

Evaluating portal venous hemodynamics with 4D flow: how essential is the temporal dimension?

Benjamin R Landgraf¹, Kevin M Johnson², Christopher Francois¹, Alejandro Roldan¹, Oliver Wieben², and Scott Reeder^{1,2}

¹Radiology, University of Wisconsin - Madison, Madison, Wisconsin (WI), United States, ²Medical Physics, University of Wisconsin - Madison, Madison, Wisconsin (WI), United States

Background: Portal hypertension (PHTN) is a life-threatening consequence of cirrhosis. It can lead to serious complications such as portosystemic collaterals (varices), ascites, hepatorenal syndrome, and splenomegaly. Current techniques to evaluate the anatomy and hemodynamics in PHTN include ultrasound[1] and conventional PC MR imaging. These techniques have important limitations, such as insufficient volumetric coverage, increased scan times, and an inability to visualize flow in complex morphological changes that commonly occur with PHTN. A comprehensive diagnostic method to assess both the hemodynamics and morphology of the entire abdomen from a single examination is highly desirable and was recently introduced in the form of time-resolved 3D phase contrast (“4D flow”) MRI [2]. A radially undersampled approach, PC-VIPR, was shown to provide both high spatial and temporal resolution over the entire abdomen [3]. While scan time for an accelerated time-resolved radial 4D flow acquisition is short (~12 min) in comparison to Cartesian based 4D flow methods, further reductions may be possible by exploiting the non-pulsatile nature of portal venous blood flow [4]. The purpose of this study was to compare the accuracy of time-averaged versus time-resolved 4D flow MRI and to determine the degree of scan time reduction that can be achieved while maintaining high quality angiograms and accurate quantification of blood flow.

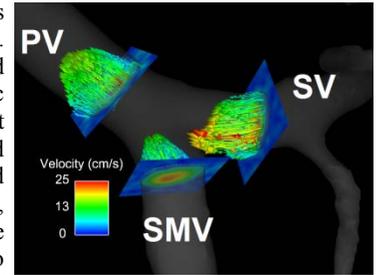


Figure 1: Consistency of blood flow quantification was assessed by measuring flow rates in the superior mesenteric, splenic and portal veins.

Methods: Forty-four subjects (47.8±14.1 years, 84.3±17.4 kg; 29 male, 15 female) were included in this HIPAA-compliant and IRB-approved study after obtaining informed consent. This study included 29 patients with known cirrhosis and 15 normal volunteers. All imaging was performed on a 3.0T clinical scanner (Discovery MR 750, GE Healthcare, Waukesha, WI) using a 32-channel phased array body coil (Neocoil, Pewaukee, WI). A balanced 5-point velocity encoding technique was used to improve velocity sensitivity. Images were acquired using a time-resolved 3D radially undersampled PC sequence (PC-VIPR) as previously described [3], using respiratory gating and retrospective cardiac gating. Specific image parameters included: dual echo acquisition, imaging volume = 32x32x24cm, BW=±125 kHz, with 24,000 total projections, for true isotropic spatial resolution of 1.25x1.25x1.25 mm, TR/TE = 6.1–7.8/2.1–3.2 ms, $V_{enc} = 60$ cm/s, and total scan time on the order of 10-12 minutes.

Images were reconstructed as a time-resolved series with 14 interpolated time frames per R-R cycle using temporal filtering similar to a radial version of view sharing [5]. In addition, different time-averaged reconstructions using 100%, 50%, 33%, 25%, 20%, 10%, and 5% of the acquired projections were used for reconstruction to mimic reduced scan times of 12, 6, 4, 3, 2.4, 1.2, and 0.6 minutes. PC angiograms for all datasets were generated by complex difference processing, segmented (Mimics, Materialise, Ann Arbor, MI), and visualized (Ensign, CEL, Apex, NC).

