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Accelerated cine DENSE MRI using compressed sensing and parallel imaging

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Background

Cine DENSE (Displacement Encoding with Stimulated Echoes) provides accurate and high-resolution displacement and strain imaging of the heart; however, image acquisition times are relatively long and, due to properties inherent to stimulated echoes, signal-to-noise ratio (SNR) is relatively low. Accelerated cine DENSE could substantially shorten scan times and/or provide improved spatial and/or temporal resolution; however, the low SNR, requirement to preserve phase information, and cardiac motion present technical challenges. We aimed to develop acceleration methods that overcome these challenges.

Methods

A variable-density spiral cine DENSE sequence was implemented on a 1.5T scanner (Avanto, Siemens) where the center of k-space was fully sampled and the outer portion of k-space was undersampled. Spiral interleaves were distributed uniformly within each cardiac phase and rotated by the golden angle through different cardiac phases. Cine DENSE datasets were collected from 5 healthy volunteers (age 25-28) using a 5-channel RF coil. To make comparisons, fully-sampled cine DENSE datasets with 6 to 8 spiral interleaves per image were acquired within one breathhold (20 to 26 heartbeats), and these datasets were retrospectively rate-2 undersampled. Also, prospectively rate-2 undersampled data with 4 spiral interleaves per image were acquired within a shorter breathhold (14 heartbeats). Images had spatial resolution of 1.8-2.2 × 1.8-2.2 × 8 mm and temporal resolution of 19.6 ms. All undersampled data were reconstructed using a recently-developed compressed sensing (CS) method called Block LOw-rank Sparsity with Motion-guidance (BLOSM), combined with SENSE parallel imaging. The BLOSM-SENSE algorithm exploits matrix low-rank sparsity within motion-tracked regions of SENSE-combined images. Complex-valued images were reconstructed to preserve the phase information used for displacement encoding.

Results

In Figure 1, example end-systole magnitude- (A-C) and phase-reconstructed (D-F) fully-sampled (A,D), retrospectively-undersampled (B,E), and prospectively-accelerated (C,F) DENSE images and strain maps (G-I) are shown, demonstrating excellent performance of the BLOSM-SENSE reconstruction method. Figure 2 shows that quantitation of myocardial displacement by retrospectively rate-2 accelerated cine DENSE is accurate compared to fully-sampled data. Using prospectively-accelerated cine DENSE, circumferential strain curves from all 5 volunteers demonstrated typical values and patterns for healthy subjects (C).

Conclusions

Rate-2 accelerated spiral cine DENSE with the BLOSM-SENSE reconstruction method provides high-quality complex images. Retrospective undersampling of fully-sampled datasets demonstrated accurate displacement and strain measurements. Prospectively undersampled cine DENSE demonstrated typical myocardial strain measurements, using approximately half the data acquisition time of conventional cine DENSE.

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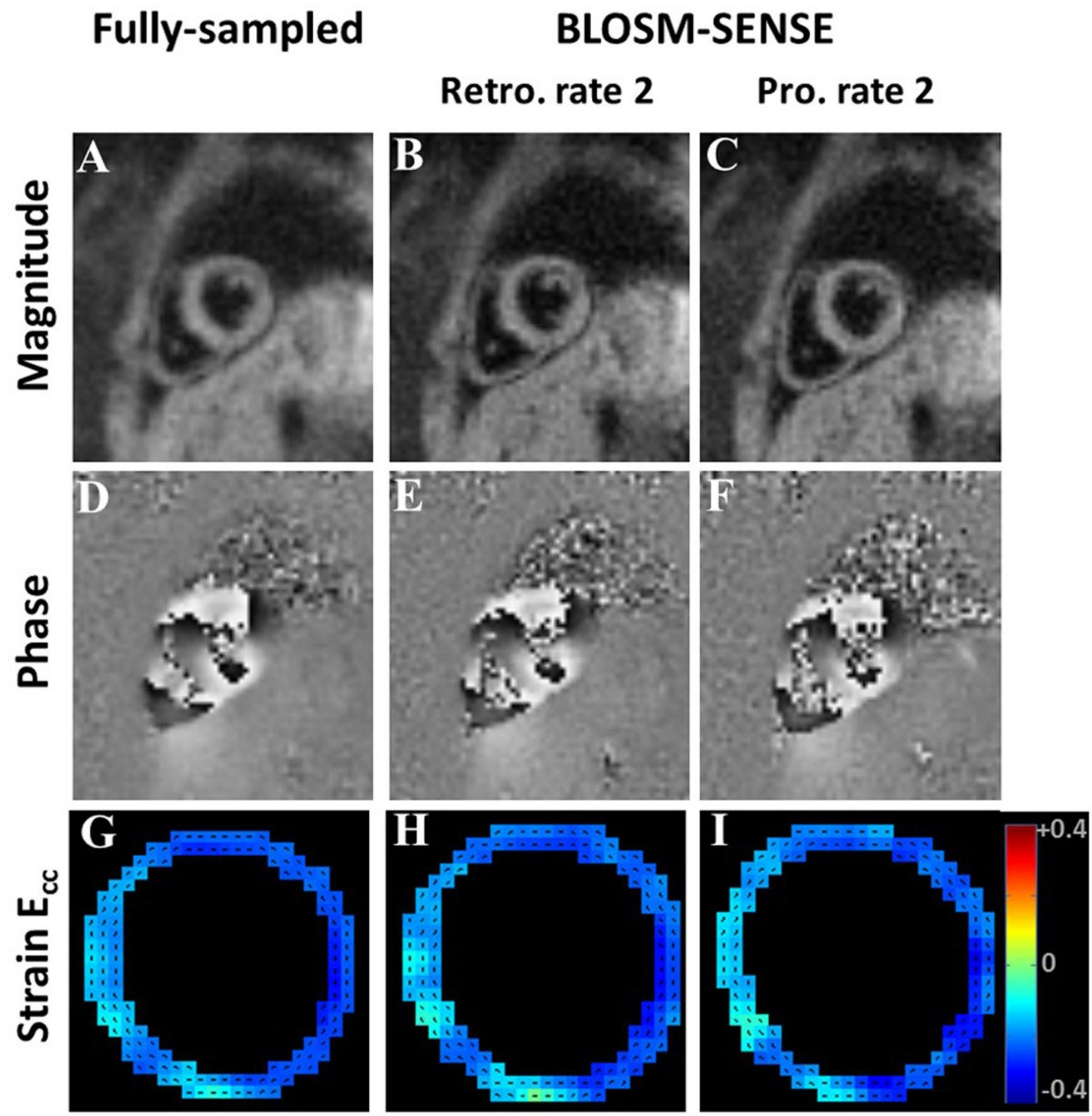

