Assessment of Blood Flow Hemodynamics of Liver Cirrhosis Patients after Treatment with a TIPS Stent-graft using a flow-sensitive 4D MRI Imaging at 3 Tesla

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Introduction: Patients with advanced liver cirrhosis often develop a hyperdynamic syndrome characterized by increased splanchnic inflow and hepatic resistance. As a result, portal hypertension can occur with potentially life-threatening complications like ascites, oesophageal varices and bleeding, which are often an indication for treatment with the transjugular intrahepatic portosystemic shunt (TIPS) [1,2]. As TIPS stent-grafts might have malfunctions with time they have to be assessed regularly. This can be performed either invasive by transjugular intervention with measurement of the portosystemic pressure gradient or non-invasively by Duplex-sonography [3]. Well established imaging techniques for evaluating the hepatic morphology and vasculature include perfusion imaging or non-contrast-enhanced and contrast-enhanced MRA [4,5]. Recent studies present promising results by using flow-sensitive 4D MRI as a user-independent method to assess 3D portal venous flow [6]. The purpose of this study was to 1) extent hepatic vascular coverage to simultaneously visualize and quantify arterial and portal venous hemodynamics using flow-sensitive 4D MRI and 2) investigate its feasibility to evaluate hepatic hemodynamics in patients with liver cirrhosis before and after treatment with a TIPS stent-graft.

Methods: Five liver cirrhosis patients (age=66.4±7.0) underwent flow-sensitive 4D MRI before stent-graft implantation and after a time period of 3 to 4 weeks. 10 normal volunteers (age=56.0±6.1) were included as control subjects. All measurements were performed using a 3T MRI system (TRIO, Siemens, Germany). ECG and respiratory gating with a navigator at the spleen-lung interface were used. An axial oblique 3D volume was acquired with a velocity sensitivity of 100cm/s (spatial resolution=1.6x2.1x2.4mm³, flip angel=7°, TE=2.7ms, TR=7.9ms, temp. res.=62ms). To visualize the large hepatic vessels as well as the TIPS-region a 3D phase contrast angiogram was calculated from the 4D data and displayed by iso-surface rendering (fig.1). Flow patterns were evaluated using 3D flow visualization (EnSight, CEI, Apex, USA) including 3D streamlines and time-resolved particle traces originating from emitter planes positioned at anatomical landmarks in the arteries, portal vein as well as TIPS-region as illustrated in fig. 1. Semiquantitative grading was performed according to visualization of the vessels (2=fully visible, 1=partly visible, 0=not visible) and leakage into adjacent vessel system. Quantitative flow analysis included vessel lumen segmentation (Matlab, the Mathworks, USA) and retrospective extraction of regional peak and mean velocities, flow volume, vessel area as well as pulsatility (PI) and resistance indices (RI). In the 10 normal volunteers, flow quantification results were compared to measurements obtained at the same anatomical locations by clinical reference standard US.

Results: Comprehensive depiction of hepatic venous and arterial hemodynamics as shown in fig. 1 could successfully be performed for most patients and volunteers. 3D visualization was limited for pre-interventional patients and the left intrahepatic portal vein branch (table 1). Noticeably, substantial changes in post-TIPS hepatic 3D blood flow characteristics could successfully be demonstrated in all patients. Blood flow could clearly be visualized and quantified even inside the TIPS sent graft indicating only minimal artifacts from the stent material (fig. 1, white arrows). Regional flow quantification comparing pre- and post-TIPS-stent-graft implantation demonstrated an increase of velocities and flow volume in the venous system as well as the hepatic artery (fig. 2). Pulsatility and resistant indices were consistently reduced in all arteries. In normal controls, comparison with the reference standard Doppler Ultrasound showed a partially significant trend towards lower maximum and mean velocities in MRI ($p=0.001$ to $p=0.9$) and significantly lower vessel for US ($p<0.01$). Flow volume, RI and PI revealed no significant difference between MRI and US.

Discussion: We were able to qualitative and quantitative evaluate arterial and portal venous hemodynamics of liver cirrhosis patients before and after TIPS-stent-graft implantation. As expected from the literature, maximum and mean velocities were underestimated by 4D MRI compared to Doppler US while vessel areas revealed higher values [7]. After TIPS-stent-graft implantation velocities and flow volume in the hepatic artery as well as venous system were substantially increased. Flow-sensitive 4D MRI may be a standardized method with complete volumetric and functional coverage hepatic 3D blood flow providing complementary information to Doppler US on whole organ hemodynamics in liver cirrhosis patients after TIPS-stent-graft implantation.

