Feasibility of single breath-hold CINE with combined Simultaneous Multi-Slice (SMS) and Region-Optimized Virtual (ROVir) coils

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Synopsis

Conventional clinical cardiac MRI protocols use a large number (>20) of breath-holds for capturing cinemagraphic (CINE) scans of the heart in various views. Patients become fatigued from this kind of scan protocol, decreasing quality of breath-holds and consequently degrading image quality. Recent advances in accelerated techniques such as simultaneous multi-slice (SMS) and compressed sensing have been employed to drastically reduce CINE imaging scan time and the number of required breath-holds. One potential method capable of further accelerating CINE imaging is to drastically reduce the FOV to only include the heart, which could result in 4 to 5-fold acceleration. However, naively reducing FOV will normally result in severe aliasing. In this work, we hypothesize that reduced-FOV SMS CINE can be achieved by using a novel beamforming approach, Region-Optimized Virtual (ROVir) coils, which can use the characteristics of a multi-channel receiver array to suppress signal from unwanted spatial regions. This technique can potentially achieve single breath-hold whole heart CINE. We test the proposed single breath-hold SMS+ROVir CINE against conventional multi-breath-hold CINE in normal volunteers with respect to contrast to noise ratio (CNR) and standard cardiac function parameters.

Methods

Pulse Sequence Design and Image Reconstruction: SMS bSSFP CINE was achieved by implementing a gradient-controlled local Larmor adjustment (GC-LOLA) to restore the frequency response and stabilize banding artifacts across SMS acquired slices. GC-LOLA unbalances the slice gradient by a small constant and homogenizes RF phase cycles across all slices by adjusting the local Larmor frequency and aligning slice-specific frequency responses. This allows for predictable band placement across all slices and removes banding artifacts that might otherwise disrupt image quality (i.e., banding in blood pool). Prior to image reconstruction, virtual coils were obtained using ROVir, which linearly mixes the original receiver array channels in a way that optimally maximizes signal from the region of interest while also suppressing signal from unwanted spatial regions. SMS k-space data reconstruction from the ROVir coils was then performed with Split-Slice GRAPPA.

In vivo Study: Four healthy subjects were recruited with institutional IRB and scanned on a clinical 3T system (MAGNETOM Prisma, Siemens Healthcare, Erlangen, Germany). Full FOV (360mm x 360mm; matrix = 225 x 225) and 4-fold reduced phase encoding FOV (360mm x 90mm; matrix = 225 x 58) whole ventricular CINE were acquired with the prototype SMS (factor 2) using matching bSSFP CINE sequence parameters (TR = 3.1 ms, TE = 1.8 ms). For full FOV measurements, 4 breath-holds were needed to cover the whole LV. A single cardiac phase was acquired with the full FOV measurement was used as calibration data for ROVir. For reduced FOV measurements, only a single breath-hold was needed. Noise scans were also performed by turning off the RF and collecting 200 samples of noise at each pixel with the same CINE sequence parameters above.

Image Analysis: CNR analysis was performed by first calculating the variance at each pixel from the noise scans. Afterwards, the absolute signal difference of the left ventricular myocardium and the blood were normalized by the noise estimates. Cardiac function parameters including end diastolic volume (EDV), end systolic volume (ESV), and ejection fraction (EF) were calculated with manual segmentation. Statistical comparisons were performed with Wilcoxon rank test to test for differences with a significance level of 0.05.

Results

For reduced FOV CINE, reconstructing with either SMS only or ROVir only resulted in significant aliasing, severely degrading image quality when compared to the full FOV reference CINE (Figures 2 and 3). The proposed combination of SMS+ROVir substantially reduced aliasing (qualitatively) from both in-plane and through-plane sub-sampling. For all subjects, myocardial to blood CNR for single breath-hold SMS+ROVir CINE (35.8 ± 5.9) was significantly (p < 0.02) decreased compared with reference full FOV CINE (38.4 ± 6.1). However, cardiac function parameters for single breath-hold SMS+ROVir CINE (EDV = 125.8 ± 12.2 ml; ESV = 49.5 ± 12.7 ml; EF = 61.3 ± 4.9 %) was not significantly different compared with full FOV SMS reference CINE (EDV = 127.5 ± 12.1 ml; ESV = 53.1 ± 9.7 ml; EF = 59.4 ± 6.8 %) (Figure 4).

Conclusion

We demonstrated the feasibility of combining SMS and ROVir reconstruction for highly accelerated CINE imaging (8-fold reduced scan time), enabling single breath-hold whole ventricular acquisition. Single breath-hold SMS+ROVir whole-heart CINE yielded cardiac function parameters with no significant bias when...
compared to SMS CINE. Future work will include combining SMS+ROVir with compressed sensing reconstructions for further acceleration and evaluating its potential utility in patients with a variety of cardiomyopathies.

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References

Figures

Figure 1. (A) Depictions of the regions of interest (green boxes) and the unwanted spatial regions (red boxes). (B) Coil-combined images from ROVir coils that optimally separate the region of interest from unwanted spatial regions corresponding to (A).

Figure 2. (A) Naïve FFT reconstructions and (B) SMS reconstructions of reduced FOV data from an original 30-channel coil array. (C) Naïve FFT reconstructions and (D) SMS reconstructions from 12 virtual coils obtained by applying ROVir to the same reduced FOV data. (E) Reference 4-slice full FOV data from the original coil array.

Figure 3. Animated GIF of representative (Top) naïve FFT reconstructions and (Bottom) SMS+ROVir reconstructions of 8-slice data whole ventricle reduced FOV CINE.
Figure 4. Comparison of blood to myocardial contrast to noise ratio (CNR) and cardiac function parameters (EDV = end diastolic volume, ESV = end systolic volume, EF = ejection fraction) between single breath-hold SMS+ROVir reduced FOV CINE with reference multi-breath-hold SMS full FOV CINE. CNR was significantly lower for SMS+ROVir compared to reference, while no significant difference was found in quantifying cardiac function parameters.