Respiratory-Resolved Flow Effects in the Chest Assessed with Double-gated 4D flow MRI

Eric Mathew Schrauben[1], Ashley Anderson[2], Kevin Johnson[1], and Oliver Wieben[1,3]

[1]Medical Physics, University of Wisconsin - Madison, Madison, Wisconsin, United States, [2]Medical Physics, University of Wisconsin - Madison, Madison, WI, United States, [3]Radiology, University of Wisconsin - Madison, Madison, WI, United States

Background: Typical cardiovascular MRI exams compensate for respiratory motion through the use of breathholds, during inspiration or expiration, for shorter exams. Prospective gating by bellows or navigator signals is used for longer acquisitions or uncooperative patients. These approaches, while essential for reproducible and robust imaging, limit data acquisition to the quiescent phase of respiration [1]. Potential variations in cardiovascular function due to the breathing cycle are usually ignored, though the motion of the chest wall and resulting intrathoracic pressure changes have been shown to significantly affect parameters such as flow in the great vessels [2]. Here we investigate respiratory effects on the net flow and cardiac flow waveforms on arteries and veins in the chest. This is accomplished with a recently introduced retrospectively double-gated (cardiac and respiratory) reconstruction scheme [3], based on a 4D MR flow radially undersampled sequence (PC VIPR [4, 5]).

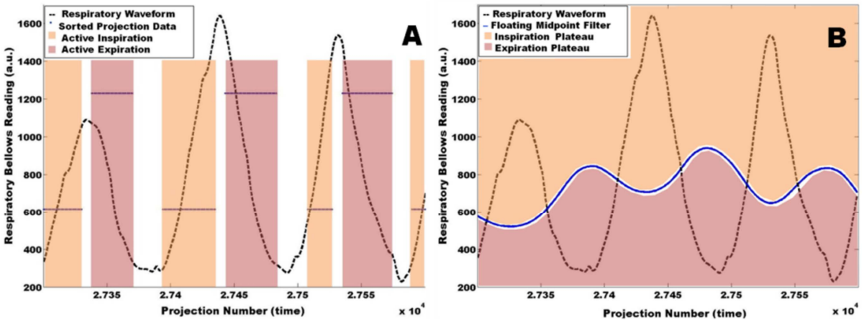

Fig. 1 Example sorting of projections from the respiratory waveform illustrate arbitrary retrospective sorting: active inspiration and expiration excluding transition plateaus (A) and plateaus using a moving average filter (B).

Methods: Ten healthy volunteers were imaged on a 3T system (Discovery MR750, GE Healthcare) using PC VIPR prescribed over a large chest imaging volume (FOV = 32 x 32 x 32 cm^3, time resolution = 65 ms, TR/TE = 5.5/2.3 ms, α = 15°, Venc (optimized by 2D PC breathhold scan) = 110-150 cm/s, projection number ≈ 40000, 15 cardiac time frames). Radial projections allow for flexible sorting retrospectively due to pseudo-random sampling and the inherent oversampling of the center of k-space. Our traditional retrospective ECG gating was expanded to incorporate additional sorting of the data into respiratory phases based on the bellows signal (Fig. 1) to provide cardiac series of flow data for separate respiratory phases. While several schemes are possible, here we investigated four respiratory phases: active inspiration and expiration (Fig 1A), and the inspiration and expiration plateaus (Fig 1B), all of which were reconstructed from a single acquisition in offline processing. Cardiac timeframes are reconstructed using temporal view sharing to maintain short scan times while improving image quality by reducing undersampling artifacts [6]. This process results in a dual-retrospectively-gated PC MR exam. Data were continuously acquired during free breathing, in contrast to prospectively gated chest PC MR exams that discard 50-60% of data. Thus total scan time was unchanged. Flow analysis was performed in the ascending and descending aorta (AAo, DAo) at the level of the pulmonary artery, the superior and inferior vena cava (SVC, IVC), and the pulmonary artery (PA) (Fig. 2a). The expiration plateau phase (Fig. 1b, lower), representing the lower 50% of the respiratory waveform captured by prospective bellows gating, was used as the reference standard by which other phases were compared. Percent differences from the expiration plateau of total flow over the cardiac cycle for each phase were calculated.

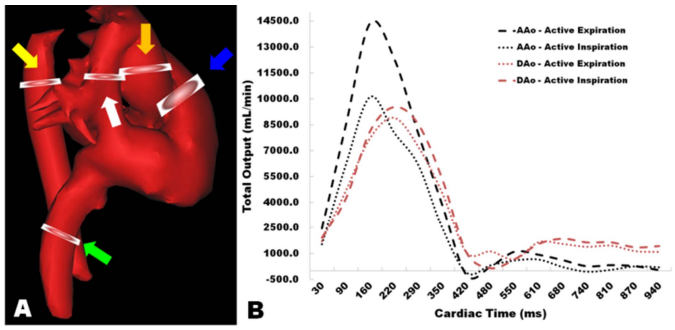

Fig. 2 Example locations of measurement planes during active inspiration (A, arrows: orange - AAo, yellow – DAo, blue – PA, white – SVC, green – IVC). Blood flow waveforms (B) exemplify differences seen in varied phases and vessels.

Average Total Cardiac Flow Percent Changes from Expiration Plateau

	AAO	DAO	PA	SVC	IVC
	%	%	%	%	%
Inspiration Plateau	12.8	-7.1	14.8	14.8**	11.7
Active Inspiration	-26.6*	-19.2*	-17.3*	-0.7	-1.8
Active Expiration	-12.1	-12.4*	-17.9*	6.0	14.9

* moderately significance (0.01 ≤ p < 0.05)
** strong significance (0.001 ≤ p < 0.01)

Table 1. Summarized results across phases and cardiac vessels.

Results and Discussion: Figure 2a demonstrates retrospective selection of measurement plane from a 3D reconstructed anatomy allowing for easy selection of planes perpendicular to the expected direction of flow. Figure 2b exhibits flow differences throughout the cardiac cycle between active phases within the AAo and Dao for one representative subject. Respiratory motion causes waveform phasic differences in the form of peak delays. Table 1 displays percent changes from the expiration plateau measurements averaged over the cardiac waveform and over all volunteers for each of the 5 vessels. Large percent differences are observed in most cases, with consistently reduced flow (negative, 7-30%) during active inspiration compared to the expiration plateau. The most significant changes occur in the SVC between plateaus. Pressure gradients occurring in the chest during respiration and the pliable and varied nature of venous structures create the largest respiratory induced changes in the veins.

Conclusions: This pilot study shows the varied and significant blood flow changes within the great vessels that result from respiratory motion. It also demonstrates the viability of a novel 4D free-breathing acquisition and reconstruction that allows for simultaneous retrospective cardiac and respiratory gating.

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References: **1.** TS Sachs et al. *MRM* 1994. **2.** Thompson, McVeigh. *MRM* 2006 **3.** EM Schrauben et al. 20th ISMRM Proceedings, 2012 **4.** Gu et al. *AJNR* 2008. **5.** KM Johnson et al. *JMRI* 2008 **6.** J. Liu et al. *IEEE TMI* 2006.