Single Breath-hold Whole-heart Inner Volume Black-blood Cardiac MRI using SSFSE with Parallel Imaging

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Introduction

Black-blood imaging provides excellent cardiac and vascular morphological information. Conventionally, these images are obtained using segmented fast spin echo (FSE), acquiring 1-2 slices per 10-15 sec. breath-hold. With 8-10 slices to cover the whole heart, this results in prolonged examination time and patient discomfort. The use of half-Fourier single-shot FSE (SSFSE) would substantially shorten the scan time, allowing acquisition of all slices in a single breath-hold. However, to obtain adequate spatial resolution, long echo train lengths (ETL) are required, resulting in image blurring. To address this issue, an inner volume technique[1] together with parallel imaging using the Array Spatial Sensitivity Encoding Technique (ASSET), which is similar to SENSE[2], was applied to the black-blood SSFSE sequence.

Methods

Experiments were performed on 7 healthy volunteers (5 males, 32-44 yo) in a 1.5 T TwinSpeed MR scanner (GE Medical Systems, Milwaukee WI, USA), using a 4-element torso phased-array coil. The half-Fourier SSFSE pulse sequence was modified such that the 90° excitation RF pulse and the 180° refocusing RF pulses were played along orthogonal gradient orientations, thus producing spin echoes only from their intersecting volume. Hence, the field-of-view (FOV) along the phase-encoding (PE) direction could be smaller than the total object without suffering from aliasing artifact. For a given spatial resolution this meant the number of PE lines (thus ETL) could be reduced; alternatively, the spatial resolution could be improved with the same ETL. The design of the excitation pulse was optimized to provide good inner volume profile without adversely affecting the echo spacing (ESP) – a 3 msec, 3 kHz, minimum phase Shinnar-LeRoux pulse was used, and the resulting ESP ranged from 4.1-5.1 msec. Double inversion-recovery (DIR) pulses were applied at an appropriate inversion time before the excitation pulse to produce black-blood images. For each slice, the ECG trigger delay was set to acquire data at end-diastole. An interval of 2 heartbeats between subsequent slices provided time for spin magnetization recovery between the 90° pulses. The 8-10 slices for the whole heart could therefore be obtained in a single breath-hold of 15-20 sec. Short- and long-axis cardiac images were acquired at various resolutions, FOV and ETL, and the image quality compared visually. A receiver bandwidth of ±62.5 to ±83.3 kHz and a 10 mm slice thickness were used.

ASSET parallel imaging was also applied to further reduce ETL. Conventionally, the coil sensitivity map, required for ASSET reconstruction, was acquired using 2D slices covering the full FOV of the object. For inner volume scans, however, this could result in edge detection error since the acquired image's edges are far from those of the whole object. To overcome this, this calibration scan was performed using also an inner volume scheme, with a FOV just slightly larger than the actual ASSET scan's FOV, to allow for position change due to motion, and with the calibration slices prescribed along the same orientation as the actual ASSET scan.

Results

Fig. 1 shows a slice (out of 8 slices acquired in a single breath-hold of 16-17 sec.) of short-axis cardiac MRI from one of the volunteers. In Fig. 1a, a full FOV scan of 30x30 cm^2 with a spatial resolution of 256x192 requires an ETL of 102. With an ESP of 4.1 ms, the >400 ms acquisition window (AW) produced a rather blurred image. An attempt to reduce ETL to 64 by using 60% FOV in the PE direction produced wrap-around artifacts (Fig. 1b) if the inner volume excitation scheme was not applied, but no wrap-around (Fig.1c) if using inner volume. The ETL was further reduced to 46 by using ASSET, improving the image sharpness (AW<190 ms), while maintaining the same spatial resolution. Fig. 2 shows examples of improving the spatial resolution while keeping the same ETL (70) by the use of inner volume and ASSET. Finally, Fig. 3 shows all 8 slices covering the whole heart, from apex to base, obtained using the same parameters as in Fig. 2c (inner volume with 70% FOV along the PE direction, together with ASSET, ETL=70, 256x256) in a single breath-hold of 16 sec.

