Feasibility Study of a Double Self-gating Technique for Free-breathing Time-resolved 3D Imaging

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Introduction:

1D projection-based respiratory self-gating (RSG) [1] and cardiac self-gating (CSG) [2] were recently proposed for free-breathing coronary MRA and 2D cardiac cine imaging, respectively. This work is a general feasibility investigation of a new double self-gating (DSG = RSG+CSG) scheme with 3D projection (PR) sampling for free-breathing time-resolved 3D (4D) imaging.

Theory and Methods:

In the traditional RSG method, a superior-inferior (SI) 1D projection was acquired and its centre of mass (COM) was calculated to gate the following segmented data acquisition. However, due to the static anterior chest wall signal superimposed into the SI projection, the accuracy of the COM-based gating signal is significantly lowered. Regional saturation pulses can suppress the undesired static signal but are incompatible with cine data acquisition. To alleviate this problem in time-resolved imaging, a new 2-projection RSG method (acquisition of a SI projection and a SI projection with anterior-posterior (AP) dephasing) was used. The magnitude of the averaged SI projection is:

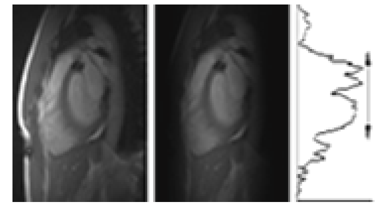

Figure 1. 2-projection method for suppression of chest wall signal

$$\left|\overline{p}(x)\right| = \left|\int \left(\rho(x,y) + \rho(x,y)\cdot e^{j\lambda\cdot y}\right)/2\cdot dy\right| = \int \rho(x,y)\cdot\cos(\lambda\cdot y/2)\,dy$$

where x and y is the SI and AP direction, respectively, λ represents the degree of AP dephasing. Thus, $|\overline{p}(x)|$ (RSG projection) is equivalent to the magnitude of an SI projection of the imaging slice with a sinusoidal amplitude mask applied along AP direction. With the proper AP dephasing gradient moment, an amplitude mask with $\lambda y/2=0$ at the centre of the heart and $\lambda y/2=\pi/2$ at anterior chest wall can be generated, as shown in Figure 1. Therefore, signal of the RSG projection primarily comes from the heart (mid-abdomen) such that positional shift of the RSG projection profile more accurately depicts the breathing-induced SI displacement of the heart.

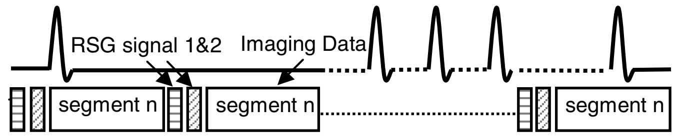

Figure 2. A section of the 4D DSG sequence

For these studies a new sequence was implemented based on a TrueFISP cine sequence using a 3D radial k-space trajectory providing isotropic spatial resolution and a good compromise between imaging time and image quality [3]. As shown in figure 2, a RSG unit (1st: SI projection, 2nd: SI projection with AP dephasing) was acquired before each segmented data acquisition and each radial k-space segment was repeatedly acquired for one respiratory cycle (4 seconds) approximately. Data were collected using a Siemens 1.5T Sonata system and processed offline using Matlab. The image reconstruction procedure consisted of two majors steps: CSG and RSG. First, echo peak amplitude of each odd-numbered radial k-space line was extracted and low-pass filtered to yield a CSG signal. Peak detection was used to derive a synchronization signal for retrospective cardiac gating. A view-sharing factor-of-2 was used to double temporal resolution [2]. Next, the RSG signal, representing the SI displacement of the heart due to breathing during acquisition of each RSG unit was derived from the RSG projections using phase-dependent template matching. Then, the most consistent heart position was identified as the gating position and all radial k-space lines with a displacement within a threshold were motion-compensated and used for image reconstruction. Basic imaging parameters of the volunteer scans were: sagittal orientation, readout points: 256, view number: 6000, resolution: 1.2×1.2×1.2 mm^3, flip angle: 60º, TR/TE: 3.7/1.85 ms, lines/segment: 28.

Results:

Figure 3 shows a random segment of the derived RSG signal (bold solid line) plotted on top of the corresponding RSG projections. The region of the heart in the RSG projection has an outstanding displacement pattern consisting of a relatively fast component induced by cardiac motion and a relatively slow component induced by respiratory motion. The RSG signal clearly approximates the breathing-induced positional shift of the RSG projection. Also, by comparing the CSG signal (dotted line) and the ECG triggers (vertical lines) simultaneously recorded, good synchronization is observed.

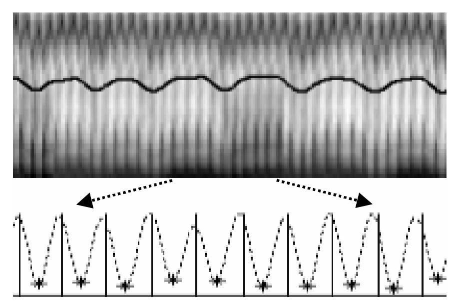

Figure 3. RSG projections vs. RSG signal (up), ECG triggering vs. CSG (down)

Discussion:

The proposed 2-projection method is compatible with time-resolved data acquisition and enables more accurate heart displacement measurement and respiratory motion compensation. Our preliminary results showed the feasibility of implementing this DSG scheme for suppressing respiratory and cardiac motion artefacts in free-breathing time-resolved imaging applications, including whole-heart cardiac cine imaging, time-resolved coronary MRA and phase-contrast velocity-quantification imaging. Further work is necessary to verify the effectiveness of this technique in the clinical setting.

References: [1] Stehning C, et al, MRM 2005;54:476; [2] Larson AC, et al, MRM 2004;51:93; [3] Barger AV, et al, MRM 2002;48:297