High quality Real-Time Cardiac MRI using Self-Calibrating Radial GRAPPA with Sparsification

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Introduction:

It has been recently shown that real time cardiac MRI is feasible using the parallel imaging (pMRI) concept without the need of extra calibration data by employing a Cartesian time interleaved acquisition scheme similar to TSENSE [1] and TGRAPPA [2]. However, at high frame-rates (high pMRI reduction factors) the g-factor noise enhancement associated with pMRI reconstruction can severely degrade image quality. Further work demonstrated that by removing the temporal average (DC) prior to pMRI reconstruction significantly reduced g-factor noise is observed [3,4]. In addition, radial k-space coverage in combination with parallel MRI has been shown to provide more benign g-factor behavior and incoherent residual aliasing artifacts compared to Cartesian pMRI [5]. In this work we employ a highly undersampled (16 radial projections per frame) time-interleaved radial data acquisition in combination with a dedicated radial GRAPPA algorithm, applied after subtraction of the temporal average in order to accomplish high quality real-time cardiac MRI at a frame rate of 20fps with $2mm^2$ in-plane resolution.

Material and Methods:

Volunteer measurements were performed on a 1.5T clinical scanner using 15 channels in total from a spine-body matrix combination. A time-interleaved radial bSSFP sequence (FOV = 380mm, TR=3.2ms, 16 projections per frame, 192 readout points) was employed to track the beating heart for approx. 10s in one breath-hold at a frame-rate of 20fps in the short axis view. In addition, a fully encoded radial bSSFP cardiac gated CINE experiment (192 projections, 21 phases) served as a reference.

Prior to the radial GRAPPA reconstruction the temporal average of each projection was subtracted from the radial projections in order to allow for improved pMRI performance. After GRAPPA the temporal average image is added back to yield the final reconstruction.

<u>Self-Calibrating radial GRAPPA reconstruction:</u>

Similar to other previously proposed radial GRAPPA methods [6,7,8,9], the undersampled radial data is gridded to Cartesian k-space to serve as Auto Calibration Signal (ACS) for the following radial GRAPPA algorithm that operates in radial k-space. For any missing point in the undersampled radial k-space a unique non-Cartesian GRAPPA kernel can be specified. This non-Cartesian GRAPPA kernel can be (similar to the weights calibration in standard Cartesian GRAPPA) shifted by Δky and Δkx steps within the fully sampled ACS region. However, in contrast to the Cartesian case the locations of the source and target points within the ACS region do not fall on a Cartesian grid. However, the correct source and target signals can be derived by degridding (interpolating) the Cartesian ACS data to the required source and target locations. Here, this has been accomplished using the Fessler toolbox [10]. Finally, the corresponding GRAPPA weights can be calculated by fitting the source signals to the target signals. In order to speed up the reconstruction process the radial k-space is segmented in both the read-out (8 segments) and the angular (6 segments) direction as suggested by Griswold et al [11]. In contrast to the original radial GRAPPA version where the segments are treated as Cartesian and are calibrated from a fully-sampled radial reference data set, we employ a representative non-Cartesian GRAPPA kernel taken from the center of each segment and which is calibrated from the ACS data. In this way, successful calibration is ensured without the need for fully sampled reference data even for small segments sizes [11,12].

Results:

Fig 1. shows two representative time frames in the systole and diastole taken (a) from the fully-sampled (192 projections) gated CINE experiment and from the corresponding artificially accelerated (16 Projections) radial GRAPPA reconstructions (b) without and (c) with subtraction of the temporal average. In addition, in order to demonstrate the feasibility of the presented approach for real-time cardiac imaging, a series of frames (zoomed) reconstructed from the accelerated (16 Projections) real-time experiment are shown in Fig.2.

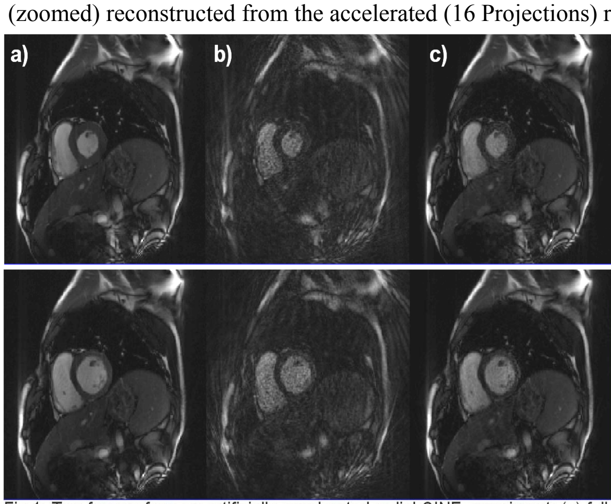

Fig 1: Two frames from an artificially accelerated radial CINE experiment: (a) full reference (192 rprojections) and selfcalibrating radial GRAPPA (16 projections) (b) without DC subtraction and (c) with DC subtraction.

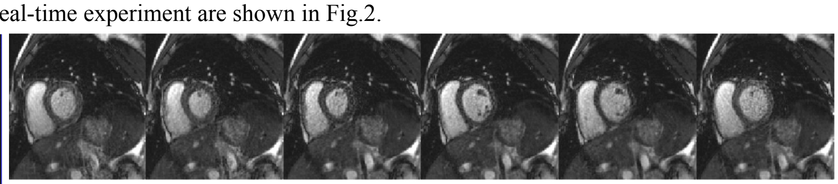

Fig. 2: radial GRAPPA accelerated real time cardiac MRI at a frame rate of 20fps using only 16 radial projections per time frame. 6 representative frames out of the image series are shown.

Conclusion:

In this work, the concept of DC subtraction for improved self-calibrating radial GRAPPA has been applied to real-time cardiac MRI. It is shown, that significantly improved image quality is achieved if the temporal average is subtracted prior to the radial GRAPPA procedure allowing for high quality cardiac imaging in high temporal and spatial resolution.

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