Method for Investigating Respiratory Influence on Flow with Radial Trajectories

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Introduction: It is long documented that pressure changes in the chest due to the respiratory cycle have an impact on flow, particularly in venous return [1] and cerebrospinal fluid (CSF) flow [2]. However, these effects are typically ignored in phase contrast (PC) MR flow measurements since they have no effect on the arteries more common in clinical flow imaging. Recently, there has been renewed interest in cranial venous imaging, especially in the context of the CCSVI hypothesis [3], as well as a continued interest in improved CSF flow imaging. We developed a novel approach to allow for flow sensitive acquisitions with cardiac and respiratory gating. This study describes the flexible approach, and evaluates effects of active respiration on cardiac-gated 2D PC MR flow measurements using radial trajectories. Several methods for dividing data into physiologically significant respiratory phases are proposed.

Methods: Radial trajectories with pseudo-random projection ordering result in a relatively even distribution of projections in k-space. Such a radial view ordering allows for reconstruction from arbitrary subsets of data with minimal structured noise from undersampling, a property that is used here to enable retrospective gating to the cardiac and the respiratory cycle. Respiratory position and position within the cardiac cycle are recorded throughout the acquisition. The projections can be grouped into respiratory phases based on different schemes as shown in Figure 1, the most simple being 2 phases: inspiratory and expiratory plateaus. Within each respiratory phase, the projections are grouped into equally spaced cardiac phases.

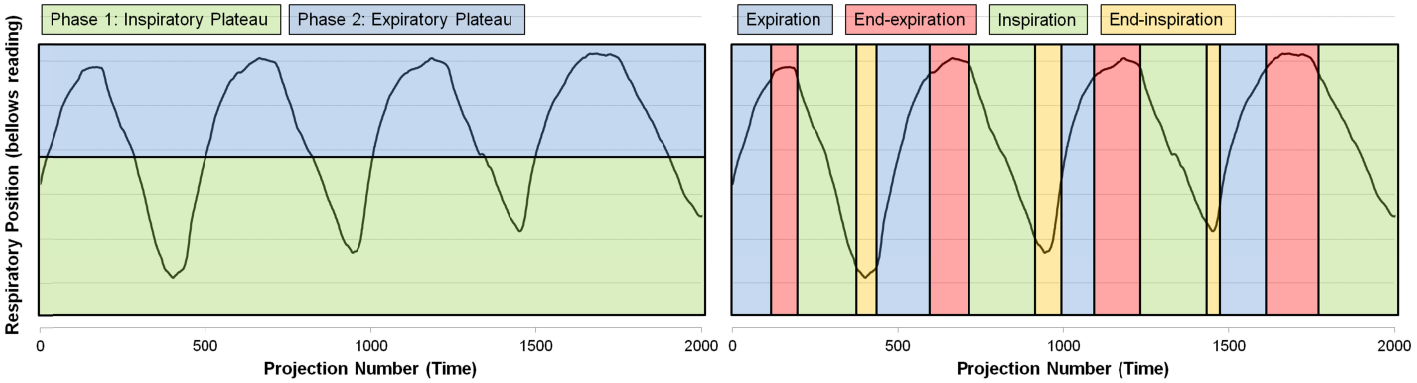

Figure 1 – Recorded respiratory bellows waveform for four breaths showing two methods for determination of respiratory phases. Left: projections divided based on the median respiratory position. Each phase contains approximately the same number of projections. This method provides results similar to a 50% efficiency respiratory-gated acquisition, but with 2 phases. Right: projections divided based on the respiratory signal derivative to provide phases during maximum abdominal pressure gradients – active inspiration and expiration. Respiratory motion may be an issue with this method.

The scheme was tested on CSF flow measurements from three healthy volunteers in accordance with an IRB protocol. Respiratory position was recorded using a bellows; cardiac triggers were recorded with a pulse oximeter on the index finger. Images were acquired using a clinical 3T scanner (GE Healthcare Discovery^{TM} MR 750; Waukesha, WI) with a 2D radial PC sequence [4]. Axial slices were prescribed between the C2 and C3 vertebrae: TR/TE = 9.4/6.1 ms, tip = 5°, resolution = 0.9x0.9x5 mm, and V_{enc} = 8 cm/s. Data were acquired during free breathing for 2:32 min, for 8000 total projections. Cardiac-gated image series were reconstructed for each respiratory phase using a tornado filter, a temporal data filter similar to view-sharing in Cartesian acquisitions [5].

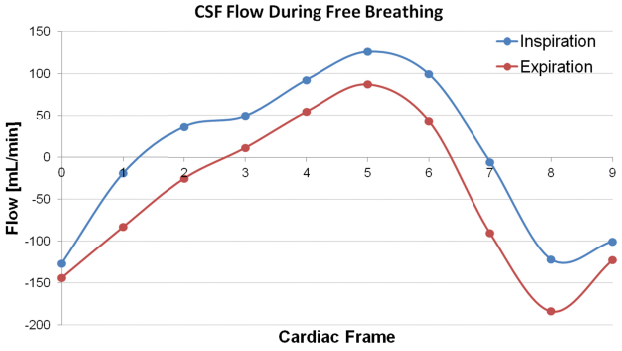

Figure 2 – CSF flow through the spinal canal during free breathing. The respiratory effect on the flow waveform and total flow is clearly depicted.

Results: Figure 2 shows representative flow waveforms for CSF flow in the spinal canal. Since there is no respiratory motion in the neck, respiratory phases were determined based on the first derivative of the respiratory waveform, as shown on the right in Figure 1. Waveforms for inspiration and expiration phases are shown.

Conclusions: We implemented a method for retrospective double-gating radial PC flow acquisitions to evaluate the effects of active respiration on flow. The technique was used to demonstrate the influence of the respiratory cycle on CSF flow in the foramen magnum during free breathing. Though these effects are likely negligible in the higher-pressure arterial system, we believe that the influence of the respiratory cycle cannot be neglected in CSF flow measurements and venous flow assessment in the neck. Finally, this method may have applications beyond flow imaging, such as lung function evaluation or respiratory motion compensation.

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References: [1] Nordenström *et al*, *AJR* 95(3), 1965. [2] O'Connell, *Brain* 1943. [3] Zamboni *et al*, JNNP 80, 2009. [4] Barger, *MRM* 43(4), 2000. [5] Liu *et al*, *IEEE TMI* 25(2), 2006.