Prospective Correction of Affine Respiratory Motion for Non-Cartesian Coronary MRI

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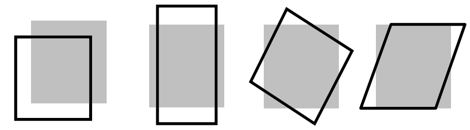
Introduction:

Free-breathing navigator-gated coronary MRA in combination with slice-tracking has made substantial advances in the recent years [1]. Nevertheless, the typically chosen gating window of approx. 5mm may lead to a considerable increase in scan time, especially in case of irregulary or drifting breathing patterns. Recently, a patient-specific, navigator-driven prospective motion correction approach based on affine transformations was introduced for cartesian scanning schemes providing the potential of using larger gating windows without compromising image quality [2]. In the present work, this technique has been extended to spiral and radial imaging techniques and implemented on a clinical scanner. Phantom experiments test the basic technical performance and in-vivo experiments demonstrate the potential of the technique for coronary MRA.

Theory:

In general, motion spoils the k-space formalism, which makes it difficult to solve the imaging equation in MRI, even if the distortions are known exactly. We show that motion described by affine transformations can be corrected prospectively for arbitrary imaging sequences during signal excitation and reception as well by appropriate tuning of the sequence parameters: insertion of formulae 2-4 (Fig.1) into the *Bloch* equations formally removes the time variance of the position vector (formula 1). Thus, the patient-specific prospective correction of affine respiratory motion described in [2] can be extended to non-cartesian imaging sequences.



$$\mathbf{r}(t) = \mathbf{A}(t)\cdot(\mathbf{r}' + \mathbf{r}_0(t)) \qquad (1)$$

$$\mathbf{G}(t) = {}^{t}\mathbf{A}^{-1}(t)\cdot\mathbf{G}'(t) \qquad (2)$$

$$B_1(t) = B'_1(t)\cdot\exp\left(-i\gamma\int_0^t \mathbf{G}'(\tau)\cdot\mathbf{r}_0(\tau)\,d\tau\right) \qquad (3)$$

$$M_{xy}(t) = M'_{xy}(t)\cdot\exp\left(-i\gamma\int_0^t \mathbf{G}'(\tau)\cdot\mathbf{r}_0(\tau)\,d\tau\right) \qquad (4)$$

Figure 1: affine motion (translations, scalings, rotations and shearings, top row and 1) can be precompensated by adapting gradient, transmitter and receiver waveforms (2-4).

Methods:

The new technique has been fully integrated on a clinical scanner platform (Philips Gyroscan INTERA) as a research patch called BACCHUS (Breathing Artifact Correction for Cardiac High-Resolution Imaging Using Patient-Specific Motion Models). The approach consists of a calibration scan, where the respiratory motion model is adapted to the specific patient using image registration techniques, and the actual diagnostic scan, where the calibrated model is used for prospective motion correction. The details of the calibration scan are given in [2]. For practical reasons, the prospective correction is limited to inter-view-motion in the present implementation. Thus, the correction of the translational motion component results in simple frequency- and phase offsets of the excitation pulse and the receiver signal demodulation. Spiral imaging is an exception, because the more complex demodulation of the acquired signal is performed during image reconstruction. The non-translational motion components are corrected by linear transformation of the gradient coordinate system without regarding sequence-specific details. Thus, the technique works for cartesian as well as radial and spiral sequences. Experiments have been performed on phantoms and on 5 healthy volunteers at 1.5 T. The basic technical performance of the technique was evaluated in experiments using a cylindrical quality phantom, which was eccentrically rotated to mimic motion (Fig.2). In the volunteer experiments, the RCA was imaged without respiratory gating. Navigators through diaphragm, chest wall and heart were used to steer the motion model [2].

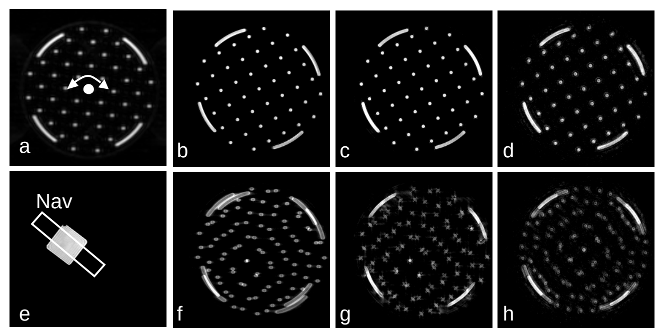


Figure 2: Phantom experiments: The calibration scan determined the relation between actual motion (a) and navigator, which was placed in a different section of the phantom (e). The rotation of the phantom resulted in translation and rotation with respect to the gradient centre, which was corrected prospectively in the subsequent scans (b: cartesian, c: radial, d: spiral). Corresponding experiments without motion correction led to sequence-specific artefacts (f-h).

Results:

In the phantom experiments (Fig.2) no significant motion artefacts were noticed for any of the applied sequences in case of prospective motion correction. Without correction typical artefacts like ghosting, streaking and spiral blurring were found. In the volunteer experiments the RCA was well resolved up to the distal parts in most cases (Fig.3). In case of radial imaging slight streaking artefacts originating from regions outside the heart arose, where the model calibration did not hold.

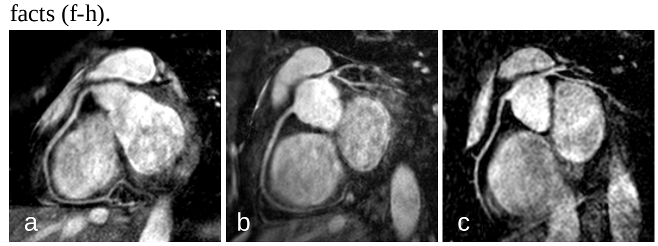


Figure 3: Selected volunteer experiments: The RCA was imaged without respiratory gating using patient specific prospective affine motion correction. ECG-triggered cartesian (a,b) and radial (c) balanced 3D-FFE sequences were used (flip angle = 110°, FOV = 270 mm, 10 slices, 1×1×3 mm³ resolution, TE/TR=2/4 ms). The scan time was about 2 minutes in all cases.

Discussion and Conclusion:

This work demonstrates that patient-specific correction of affine respiratory motion is feasible on a clinical scanner despite the complexity of the approach. Furthermore, it has been shown that this technique is technically feasible even for advanced non-cartesian imaging trajectories. Thus, new degrees of freedom have been introduced for advanced motion correction. The initial in-vivo experiments on coronary MRA indicate that the approach may allow a larger gating window without compromising image quality, which may be used for scan time reduction. Furthermore, it may be expected that this approach improves image quality for a given gating window. Since the motion model is adapted to individual motion, an even greater effect may be expected for patients, which show a wider variation of motion patterns than young healthy volunteers. However, this has to be proven in a clinical evaluation.

References:

1. Kim et al. N Engl J Med. 2001 Dec 27;345(26):1863-9.
2. Manke et al. Magn Reson Med. 2003 Jul;50(1):122-31.