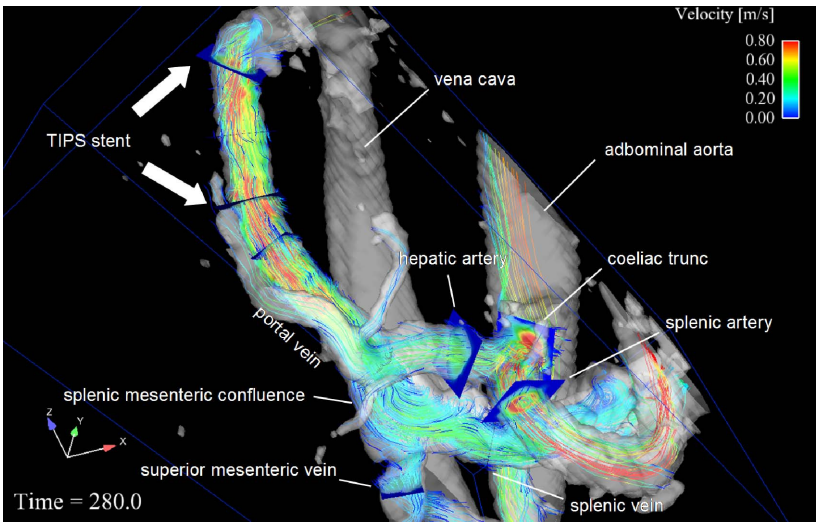

Figure 1: 3D streamline visualization of arterial and portal venous blood flow of a liver cirrhosis patient after TIPS-stent-graft implantation. In the TIPS region a high peak velocity can be appreciated with inflow from the left intrahepatic portal vein branch and outflow in the vena cava. The blue 2D analysis planes show the emitter planes used for initiation of streamlines and particle traces as well as for quantification of flow parameters (area, flow, peak velocities, RI, PI). Color coding = local blood flow velocity.

Flow visualization	visibility			visibility	
	reader A	reader B		reader A	reader B
sup. mes. vein	95%	95%	truncus	100%	100%
splenic vein	90%	90%	splenic artery	95%	95%
spl.-mes. confl.	100%	100%	hepatic artery	100%	100%
PV right branch	95%	95%	sup. mes. art.	100%	100%
PV left branch	75%	75%			
slines leakage	yes in 90%	yes in 73.8%	ptraces leakage	yes in 60%	yes in 60%

Table 1: Summary of the results of the qualitative image grading

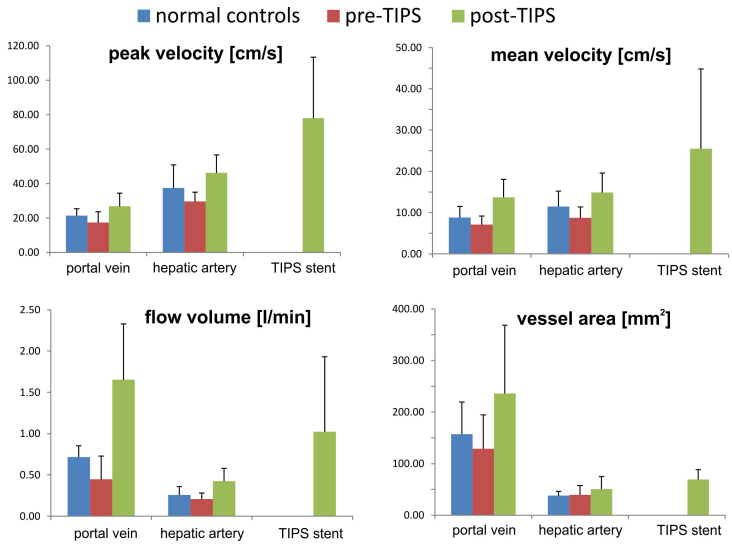

Figure 2: Summary of the results of flow quantification in the portal vein, hepatic artery and inside the TIPS stent. The expected increase in in post-TIPs velocities and flow in patients (n=5) can clearly be appreciated. Compared to normal controls (n=10) pre-TIPS velocities were lower in all vessels and even surpassed normal values after TIPS intervention.

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