# Evaluation of of Normal and Altered Hepatic Arterial und Portal Venous 4D Hemodynamics in Patients with Liver Cirrhosis before and after Treatment with TIPS

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**Introduction:** Among all digestive diseases, in the last decade chronic liver diseases were one of the most important causes of death and hospitalization in the USA [1]. Especially patients with liver cirrhosis can develop serious complications due to increased portal vein pressure [2]. As a common nonsurgical technique transjugular intrahepatic portosystemic shunting (TIPS) is currently used to decompress the portal circulation and to treat the major complications of portal hypertension [3]. In previous studies, Doppler ultrasound (US) [4], 2D phase contrast MRI [5] and CT [6] were used to investigate normal and pathological hemodynamics in the great hepatic vessels. Flow-sensitive 3D MRI was applied in a number of studies e.g., for the evaluation of supraaortic and intracranial arteries, left heart and thoracic aorta [7,8]. Recent work [9] successfully applied this technique in the portal venous system. The hepatic arteries, however, could not be evaluated. It was the purpose of this study to visualize and quantify blood flow changes in patients before and after treatment with TIPS and to demonstrate the feasibility of 4D MRI for investigation of the flow characteristics and hemodynamics in both the portal venous system and the great hepatic arteries. Flow quantification results of the volunteers were compared to the reference standard US.

**Methods:** All examinations were performed on a 3T MR System (Siemens, Erlangen, Germany) using flow-sensitive 3-dimensional MRI based on an RF-spoiled gradient-echo sequence. All measurements (10 volunteers; 5 male/5 female, mean age 56+/-6,15 and 2 patients; 1 male, 60y and 1 female, 49y) were prospectively gated to the ECG cycle. Additionally, a prospective respiratory gating with a navigator at the spleen-lung interface was applied. Pulse sequence parameters: venc=100m/s, spatial res.=1.6x2.1x2.4mm$^3$, $\alpha$=7°, TE=2.7ms, TR=62.4ms, temporal res.=45ms, axial-oblique 3D Volume. To visualize the great hepatic vessels and the TIPS-region a 3D phase contrast angiogram was calculated from the 4D data and displayed by iso-surface rendering (fig.1). For evaluation of the flow pattern (EnSight, CEI, Apex, USA) analysis was based on streamlines and time-resolved particle traces originating from predefined emitter planes positioned in the portal vein, arteries and in the TIPS-region (fig.1). All streamline and particle trace images were qualitatively graded according to: Visualisation of the vessels (2=fully visible, 1=partly visible, 0=not visible), leakage into adjacent vessel system, existence of vortices and type of inflow into the portal vein confluens. For flow quantification vessel lumen segmentation (Matlab, the Mathworks, USA) was performed in analysis planes, positioned in the same locations as the streamline and particle trace emitter planes (fig.1). Flow volume, peak velocity, mean and maximum velocity averaged over the cardiac cycle (avg(V), avg($V_{max}$)) and vessel area were calculated and the measured values of the volunteers were compared to US (tab.2).

**Results:** Streamline and particle trace visualization (fig.1) was successfully performed in all volunteers and patients. Qualitative flow analysis revealed clear depiction of almost all vessels (score=2), only the intrahepatic portal vein branches showed an impaired visibility (average scores right PV=1.9+/-0,32; left PV=1.6+/-0,84). In one case the splenic artery was not visible due to a failure at the exam scheduling (score=1.8+/-0,63). In the 2 patients after TIPS the surgically induced shunt flow could clearly be visualized as shown in fig. 1B for one patient. Moreover, the distribution of peak velocities was inhomogenous in both patients after TIPS with a vortex in the distal portal vein in patient 1 (fig.1B), whereas all volunteers showed a homogenous flow distribution. Flow distribution in the splenic-mesenteric confluence showed a caudal/cranial distribution pattern in both patients and in 3/10 volunteers. As expected, flow quantification revealed a clear increase of flow volume, maximum, mean maximum and mean velocities after TIPS-treatment in patient 1. Except for flow volume, similar results were found for patient 2 after TIPS (tab.1). In accordance with the previous literature, comparison of MRI and US values for the 10 volunteers revealed a significant (p=0,001–0,005) underestimation of the maximum, mean maximum and mean velocities by MRI. On the other hand vessel area measurements were lower for US (p=0,01). A moderate significant correlation between MRI and US (tab.2) (r=-0,48–0,66) was evident.

**Discussion:** The results of this feasibility study demonstrate the feasibility of time-resolved 3D phase contrast MRI for visualization and quantification of normal and pathological hemodynamics in the great hepatic vessels. In one patient who underwent flow-sensitive MRI before and after treatment, considerable blood flow changes after treatment with TIPS could be identified. Quantitative analysis revealed a clear increase of velocities and flow volume after TIPS, conjecturally resulting from the decompression of portal circulation. Additional prospective studies are required to confirm these results. In accordance with the literature, lower values for velocities [10] and higher values for areas were measured by MRI [9,10]. Statistical analysis showed a moderate correlation between MRI and the reference standard Doppler ultrasound, probably due to the user dependent measurements with US. Our findings underline that 4D MRI has the potential to be established in the clinical routine to examine the outcome of TIPS-treatment as an alternative, user independent method compared to US.

