Time-Resolved 3D MR Velocity Mapping of the Great Hepatic Vessels at 3T: Simultaneous Visualization of Arterial and Venous Hemodynamics and Comparison with Ultrasound

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Introduction: The blood supply of the liver is autoregulated by the hepatic arterial buffer response to countervail alterations of the portal venous blood flow [1]. Especially chronic liver diseases are associated with pathological vascular hemodynamics of both the portal venous system and the coeliac trunk [2], so it is of clinical relevance to evaluate blood flow characteristics in the portal vein as well as in the hepatic arterial system at the same time. In previous studies the dependence of the portal venous perfusion on the size of the hepatic artery was evaluated with Doppler ultrasound (US) [3,4] or CT [5]. Recent studies used contrast enhanced MR angiography to examine the haemodynamics of the great hepatic vessels [6]. Flow-sensitive 3D MRI flow analysis was applied in a number of studies e.g., evaluation of supraaortic arteries, intracranial circulation, heart and the thoracic aorta [7,8]. It was the purpose of this study to simultaneously visualize and to quantify the vascular hemodynamics of both the portal venous system and the coeliac trunk including the hepatic artery in healthy volunteers using flow-sensitive 4D MRI at 3T. Results were compared to the reference standard US.

Methods: Time-resolved blood flow of the great hepatic vessels was assessed in a group of four healthy volunteers (3 woman and 1 man, age 50-53 y) with a 3T MRI (Magnetom Trio, Siemens, Erlangen, Germany). Data was acquired using a time-resolved, RF-spoiled gradient-echo sequence with 3-directional velocity encoding (flow-sensitive 4D MRI). Following parameters were employed: venc =100m/s, spatial res. = 1.6 x 2.1 x 2.4mm^3, α = 7°, TE =2.7ms, TR = 62,4ms, temporal res. = 45ms. Data were acquired in an axial-oblique 3D Volume. Prospective ECG and respiratory gating (navigator at the spleen-lung interface) were used to minimize breathing and wall motion artefacts [9]. To visualize the portal venous and arterial vessels a 3D phase contrast angiogram (3D-PC-MRA) was calculated from the 4D data and displayed by iso-surface rendering (fig. 1). For evaluation of the flow characteristics (EnSight, CEI, Apex, USA) analysis was based on time-resolved streamlines and particle traces originating from predefined emitter planes positioned in the portal vein, coeliac trunk and in the hepatic and splenic arteries (fig. 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, existence of vortices and type of inflow into the portal vein confluens (fig. 1). Flow quantification was performed in manually positioned analysis planes in the portal vein and hepatic artery (see fig. 1) and included frame-wise lumen segmentation (Matlab, the Mathworks, USA). Flow volume, peak velocity, mean and maximum velocity averaged over the cardiac cycle (avg(V), avg(V_{max})) and vessel area were calculated and compared to Doppler US (tab. 2).

Results: 3D streamline (fig. 1) and particle trace visualization of both venous and arterial hemodynamics was successfully performed in all volunteers, only one vessel (splenic artery) could not be depicted in one case. Flow distribution in the splenic-mesenteric confluence originating from emitter planes in the superior mesenteric vein and splenic vein showed a caudal and cranial distribution pattern in three of four subjects (tab. 1). As expected higher blood flow velocity in the arterial vessels can clearly be appreciated (red streamlines in figure 1). In accordance with previous literature comparing MRI and US [10] values of the maximum, mean maximum and mean velocities were underestimated by MRI for the portal vein system by 30,83 +/- 5,06 % as well as for the arterial system by 37,54 +/- 8,55 %. On the other hand vessel area measurements with the US resulted in lower values compared to MRI (tab. 2). Statistical analysis showed a highly significant correlation ($r = 0{,}72$, $p < 0{,}001$) between MRI and US (fig. 2).

