Visualization and Quantification of 3D Flow Characteristics in the Portal Venous System

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Introduction: Chronic liver disease is an important cause of morbidity and mortality. Almost 20% of patients have cirrhosis at presentation [1]. Previous studies have shown that alteration of hepatic perfusion parameters measured with CT or ultrasound in patients with liver cirrhosis correlate with the severity of chronic liver disease and the therapeutic outcome [2,3]. Recent studies assess liver cirrhosis by using color doppler velocity profile and contrast- enhanced sonography [4]. Early evaluation of the portal venous system with magnetic resonance velocity mapping 2D phase contrast MR angiography was applied [5]. Recent studies measuring degree of cirrhosis and portal hypertension with MR imaging and doppler US apply dynamic contrast material enhanced MR imaging [6]. The aim of this study was to provide improved diagnostic information by visualizing and quantifying comprehensive 3D vascular hemodynamics in the portal venous system using flow-sensitive 4-dimensional MRI at 3T.

Methods: For the assessment of time-resolved 3D blood flow in the portal venous system, flow-sensitive 4D MRI was employed using a 3T MR system (TRIO, Siemens, Germany) and 3-dimensional MR velocity mapping in a group of 18 volunteers (age=28.6+/-3.1): venc =50cm/s, spatial res. = 1.6 x 2.1 x 2.4mm^3, axial oblique 3D volume, 36 slices/slab, α = 7°, TE =3.0ms, TR = 44.8ms, temporal res. = 45ms. Respiration and wall motion artefacts were minimized by ECG and respiratory gating applying a navigator at the spleen-lung interface. The flow in the portal venous system was evaluated using 3D flow visualization (EnSight, CEI, Apex, USA) [7, 8].
Analysis was based on time-resolved 3D streamlines and particle traces originating from 6 emitter planes virtually positioned in the portal venous system (figure 1). All streamline and particle trace images were qualitatively graded according to the following categories: Visualisation of the vessels (2 = fully visible, 1 = partly visible, 0 = not visible), leakage into adjacent vessel system, maximum flow distribution, existence of vortices or retrograde flow, and type of inflow into the portal vein confluens (figure 1). Additional quantitative flow analysis using a home built tool (Matlab, TRhge Mathworks, USA) included interactive positioning of an analysis plane in the portal vein (see figure 1), vessel lumen segmentation, and flow quantification. For all volunteers flow waveforms over the cardiac cycle as well as peak velocity, minimal velocity and mean velocity were calculated (figure 2). Data in 15 volunteers were compared to the reference standard Doppler US (Hitachi EUB 7500 HV, Hitachi Medical Systems, Europe).

Results: 3D streamline and particle trace visualization in the complete portal venous system (mesenteric and splenic vein, portal vein, intrahepatic right and left portal vein) could successfully be performed for all subjects. Visual inspection revealed that dorsal and ventral filling of the portal vein was consistently realized by flow originating in the mesenteric and splenic veins, respectively. The results of blood flow velocity quantification are summarized in figure 2 and table 2. The temporal evolution of velocities over the cardiac cycle (figure 2) revealed relatively constant mean velocities over the entire RR interval as expected for venous flow. Nevertheless, moderate pulsatility of the venous flow was still present as illustrated by the increase of mean flow during the diastolic period and clearly visible temporal changes in the maximum velocities. Peak velocity measurements in the MRI excellent correlate with results from Doppler US.

Flow visualization	visibility	Velocity distribution	
superior mes. vein	2,00	isolated flow acceleration in streamlines	n = 4
splenic vein	1,84	isolated flow acceleration in particle traces	n = 3
portal vein con. prox.	2,00		
portal vein con. dist.	2,00	Flow Distribution in confluens (smv/ splenic v.)	
right portal vein	2,00	dorsocaudal / cranioventral	n = 8
left portal vein	1,79	caudal / cranial	n = 7
		ventrocaudal / dorsocranial	n = 2
leakage	yes in 17/18	dorsal / ventra	n = 1

Table 1: Summary of the results of the qualitative image grading in 18 subjects

Discussion: The results of this study demonstrate feasibility of visualization and quantification of 3D flow characteristics in the portal venous system. Peak velocity was comparable to Doppler US measurements in contrast to current studies that suspect an underestimating of the MRI values. A limitation was related to the low spatial resolution occasionally preventing clear separation of the portal vein and surrounding vessels resulting in a leakage. 3D MR velocity mapping may be a method for better understanding effects in patients with a modified flow characteristics in portal venous system, like retarded or retrograde flow. Using MRI we might have a standardized method not investigator dependent giving more detailed information about morphology and haemodynamics compared to US.