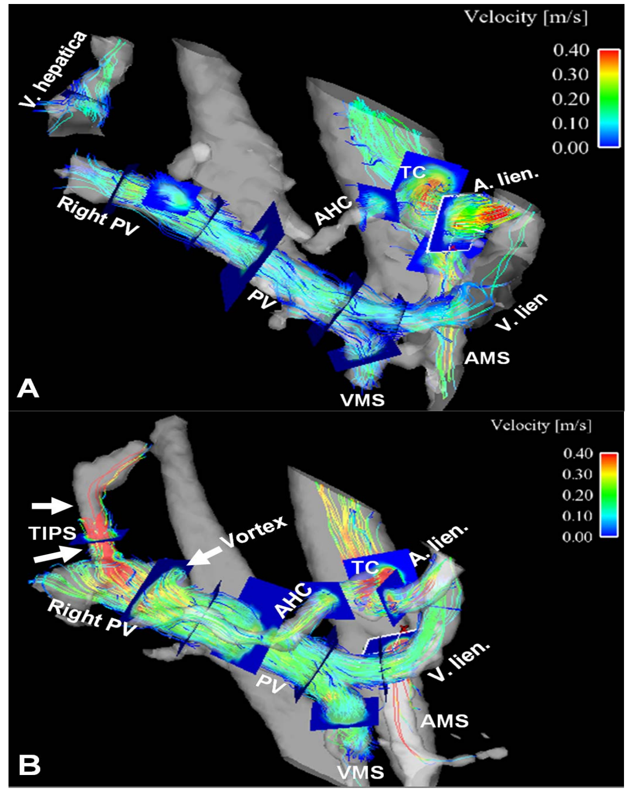


**Fig. 1**: 3D-PC-MRA (gray shaded iso-surface) clearly depicted hepatic vascular geometry before (A) and after (B) TIPS insertion on the right PV. Streamline visualization originated from predefined emitter planes provide an overview of the 3D blood flow patterns with inhomogenous flow distribution in the distal and right PV after TIPS. In the TIPS-region a high peak velocity can be appreciated and a vortex in the distal PV can be observed (B). PV: portal vein, VMS and AMS: superior mesenteric vein and artery, V. and A. lien: splenic vein and artery, AHC: hepatic artery, TC: coeliac trunk, TIPS: transjugular intrahepatic portosystemic shunt.

| | *Patient 1* | | *Patient 2* |
|---|---|---|---|
| | *Before TIPS* | *After TIPS* | *After TIPS* |
| **Flow** [l/min] | 0,62 | 2,93 | 1,33 |
| **peak V** [m/sec] | 0,26 | 0,43 | 0,51 |
| **avg($V_{max}$)** m/sec] | 0,22 | 0,39 | 0,38 |
| **avg(V)** [m/sec] | 0,1 | 0,22 | 0,15 |

**Tab. 1:** MRI flow quantification results of the right portal vein before and after TIPS insertion compared to Doppler US

| | | *PV* | *r (PV)* | *TC* | *r (TC)* |
|---|---|---|---|---|---|
| **Flow** [l/min] | **MRI** | 0,63 +/- 0,21 | 0,64 | 0,58 +/- 0,22 | 0,09 |
| | **US** | 0,94 +/- 0,59 | | 0,78 +/- 0,31 | |
| **peak V** [m/sec] | **MRI** | 0,21 +/- 0,04 | 0,22 | 0,78 +/- 0,16 | 0,19 |
| | **US** | 0,32 +/- 0,10 | | 0,95 +/- 0,99 | |
| **avg($V_{max}$)** m/sec] | **MRI** | 0,18 +/- 0,03 | 0,33 | 0,42 +/-0,09 | 0.02 |
| | **US** | 0,26 +/- 0,08 | | 0,53 +/- 0,43 | |
| **avg(V)** [m/sec] | **MRI** | 0,09 +/- 0,03 | 0,66 | 0,23 +/- 0,09 | -0,48 |
| | **US** | 0,14 +/- 0,03 | | 0,34 +/- 0,21 | |

**Tab. 2:** MRI flow quantification results of the portal vein (confluens) and coeliac trunc compared to Doppler US

**1.**Everhart JE et al.. Gastroenterology 2009; 136:1134–1144.**2.**Abraldes JG et al.. Hepatology 2003; 37:902–908.**3.**Colombato L. J Clin Gastroenterol. 2007; 3:344- 51. **4.**Platt JF, et al.. Radiology 1995; 196:95–98.**5.**Quiroga S et al.. Radiographics 2001.**6.**Yzet T et al.. JMRI 2010; 31:579-588.**7.**Frydrychowicz et al.. J Comput Assist Tomogr. 2007; 31:9-15.**8.**Frydrychowicz A, et al.. Magn Reson Imaging, 2007; 25:1085-92.**9.**Stankovic et al.. JMRI 2010; 32:466-475.**10.** Lycklama a. Nijeholt GJ et al.. J Hepatol. 1997; 26:298-304.