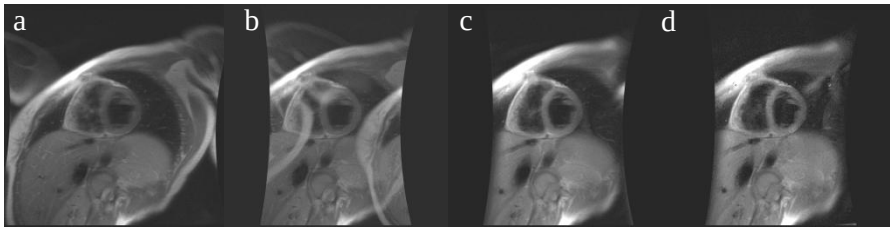

Fig. 1 Black-blood SSFSE short-axis MRI (1 of 8 slices) with 256x192 matrix: (a) Full FOV (30x30 cm^2), 102 ETL; (b) 0.6 FOV in the PE (right-left) direction without using the inner volume technique, 64 ETL; (c) same as (b) but applying inner volume, 64 ETL; (d) same as (c) plus ASSET, 46 ETL. Note improvement in image sharpness while maintaining spatial resolution. Breath-hold to acquire all 8 slices=16-17 sec. in all cases.

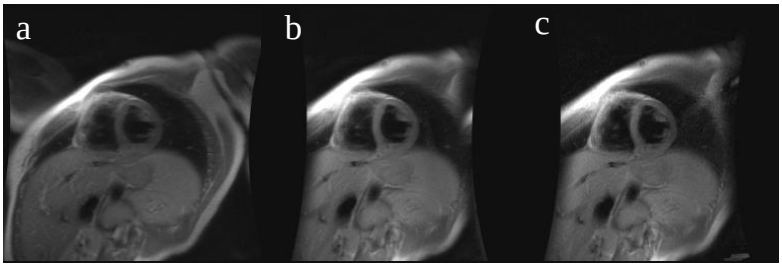

Fig. 2 Black-blood SSFSE short-axis MRI (1 of 8 slices) with a constant ETL of 70: (a) Full FOV (30x30 cm^2), matrix size=256x128; (b) 0.66 FOV in the PE direction, using inner volume, matrix size=256x192; (c) 0.7 FOV in the PE direction, using inner volume plus ASSET, matrix size=256x256.

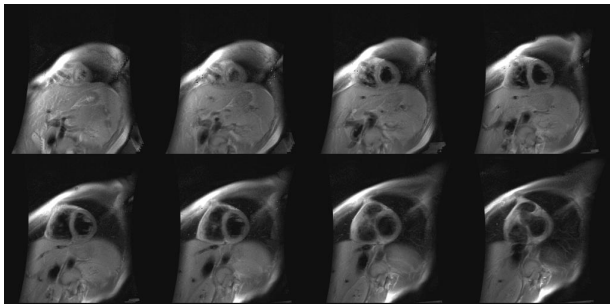

Fig. 3 All 8 slices covering the whole heart, from apex to base, acquired in a single 16 sec. breath-hold, of black-blood inner volume SSFSE with ASSET. Imaging parameters are the same as in Fig. 2c.

Discussion

We have demonstrated the application of DIR-SSFSE to acquire multi-slice black-blood whole-heart cardiac images in a comfortable single breath-hold, with the use of the inner volume technique together with ASSET to improve image sharpness and/or spatial resolution. This technique greatly improves scan efficiency and patient comfort compared with the conventional multiple breath-hold black-blood segmented FSE method. The single-shot nature of this technique also proved to provide good image quality with free breathing scans, even for multi-slice acquisitions. The use of an appropriate calibration strategy can significantly reduce artifacts resulting from performing parallel imaging with inner volume, allowing any residual artifacts to remain small and away from the heart location.

References

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