ECG-triggered, Free Breathing Coronary MRA Using Radial Balanced FFE With Intra-RR Motion Correction

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Introduction

For conventional ECG-triggered coronary MRA, cardiac motion limits the practical length of the acquisition window within the cardiac cycle. The low scan efficiency results in a significantly prolonged scanning time. To overcome this drawback, an ECG-triggered, free breathing balanced FFE sequence comprising a segmented acquisition with a prolonged sampling window in diastole is investigated in this study. Scan efficiency is increased by acquiring multiple segments in each heartbeat, while motion artifacts are reduced by maintaining a short temporal segment length. To cope with inter-view motion between the segments, affine motion correction was employed after image reconstruction. Finally, a high-resolution image was formed by combining the images from all segments. The increased scan efficiency can be used to decrease the scanning time, improve signal-to-noise, or achieve a trade-off of both. Alternatively, the motion information obtained from the diastolic time series can be used for prospective cardiac motion correction as a future refinement.

Methods

Experiments were performed on seven healthy volunteers (age range 27-47 years, 7M). The examinations were performed on a whole body 1.5T MR system (Gyroscan INTERA, Philips Medical Systems) equipped with a five-element cardiac synergy receive coil. The image acquisition was ECG-triggered with an appropriate trigger delay T_D (1) and respiratory-gated (navigator on right hemi-diaphragm, gating window 5mm) (2). Respiratory navigator, regional saturation (REST) slab and fat saturation (SPIR) were applied prior to sampling (2). The following sequence parameters were used: balanced FFE, $\alpha=60°$, $T_R=4.6$ms, FOV 330x330x30mm^3, measured voxel size 1.12 x 1.12 x 3.00mm^3, reconstructed voxel size 0.7 x 0.7 x 1.5mm^3, cardiac acquisition window $T_{AQ}=240$ms. Segmented 3D radial stack-of-stars sampling (Fig.1) comprising 4 temporal segments (segment length $T_{SEG}=60$ms) was used to reduce motion artifacts. The individual segments were radially undersampled by a factor of two to halve the total scanning time, but interleaved with an angular increment to obtain a fully sampled data set (Fig. 1). To eliminate signal from epicardial fat, separate water and fat images were reconstructed from the complex image data using a phase detection technique (3). Fat-only images of the epicardial fat (Fig. 2) were used to track the motion of the embedded coronary arteries using an affine registration algorithm (fat navigator). After motion correction, a final image was formed by summing the data from all segments (cf. 4, 5). For comparison, a conventional radial protocol was applied ($T_{AQ}=60$ms, 1 segment, no radial undersampling, Fig. 3a). For final presentation, the 3D data sets were reformatted and the signal-to-noise ratio (SNR) was measured using a software tool (6).

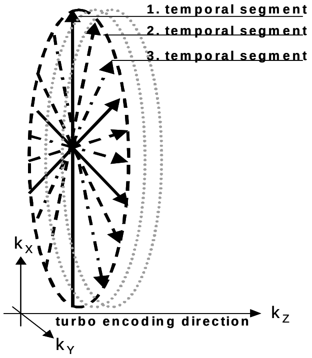

Fig 1. Scheme of segmented radial acquisition sequence

Results and Discussion

All examinations were completed successfully, and the proximal parts of the RCA and LAD could be visualized in all volunteers. The fat-only images of the epicardial fat are illustrated in Fig. 2. The motion information obtained from the fat navigator (white arrows) was used to correct inter-view motion between temporal segments. The images of all four segments were combined after affine correction. One reformatted RCA image of a healthy volunteer obtained using the segmented acquisition is shown in Fig. 3b. Compared with the conventional protocol (Fig. 3a), scanning time was halved while SNR was increased by 15%. The SNR increase is below the theoretical factor of $\sqrt{2}$, which is a result of imperfections of the affine motion registration in this preliminary study. However, small distal parts of the RCA (black arrow) could be reconstructed, which have not been visible using the conventional protocol due to an insufficient SNR. Furthermore, a strong image contrast was achieved due to the robust build-up of the steady state during the prolonged sampling window.

Conclusion

The basic feasibility of affine intra-RR motion correction for increased scan efficiency in ECG-triggered, free breathing coronary MRA has been shown. The applied segmented radial acquisition yielded a low sensitivity for intra-view motion within the frames. Furthermore, reduced undersampling artifacts allow higher undersampling and a further decrease in scanning time as a future refinement. Deriving an intra-RR motion model for the RCA and LAD from the information obtained from the epicardial fat navigator in a greater number of volunteers could be an interesting next step to facilitate prospective intra-RR motion correction during sampling.

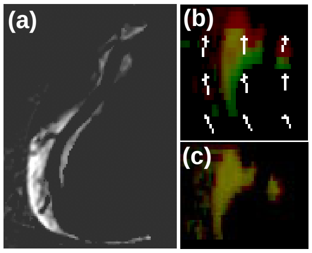

Fig 2. Epicardial fat navigator (RCA) for one temporal segment (a), transversal view of fat navigator before (b) and after affine correction (c) for two exemplary temporal segments (red/green). White arrows indicate displacement fields.

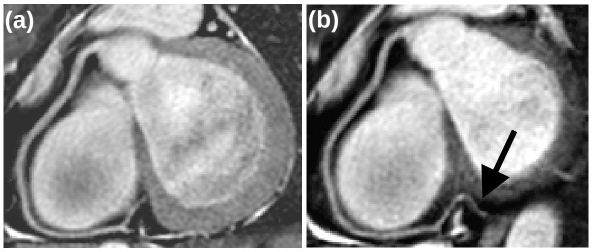

Fig 3 (a) Reformatted RCA image of a healthy volunteer obtained with a conventional protocol

(b) RCA image obtained with the segmented acquisition and halved scanning time

References

(1) Kim WY et al. Impact of bulk cardiac motion on right coronary MRA and vessel wall imaging. JMRI 14 (2001
(2) Stuber M et al. Double-oblique free-breathing high resolution 3D coronary MRA. J Am Coll Cardiol 34 (1999)
(3) Hargreaves BA et al. Fat-suppressed steady state free precession imaging using phase detection, MRM 50 (2003)
(4) Hardy CJ et al. Coronary angiography by real-time MRI with adaptive averaging, MRM 44 (2000)
(5) Graesslin I et al. Non-ECG trig., high res., bal. radial CMRA using FAWCA. Proc. ISMRM 11 (2003)
(6) Etienne A et al. "Soap-Bubble" visualization and quantitative analysis of 3D coronary MRA. MRM 48 (2003)