Flow visualization	*Visibility*	*Velocity distribution*
superior mes. and splenic vein	2	**Flow Distribution in confluens**
PV confluens prox. and dist.	2	**(smv/ splenic v.)**
right and left PV	2	
hepatic vein	2	**caudal / cranial** n = 3
coeliac trunk an hepatic artery	2	**dorsal / ventral** n = 1
splenic artery	1,5	
leakage	yes in ¾	**No Vortices**

Table 1: Results of visualization analysis

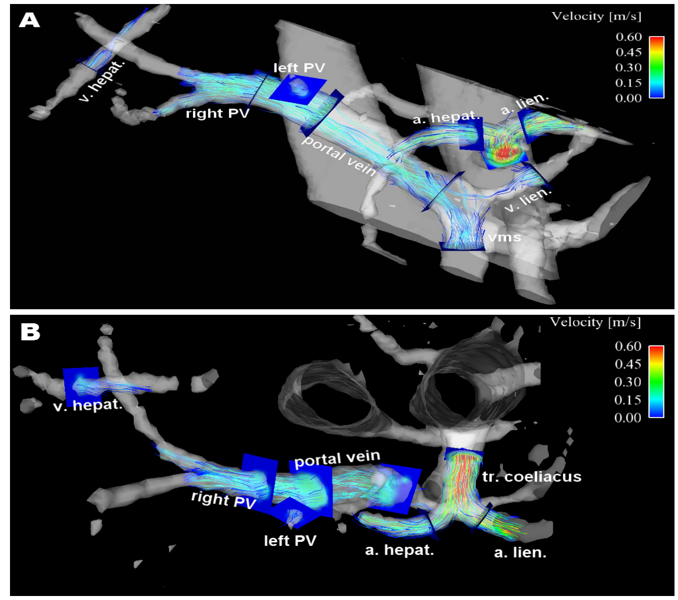

Fig. 1: 3D-PC-MRA (gray shaded iso-surface) clearly depicted venous and arterial geometry. Streamline visualization originated from predefined emitter planes positioned in the coeliac trunk, hepatic and splenic arteries, distal, proximal, left and right portal vein, mesenteric, splenic and hepatic vein. The resulting traces provide an overview of the 3D blood flow patterns at a specific time of the cardiac cycle. **A:** anterior-posterior view illustrating 3D vessel geometry. **B:** Head to foot view allows detailed depiction of the coeliac trunk, hepatic and splenic arteries.

		portal vein	*hepatic artery*
flow [l/min]	**MRI**	0.89 +/- 0.28	0,24 +/- 0.03
	US	0.98 +/- 0.30	0.19 +/- 0.07
peak V [m/sec]	**MRI**	0.27 +/- 0.04	0.37 +/- 0.06
	US	0.41 +/- 0.11	0.68 +/- 0.17
avg(V_{max}) m/sec]	**MRI**	0.22 +/- 0.03	0.24 +/- 0.01
	US	0.33 +/- 0.08	0.39 +/- 0.12
avg(V) [m/sec]	**MRI**	0.12 +/- 0.03	0.15 +/- 0.01
	US	0.16 +/- 0.03	0.21 +/- 0.05
Area [mm²]	**MRI**	132.15 +/- 57.36	27.17 +/- 2.99
	US	50.78 +/- 14.48	8.57 +/- 3.63

Tab. 2: MRI flow quantification results of the portal vein and hepatic artery compared to Doppler US

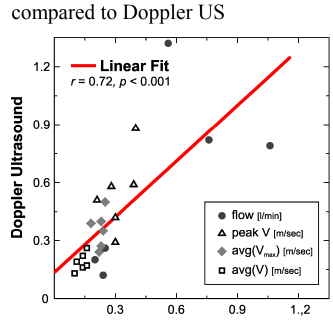

Fig. 2: Results of linear regression analysis showed highly significant correlation between MRI and Doppler Ultrasound comparing flow volume, peak velocity, mean and maximum velocity averaged over the cardiac cycle (avg(V), avg(V_{max}))

Discussion: The results of the four volunteer examinations indicate that time-resolved, 3-dimensional velocity mapping has the potential to visualize and quantify blood flow pattern and visualize flow characteristics in the portal venous and at the same time in the hepatic arterial system. In accordance with the literature lower values for velocities and higher values for areas were measured by MRI [10], but statistical analysis showed an excellent agreement between MRI and the reference standard Doppler Ultrasound. In consideration of these results, despite the small number of subjects, our findings underline that 4D-MRI could be an alternative, user indipendent method to Doppler US in investigating normal and pathological hemodynamics of the great hepatic vessels, additionally offering the opportunity to evaluate and visualize 3D hemodynamics within the entire arterial and venous system.

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