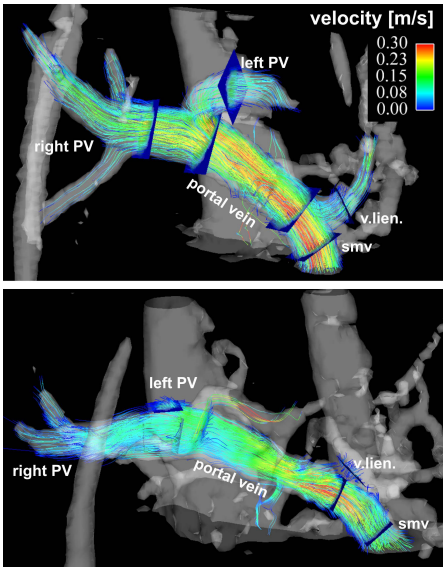

Figure 1: Examples for streamline visualization of portal venous flow with emitter planes positioned in the mesenteric and splenic vein, distal and proximal portal vein confluens and right and left intrahepatic portal vein. **Top:** Clear visibility (grading = 2) of all branches and homogenous distribution of max velocities. **Bottom:** Impaired visibility of splenic vein and left intrahepatic portal vein.

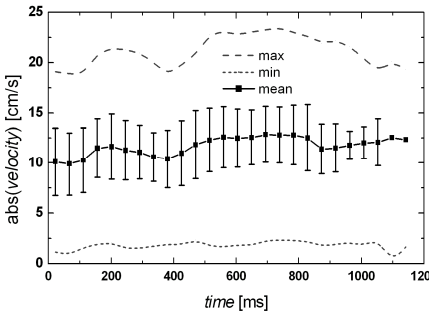

Figure 2: Min, max and mean blood flow velocity timecurves over the cardiac cycle in the portal vein average over all 18 volunteers. Standard deviation = interindividual variations of the velocities.

	MRI (n=18)	Doppler US (n=15)
peak |v|	27.4 +/- 3.9	27.0 +/- 5.2
mean peak |v|	21.1 +/- 4.4	22.5 +/- 4.4
mean |v|	11.5 +/- 4.4	N/A
early systolic |v|	9.9 +/- 3.1	N/A
diastolic |v|	12.9 +/- 2.8	N/A

Table 2: MRI flow quantification results compared to Doppler US

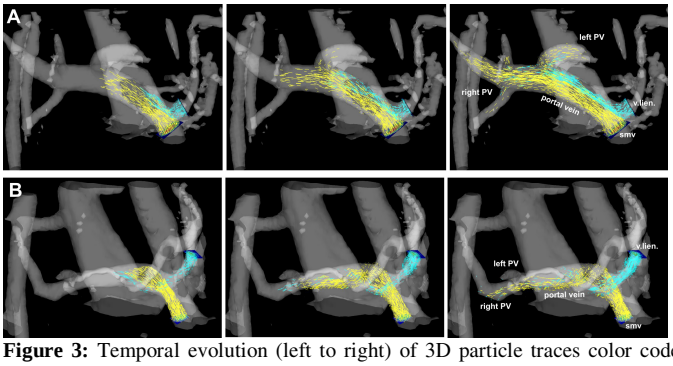

Figure 3: Temporal evolution (left to right) of 3D particle traces color coded according to their vascular origin (yellow = vena lienalis, blue: superior mesenteric vein) **A:** Typical homogenous filling with clearly separated flow channels **B:** Unusual helical mixing seen in 1 volunteer.

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