Accuracy Evaluation of a Two-projection Respiratory Self-gating Technique for Coronary MRA

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Introduction:

Suppression of respiratory motion artifacts remains a major challenge in coronary MRA (CMRA). Diaphragmatic navigator (NAV) has been the most commonly used technique in free-breathing CMRA. However, due to its indirect measurement of heart position, this method is susceptible to hysteretic problems. Furthermore, because acquisition of NAV echo disturbs steady-state signal, NAV is incompatible with 4D imaging. Instead, a newly proposed respiratory self-gating (RSG) method based on acquisition of two superior-inferior (SI) projections provides a potential approach to directly measure heart motion [1]. Its capability in 4D CMRA has been shown as well [1,2]. This work aimed to quantitatively study the accuracy of this new technique in deriving respiratory motion of the heart and preliminarily investigate its performance in free-breathing whole-heart CMRA.

Materials and Methods:

A new sequence was implemented for the accuracy evaluation purpose. As shown in Fig. 1, in each cardiac cycle, a 2D real-time (2DRT) image together with a NAV echo and two RSG k-space lines was acquired. The 2DRT image was measured at mid-diastole in a sagittal slice across the left ventricle. GRAPPA was used to reduce acquisition time. Sinusoidal dummy pulses were applied before the 2DRT data acquisition to establish steady state signal. A NAV echo was measured right before the dummy pulses. Two RSG lines were measured between the dummy pulses and the 2DRT data acquisition. In the two RSG signals, a k-space center line along the SI direction was acquired. In acquisition of the 2nd RSG line, a properly-designed anterior-posterior dephasing was applied so that summation of these two RSG lines provided effective suppression of chest wall signal and an SI RSG projection with its signal primarily from the heart was obtained [1]. Respiratory motion of the heart was estimated from the NAV echoes using a correlation factor of 0.6 and also derived directly from the RSG projections and merely the 1st SI projections using a profile matching method [2]. Translational motion of the heart derived from the 2DRT images was used as the standard to evaluate the accuracy of the above three respiratory gating methods. Signals and a 2DRT image in the same cardiac cycle at near-end-expiration were selected as the references to derive all the above motion signals so as to make the baseline heart position uniform. Next, the absolute error of the NAV and RSG motion signals within a gradually incrementing acceptance window (AW) was calculated to study the relationship of the accuracy of motion derivation with AW selection.

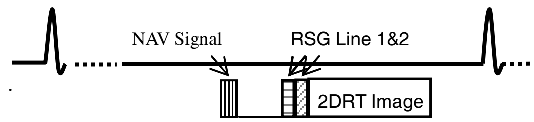

Fig 1. Acquisition scheme of the NAV, RSG, 2DRT sequence

Studies were conducted on 9 healthy volunteers using a 1.5T Siemens Avanto system. Sequence parameters included: 320×200 mm^2 FOV; 10 mm slice thickness; 256×96 matrix; TE/TR = 1.6/3.2 ms; 75º flip angle; 9 dummy pulses; acceleration factor of 3; 24 reference lines.

This 2-projection RSG technique was implemented in a segmented SSFP sequence with NAV gating and ECG triggering. The two RSG lines were acquired prior to each segmented data acquisition. Free-breathing whole-heart CMRA was conducted on healthy volunteers. Data acquisition was gated using NAV echoes, and images were reconstructed off-line with and without compensating the respiratory motion detected by the RSG method. Imaging parameters were: 320×260 mm^2 FOV; 96 partitions interpolated from 48; 1.5 mm slice thickness; 320×240 matrix; 40 lines/segment; ±3 mm NAV acceptance window; 75º flip angle; TE/TR = 1.87/3.74 ms.

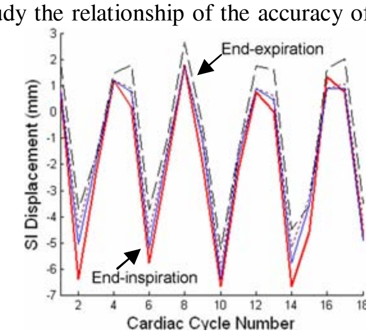

Fig 2. Motion signals derived from real-time images (solid bold), SI RSG projections (solid thin), only 1st SI projections (dotted) and NAV (dashed)

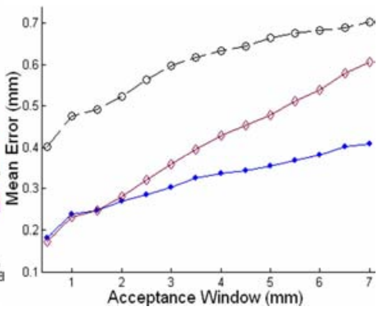

Fig 3. Mean errors of 2-projection RSG (solid), 1-projection RSG (dotted) and NAV (dashed) with different AW values

Results:

Fig. 2 shows a section of the SI respiratory motion signals derived from the 2DRT images and using the three candidate respiratory gating methods. Clearly, the motion signal derived using the 2-projection RSG method is the most consistent with the reference motion, while using the 1-projection RSG method the accuracy is lowered and the NAV motion signal shows substantially larger deviation even at end-expiration. As shown in Fig. 3, for all the three methods, the mean error increases with larger AW. Among them, the 2-projection RSG method achieves the highest accuracy ($p<0.05$). In comparison, the mean error of the NAV method is always significant larger than that of the 2-projection RSG method ($p<0.05$). The accuracy of the 1-projection RSG method is in-between and the overlapping effects of the chest wall signal introduce larger errors as the AW increases. Its accuracy is significantly lower than 2-projection RSG with an AW≥5.5mm ($p<0.05$).

In whole-heart CMRA studies, there was a close overall correlation between the NAV motion signal and the RSG motion signals. However, in some subjects, there were clear deviations between the two signals, possibly reflecting the variations in motion patterns between the heart and diaphragm. The images at a sagittal slice of a volunteer reconstructed with and without RSG motion compensation are displayed in Fig 4.a and 4.b, respectively. As indicated by the two arrows, the cross-sections of the two coronary artery branches are blurred or even undistinguishable in Fig.4.a, while the motion artifacts are greatly reduced in Fig 4.b.

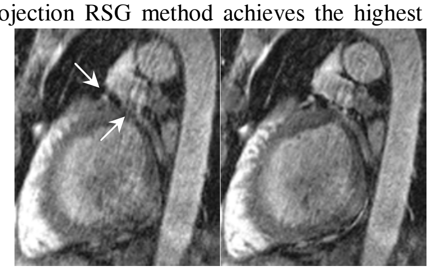

Fig.4. Images reconstructed a) without and b) with RSG motion compensation. The arrows indicate the blurred regions.

Conclusion:

With direct measurement of heart motion immediately prior to the imaging data acquisition, more accurate respiratory gating and motion compensation can be achieved with the RSG methods than diaphragm NAV. By acquiring a 2nd projection for suppression of chest wall signal, the accuracy can be further increased. In conclusion, the 2-projection RSG method is a promising and robust technique for 3D and 4D high-definition free-breathing whole-heart CMRA.

Reference: [1]. Lai P, et al. ISMRM, 2006:p1972; [2] Lai P, et al. ISMRM, 2006:p364