A pulsatility index of the mean velocity V' in the portal vein was calculated $PI = (V'_{max} - V'_{min}) / V'_{mean}$ [6]. Flow quantification consistency was assessed by using a mass conservation technique, assuming the sum of superior mesenteric and splenic vein flow to equal portal venous flow. Flow values were obtained by user-defined ROIs of planes placed within each vessel (Fig. 1). Visualization quality was assessed by emitting 100 streamlines in the proximal portal vein and calculating their average length (Fig. 2). Angiographic quality of axial images was graded by two experienced radiologists based upon background (scale: 0-2, 0=substantial, 2=minimal) and blurring (scale 0-4, 0=severe blurring, 4=no blurring).

Results: The 5-point PC-VIPR acquisition and subsequent flow quantification and assessment were successfully performed in all 44 subjects and all reconstructions. The pulsatility index was calculated to be 0.45±0.25. Flow measurements were more consistent in the time-averaged than the time-resolved reconstruction, using all acquired data with errors of 5.2%±4.4 and 3.9%±3.1, respectively. Further results are listed in Table 2.

Discussion: As expected, the results show an improved image quality of the PC angiogram and improved consistency of flow measures (conservation of mass) and visualization (streamline length) at longer scan times. However, a scan time of 3-4 min appears sufficient to visualize and quantify flow in the portal venous system with only slightly degraded image quality compared to the 12 min scan. Flow consistency was also comparable to the dynamic 12 min scan. Therefore, we conclude it may be possible to reduce scan time by about 75% using time-averaged reconstruction for visualization and quantification in the portal venous circulation. Dynamic analysis is required when flow in the hepatic arteries (pulsatility) or the hepatic veins (motion within the cardiac cycle and reverse flow) are of interest.

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References:

- [1] Finn AJR 1993,
- [2] Stankovic JMRI 2010
- [3] Frydrychowicz JMRI 2011
- [4] Gorg BJR 2002
- [5] Liu TMI 2006
- [6] Shih WJG 2006

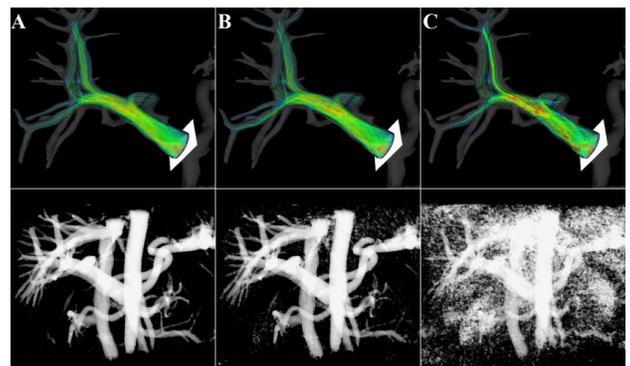


Figure 2 - Streamline visualization and angiography from (A) 12, (B) 4, and (C) 1.2 minute equivalent scan-time reconstructions.

	12 minutes	6 minutes	4 minutes	3 minutes	2.4 minutes	1.2 minutes	0.6 minutes
Conservation of Mass (PV-SMV+SV) / PV	3.9% ± 3.1	4.1% ± 3.3	4.5% ± 4.2	5.4% ± 4.7	4.9% ± 5.0	7.0% ± 7.5	6.8% ± 7.9
Streamline Length (mm)	46.9 ± 7.4	43.0 ± 7.0	39.3 ± 6.2	38.0 ± 6.8	38.0 ± 12.5	33.4 ± 13.3	28.5 ± 15.3
Angiography Score							
Background	1.98 ± 0.15	X	1.34 ± 0.61	X	X	0.41 ± 0.50	X
Blurring	3.98 ± 0.15		3.11 ± 0.75			1.30 ± 0.95	

Table 1 - Results from the time averaged reconstructions. X denotes that an assessment was not performed. PV = portal vein. SMV = superior mesenteric vein. SV = splenic vein.