure 3*). This patient was confirmed to have an arterio-portal-venous fistula draining into the TIPS and portal-circulation, thereby increasing the portal pressure and rendering the ascites refractory even after TIPS-implantation.

Discussion: 4D-flow MRI is feasible for characterization of portal blood flow before and after after TIPS-implantation. The results confirmed that the portal blood flow generally increases after TIPS-implantation, as expected. 4D-flow MRI allowed quantification of the ratio of blood flow in the TIPS-stent as compared to the portal vein, and thereby identified the underlying reason why TIPS-implantation did not remedy the ascites in one patient. Quantification of this ratio and longitudinal follow-up of more subtle differences (i.e. ratio > or < 1?) has potential to help identify patients with TIPS dysfunction or that are at risk of TIPS-related complications such as hepatic encephalopathy. A potential limitation of measurements in the TIPS-stent is the fact that results of total flow may be underestimated due to signal loss close to the stent wall. However, in the deployed Viatorr stents with 10 mm diameter we did not observe noticeable effects on the MR signal.

Conclusion: 4D-flow MRI can characterize and quantify the blood flow in the portal system and TIPS-stent. Further studies are needed to determine whether estimating the TIPS/PV blood-flow ratio may help to identify patients that are at risk of TIPS-related complications.

References: [1] Gu AJNR 2007; [2] Johnson MRM 2010; [3] Roldán-Alzate JMRI 2013; [4] Frydrychowicz JMRI 2011
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