Fast PC flow measurements using undersampled projection reconstruction: preliminary results in a swine model

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INTRODUCTION

Previous studies [1] have demonstrated that the hemodynamic significance of stenoses can be identified with MR flow measurement techniques. The accuracy of flow measurements improves with increasing spatial [2] and temporal resolution. With conventional MR imaging techniques, achieving increasingly higher spatial and temporal resolution requires longer scan times. However, when a vessel of interest is located in an area affected by respiratory or cardiac motion, scans must be performed within the time of a breath hold to avoid motion-induced artifacts. Commonly, in these situations, spatial or temporal resolution is compromised to complete the scan within the time of a breath hold. Such reductions often lead to reduced accuracy in flow measurements. Studies have shown that an undersampled projection reconstruction phase contrast (PR PC) method provides higher spatial resolution per unit time than traditional spin-warp encoding techniques [3]. Phantom experiments [4] have shown that the PR PC method can acquire accurate velocity information for a range of velocities within the time required for a typical breath hold. Scans performed on five normal volunteers also demonstrated that the undersampled PR PC method provided average flow measurements that corresponded well with those obtained using the commercially-available cardiac-gated phase contrast imaging sequence (Fourier method) in scan times less than an average breath hold. To further explore the characteristics of the undersampled PR PC method *in vivo*, we evaluated the accuracy of flow measurements obtained in a swine model during a breath hold in comparison with a Fourier-based PC acquisition method.

MATERIALS AND METHODS

Medium-sized pigs (65 – 70 lbs) were surgically implanted with an 8 mm diameter and 2 cm long balloon catheter (Meditech/Boston Scientific, Watertown, MA) in the suprarenal abdominal aorta according to a protocol approved by the Research Animal Resources Center. Scans were performed on a 1.5 T MR scanner (Excite HD, GE Healthcare, Milwaukee, WI) with an eight-element phased array torso coil (GE Healthcare, Milwaukee, WI). Heart rate, blood pressure, and respiration were monitored. Cine phase contrast data were obtained with a previously validated undersampled projection reconstruction (PR PC) technique [4] with the following parameters: TR/TE = 10.5/3.6 ms, RBW = ± 31.25 kHz, FOV = 20-32 cm, slice thickness = 5 mm, and frequency encoding samples = 256. Scans were performed during suspended respiration with 32 projections and 1 view per segment (vps) at locations orthogonal to the infrarenal aorta and left and right renal arteries. Scans were acquired with the balloon catheter deflated and then inflated to 0.75 and 1.5 atm, which provided three flow rates in the aorta and renal arteries. All scans were repeated with a commercially-available Fourier method with TR/TE = 6.8/3.4 ms, 2 vps, 128 phase encoding values, 128 frequency encoding values, and a ½ FOV. Images were analyzed with CV Flow (Medis, Netherlands) and flow measurements were tabulated.

RESULTS AND DISCUSSION

Figure 1 compares aortic flow over the cardiac cycle between the undersampled PR PC method using 32 projections and 1 vps and the commercially-available Fourier method with the balloon catheter inflated to 1.5 atm. The average flow rates in the aorta and left and right renal arteries, as measured in the undersampled PR PC and commercially-available Fourier acquisitions, are summarized in Table 1. A decrease in flow can be seen in each of the vessels as the balloon catheter is inflated to greater pressures. Both the undersampled PR PC and commercially-available Fourier techniques were acquired in 32 heartbeats. In the Fourier acquisition there is a factor of 2 loss in coverage, resulting in spatial aliasing in the phase encoding direction because only a ½ FOV is acquired. In 32-projection PR PC, twice the temporal resolution in the same scan time can be acquired with no loss in spatial resolution. Measurements of renal artery flow using undersampled PR PC are being correlated with an independent reference standard using a 4 mm perivascular ultrasound transit-time flow probe (Transonic, Ithaca, New York) around each renal artery.

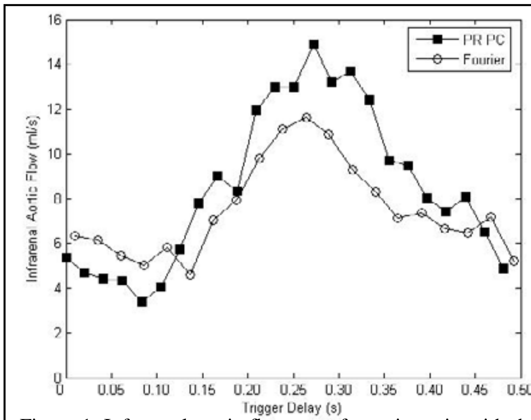

Figure 1. Infrarenal aortic flow waveforms in a pig with the balloon catheter inflated to 1.5 atm. Undersampled PR PC flow data were acquired with 32 projections and 1 vps. The Fourier acquisition data were acquired with 128 phase encoding values, and 2 vps and a ½ FOV.

Table 1. Average flow rates in the aorta and renal arteries of a single pig as measured in undersampled PR PC scans with 1 view per segment (vps), along with the measurements obtained using a cardiac-gated Fourier acquisition with 2 vps. Flow rates are shown with a balloon catheter in the suprarenal abdominal aorta expanded to 0, 0.75, and 1.5 atm.

Balloon	32 proj 1 vps (ml/s)			Fourier 2 vps (ml/s)		
Pressure (atm)	aorta	rt RA	lt RA	aorta	rt RA	lt RA
0.00	10.56	5.01	6.20	10.07	4.10	4.18
0.75	8.46	4.15	5.95	9.23	3.06	4.02
1.50	7.59	2.98	3.11	7.47	2.35	2.80

CONCLUSIONS

Preliminary data have shown that accurate flow measurements can be obtained *in vivo* with a cine phase contrast undersampled projection reconstruction technique in scan times less than an average breath hold. This technique can be used with 32 projections and 1 vps to provide greater temporal resolution and therefore better sampling of the flow waveform throughout the cardiac cycle; alternatively, more samples can be acquired along each projection line to provided better spatial resolution without increasing the scan time. Thus, undersampled PR PC provides the ability to optimize temporal and spatial resolution for acquiring data within the time of a breath hold. Undersampled PC PR may be used to identify the hemodynamic significance of stenoses, which may lead to improved treatment planning for patients with renovascular hypertension.

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REFERENCES

[1] S. Schoenberg *et al.* Radiology 1997; 203: 45-53. [2] C. Tang *et al.* JMRI 1993; 3(2): 377-385. [3] A.V. Barger *et al.* MRM 43(4): 503-9. [4] Wentland *et al.* Procs. of 13th ISMRM. 2005, 1736.