Respiratory Reordered RIGR for First Pass CMR Perfusion Imaging

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Introduction

The assessment of myocardial perfusion requires accurate quantification of the transmural extent of possible defects. Whilst the analysis of CMR first pass perfusion images is typically performed in 2D slices, it is desirable to determine the full extent of damaged myocardium in 3D. To this end, imaging time must be significantly reduced so that a complete 3D coverage of the left ventricle can be achieved in a relatively short acquisition window. In parallel to the use of rapid imaging sequences, particularly the recent deployment of parallel imaging methods for myocardial perfusion, it is possible to exploit reduced *k*-space reconstruction techniques that utilise the full information content of the *k*-space data [1-3]. Previous work [4] has demonstrated the use of RR-UNFOLD for increasing imaging speed by a factor of 2. With prospective respiratory reordering, the technique has shown great promise in retaining tracer kinetic details in the presence of free-respiratory motion. From detailed numerical analysis, it was apparent that despite the use of continuous sampling of the central *k*-space data, a certain amount of temporal smoothing still remained. To circumvent this problem, we introduce the use of Respiratory Reordered RIGR (RR-RIGR) for myocardial perfusion. The technique does not rely on temporal smoothing as redundancies in the spatial domain are exploited with the use of prior information obtained from a set of reference images.

Method

A Siemens Sonata 1.5T CMR scanner running a TrueFISP sequence (FE=144, PE=288) with prospective diaphragmatic navigator echoes was used for this study. As demonstrated in Figure (a), imaging was performed in a two-stage process. The first stage (i) involved the acquisition of reduced *k*-space images for capturing the dynamic content of the data. To measure respiratory motion, a prospective 1D diaphragmatic navigator was used. According to the position of the diaphragm, data was collected in a set of 5 respiratory bins over a period of 50 cardiac cycles. For each cardiac cycle, the navigator data was acquired after the imaging sequence to avoid cardiac filling motion. Depending on the R-R interval and R-R variability of the subject, this typically started at about 400 to 500ms after the R-wave thereby providing an ample margin to avoid missing cardiac cycles. The total imaging duration was 260ms from the start of the non-selective saturation pulse to the end of single-shot TrueFISP sequence. The saturation recovery delay was 140ms, and a 0.1mmol/kg Gd-GTPA dose was injected at approximately 3ml/s followed by a 10ml saline flush. Other imaging parameters were: 10mm slice thickness, 40-60 degrees flip angle (SAR limited), 370mm (FE) by 288mm (PE) FOV, 144 (FE) by 112 (PE) un-interpolated unfiltered pixels in the image. The *k*-space was filled with full k_y coverage in a linear order over k_y versus time, and at 2.2ms repeat time between the FISP RF-pulses. The second stage of imaging (ii) involved the acquisition of full *k*-space reference images. This was continued for a further 20 cardiac cycles. The RIGR reconstruction technique was used to construct a generalised series from the last image in each of the respiratory bins (iii). This generalised series captured the static edge information inherent to each of the diaphragm positions. The generalised series were then constrained to fit the reduced *k*-space data to generate full resolution images with edge information (iv). The RR-RIGR technique was applied to 5 normal subjects and compared to results derived from RR-UNFOLD.

Results

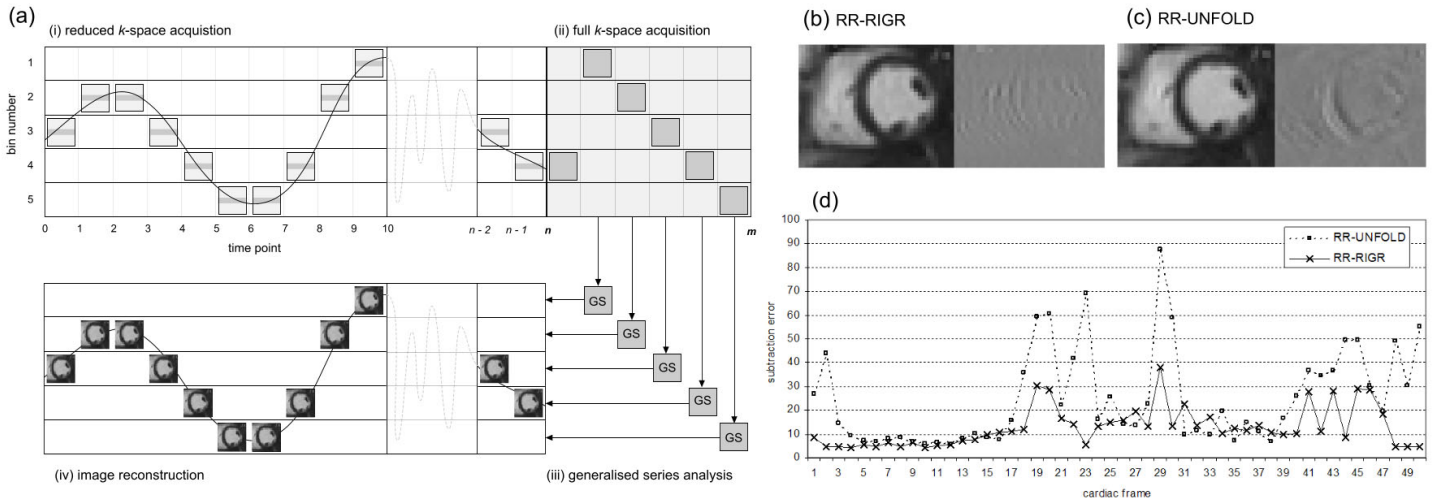

Figure (a) shows a schematic of the RR-RIGR imaging method used to provide the rapid acquisition of high definition first pass perfusion images. The processes of reduced *k*-space acquisition (i), full image acquisition (ii), generalised series analysis (iii) and image reconstruction (iv) allow the imaging speed to be increased by a factor of 2. Figure (b) shows a typical image acquired using the proposed RR-RIGR framework. For comparison, the same image generated with RR-UNFOLD is displayed in Figure (c). It can be seen that RR-RIGR may be used to remove artefacts that are inherent to the RR-UNFOLD approach. Figure (d) illustrates the reduction in residual error achieved for an example study when using the RR-RIGR technique as compared to RR-UNFOLD. Whilst in specific cases the RR-RIGR technique displayed a marked improvement over RR-UNFOLD, ringing-artefacts across the images caused the RR-RIGR technique to have a slightly greater average residual error across the 5 subjects (mean 15.7 +/- 7.2) compared to (mean 12.9 +/- 8.1) for RR-UNFOLD. However, whilst the transmural artefacts present in the RR-UNFOLD images can significantly affect the integrity of perfusion measurements, those inherent using the RR-RIGR approach tend to be of a reduced magnitude and are distributed more evenly around the image. RR-RIGR also has the advantage of reduced temporal smoothing which improves the accuracy of perfusion index quantification particularly for stress studies where contrast uptake has steeper slopes. The proposed technique will benefit from the optimal selection of reference images that best depict the static edges present during the dynamic imaging stage. It is expected that with careful selection of the reference images, RR-RIGR will be an attractive alternative to RR-UNFOLD for the rapid acquisition of first pass perfusion images.

References

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