Simultaneous Gating to the Respiratory and Cardiac Cycle with Radial MRI

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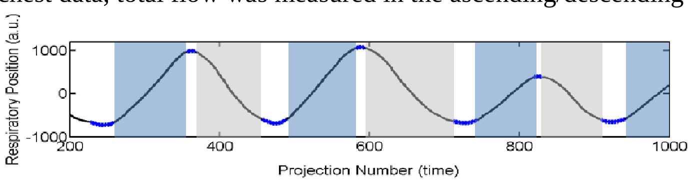
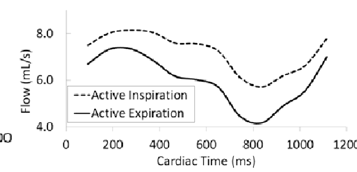
Target audience: Researchers and clinicians interested in simultaneously gating to the cardiac and respiratory cycle.

Purpose: Long confirmed a source of variability in superior and inferior vena cava (SVC, IVC) flow [1] and by extension internal jugular vein (IJV) flow, respiratory effects have been largely ignored in phase-contrast (PC) MR due to the complexity and prolonged scan when gating both respiratory and cardiac cycles. In contrast, venous ultrasound flow measures are conducted during expiration breath-holds for reproducibility. The thin, non-muscular, and pliable walls of veins are vulnerable to thoracic pressure gradients occurring during respiration. These flow changes have previously been shown to affect the SVC [1] using serial angiography and the IVC using MR [2], but have not been extended to measurements in other vascular territories and are ignored in current clinical MRI. Here we propose a method to retrospectively gate to the cardiac and respiratory cycle for quantitative flow measurements with a radial acquisition. In vivo results from pilot studies in the neck and chest are presented.

Methods: Both 2D and 3D [3,4] radial phase-contrast scans of the neck (2D: n = 6, 3D: n = 1) and chest (3D: n = 10) were performed in both the neck and chest in healthy volunteers. 2D radial neck scan parameters performed at the level of the carotid bulb: FOV = 22 x 22 cm, number of projections ≈ 10000, 256 points per projection - .86 x .86 mm^2 in-plane resolution, slice thickness = 5 mm, temporal resolution = 12 or 16 cardiac frames (see below), scan time = 3 min, TR/TE = 8.2/4.9 ms, α = 15°, receiver bandwidth = ± 125 kHz, VENC = 70 cm/s. The 3D neck sequence: FOV = $(18\ cm)^3$, number of projections ≈ 40000, 0.7 mm acquired isotropic resolution, scan time = 17 min, TR/TE = 6.4/2.2 ms, α = 15°, receiver bandwidth = ± 167 kHz, VENC (optimized with 2D Cartesian PC) = 50 cm/s. A larger FOV and higher VENC were used for chest scans. Respiratory waveforms were recorded via system bellows and the position in the cardiac cycle via ECG. Figure 1 (left) demonstrates one possible sorting pattern with active inspiration and expiration phases, separated from transition plateaus, by discarding extremes and performing a gradient operation on the respiratory waveform. The acquired radial projections are sorted into inspiration and expiration phases in an offline reconstruction. Cardiac cine datasets are generated for each phase based on their time stamp within the cardiac cycle. This retrospective sorting is possible because each readout traverses through the center of k-space line and the pseudo-random projection angle scheme results in minimal undersampling artefact. As a result, the phase contrast data is effectively gated to both the cardiac and respiratory waveform. For the IJV data, peak and total flow measurements were computed for both the right and left IJV. For chest data, total flow was measured in the ascending/descending aorta, main pulmonary artery, IVC and SVC.





Percent Change Averaged over all Volunteers

	RtIJV	LtIJV	Summed	SVC	IVC
Peak Flow	11.0*	13.2**	11.9**	10.9	21.3**
Total Flow	13.1*	13.3**	11.5**	13.3*	16.4**

* p < 0.05, ** 0.001 ≤ p < 0.01

Figure 1. Left: Example partitioning of projections into active respiratory phases (inspiration - blue shading, expiration - gray shading) using a gradient operation on the bellows signal. Plateau points are discarded (blue points). Middle: Using these respiratory phases, a time-resolved cardiac reconstruction is performed for measurement of blood flow. Right: when averaged over all volunteers in all venous structures, significantly higher peak and total flow are observed during inspiration.

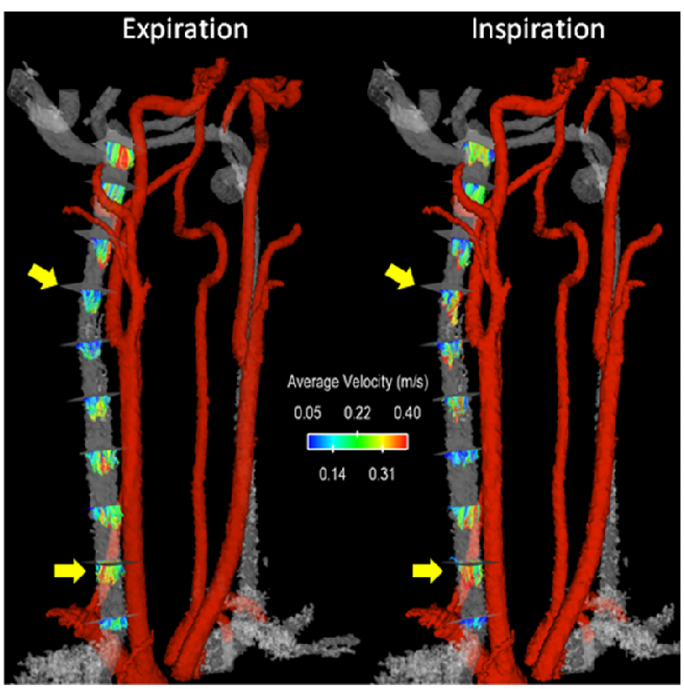


Figure 2. 3D whole vessel renderings (veins in gray, arteries in red) and cardiac time-averaged velocity vector plots. During active inspiration, velocity vectors increase in magnitude compared with the same cut planes in expiration (yellow arrows).

Results & Discussion: Fig. 1 (middle) shows representative volunteer IJV 2D PC MR blood flow waveforms between active inspiration and expiration, with a shifting of the waveform to higher values for active inspiration. For all venous structures measured, this percent change was significantly higher (Fig. 1 right) during active inspiration for both peak and total (cardiac) flow. Meanwhile, differences in the arteries proved to be insignificant (not shown here). This indicates that despite the smaller vessel size caused by negative pressure compressing veins, the resulting increase in velocity eclipses the effect of constriction to produce larger flow values as the flow is the product of the mean velocity and vessel area. Figure 2 displays 3D velocity vector plots along the length of the IJV in the neck. Clear differences are again observed between active inspiration and active inspiration. Using a 3D acquisition allows for interrogation of the entire IJV in a single, free-breathing exam.

Conclusion: The double-gating free-breathing acquisition and reconstruction technique presented here demonstrates the flexibility radial acquisitions offer for retrospective sorting of data. This pilot study exhibits the viability of a novel 2D and 3D reconstruction algorithm that allows for simultaneous retrospective cardiac and respiratory gating.

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References: 1. Nordenstrom and Norhagen, *Am J Roentgenol* 1965. 2. Thompson and McVeigh, *MRM* 2006. 3. Gu et al, *AJNR* 2005. 4. Johnson et al, *MRM* 2008.