Comparison of the accuracy in 2D and 4D PCMRI to evaluate oscillating flow in small diameters

Gwenael Page[1], Roger Bouzerar[1], Dominique Haye[2], Dong-Joo Kim[3], Hack-Jin Lee[3], Anne-Virginie Salsac[4], and Olivier Baledent[1]

[1]BioFlow Image, CHU Amiens, Amiens, France, [2]PFT Innovaltech, France, [3]Department of Brain and Cognitive Engineering, Korea, [4]Laboratoire de Biomecanique et Bioengenierie, CNRS, France

Introduction Phase-Contrast (PC) MRI is a non-invasive technique used for quantification and characterization of blood flow. 4D PC-MRI method has been assessed for flow quantification in vessels [1-2]. Acquisition time is the principal limit of this technique; especially if we want to assess flow in small vessels with a good spatial resolution. The aim of this study is to compare a high spatial resolution 2D PC MRI protocol with a 4D PCMRI protocol in a phantom with calibrated thin tubes and physiological oscillating flows.

Material & Methods Study realized with MRI compatible resin phantom, composed by 6 branches with diameters similar to those on face and neck, figure 1. It had a length of about 15cm. Phantom was placed in agar-agar gel to reproduce physiological conditions found in human being. A pump (Masterflex) connected by pipes provided a water pulsatile flow to the phantom with an average flow at 70ml/min for a frequency selected at 70cycles/min. Reynolds numbers were less than 2000 and no turbulent flows were provided in the phantom. Before MRI acquisition, an accurate flow sensor (Transonic Systems Inc.) was placed at the phantom input to measure the flow curve with high accuracy.

Sequence	2D PC-MRI	4D PC-MRI
FOV (mm^2)	120x120	250x250
Spatial Resolution (mm^3)	0.2x0.2x1	1x1x2
TR/TE (ms/ms)	21/12	11/6
SENSE	2	4
Acquisition Time (min:s)	1:53 x 4	3:18 + 3:18
Number of slices	1 x 4	40 + 40
Frames for each cardiac cycle	27	14

Table 1: Parameters settings in 2D PC-MRI and 4D PC-MRI

2D and 4D PC-MRI protocols were applied on the phantom in a 3T, Achieva dStream, Philips using 32 head coils channels. For 2D PCMRI 4 slices were placed perpendicularly on the different branches of the phantom. Velocity encoding were selected at 35cm/s, 45cm/s, 38cm/s and 30cm/s respectively to 5mm, 4mm, 3mm and 2mm branches diameters. Then, 4D PC-MRI sequence was used and the first half of the phantom was acquired with a velocity encoding set at 38cm/s in all three flow directions. The second half of the phantom with a velocity encoding set at 45cm/s in all three flow directions. Parameters during 2D and 4D PC-MRI acquisitions are displayed table 1.

Segmentation of 2D phase images was realized with Flow software (developed by BioFlow Image laboratory, Amiens CHU, France) [3] to obtain flow curve. This software has been extended to 4D PC-MRI post processing and allow automatic segmentation of the flows both in 2D and 4D. A slice was placed manually on the volume of the 4D PCMRI to reconstruct a 2D slice for comparison with 2D PCMRI, then the 2D flow and 4D flow curves were calculated. For each pixels of phase images, the norm of its velocity in 4D was calculated in function of its velocity in all three directions (Vx, Vy, and Vz), for calculating the flow curve in 4D PC-MRI, $\left\|\overrightarrow{V_{4D}}\right\| = \sqrt{V_x^2 + V_y^2 + V_z^2}$.

For each branches of the phantom, the flow curve was reconstructed along the pulsatile cycle to calculate the average flow rate. Accuracy of the flow measurement was then evaluated by calculating the difference between expected and measured flow in each branches. The obtained differences were normalized in % of the expected flow rate.

Results Figure 2 shows curves of flow obtained in 2D and 4D PC-MRI compared with control curve and figure 3 phase images in 2D and 4D PC-MRI. Accuracy of flow measurements is presented in table 2.

Phantom /Sequence	Percent error (%)	
	2D $_{PC-MRI}$	**4D $_{PC-MRI}$**
input (5mm)	7.3	9.5
branches (2,3mm)	1.2	2.4
output (4mm)	3.8	5.1

Table 2: Flow measurement accuracy percent error within branches of the phantom for 2D and 4D PC-MRI

Discussion The phantom was powered by an incompressible Newtonian fluid and we had a flow conservation, thus we summed the average flow rate value found in bifurcation branches for calculating the average flow rate within both branches. On 4D PC-MRI sequences, the lateral velocities were negligible compared to the velocities in the axis of the phantom. For both sequences we had an error less than 10%, however 2D PC-MRI measurement was more accurate, which is explained by a higher resolution and SENSE set at 2 for 2D and 4 for 4D PC-MRI. Figure 2 shows that curves of flow within branches of the phantom in 2D PC-MRI and 4D PC-MRI are similar to the control curve.

Conclusion In an experimental setup providing physiological flow, which is pulsatile flow with frequency and average flow that can be found in human being, it is possible to have 4D PC-MRI flow measurement consistent with 2D PC-MRI measurement with a clinically acceptable acquisition time. The limit of 4D PCMRI is that only one Velocity encoding can be used for such long acquisition and one VENC can't be optimal to investigate in a single acquisition veins, arteries and CSF.

References [1] Harloff and al., MRM (2009). [2] Markl and al., JMRI (2003). [3] Baledent and al., IR (2001).

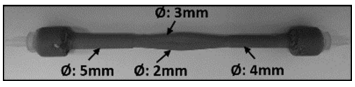

Figure 1: Resin Phantom

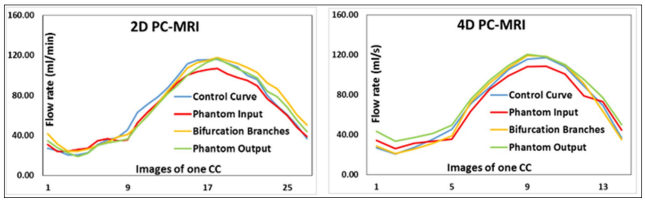

Figure 2: Comparison between standard curves and flow curves within phantom branches in 2D and 4D PC-MRI

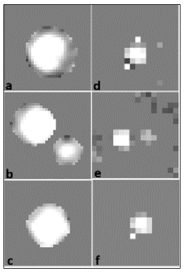

Figure 3: Phase images in 2D (a, b, c) and 4D PC-MRI (d, e, f) of the Phantom Input, Bifurcation Branches, Phantom Output (from up to bottom)