Figure 1 Example end-systolic DENSE images (A-F) and strain maps (G-I). Magnitude- (A-C) and phase-reconstructed (D-F) images from fully-sampled (A,D), retrospectively-undersampled (B,E), and prospectively-accelerated (C,F) studies are shown. The retrospectively-undersampled results (B,E,H) closely resembled the fully-sampled references (A,D,G). The prospectively-accelerated results (C,F,I) presented high quality images and strain maps from data acquired within one breath-hold using BLOSM-SENSE.

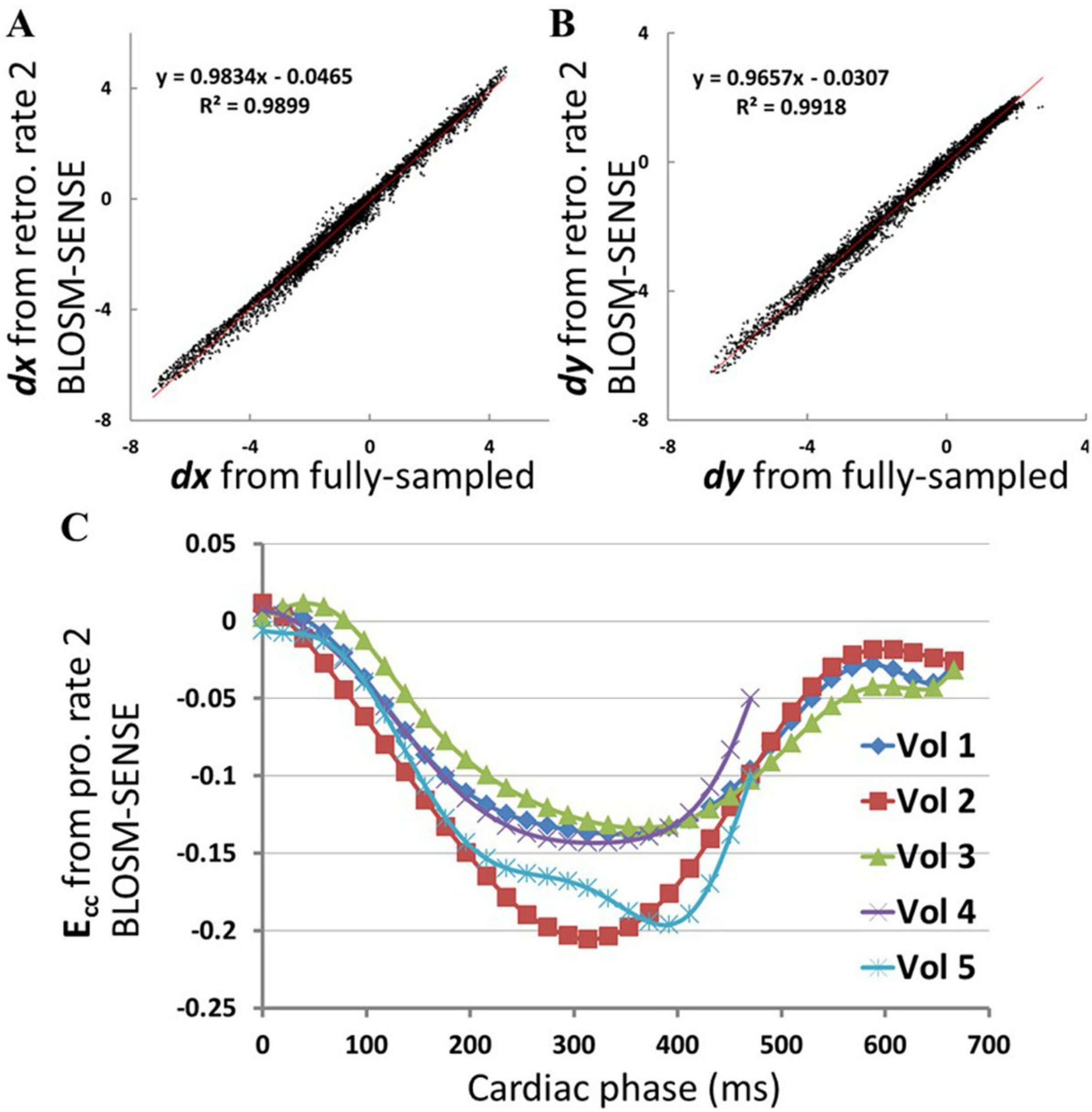

Figure 2 Quantitation of myocardial displacement (A,B) and circumferential strain (C). Example scatter plots of myocardial displacements in x (A) and y (B) directions from one volunteer. Linear regression showed good correlations of retrospectively rate-2 undersampled and fully-sampled DENSE data. The averaged correlation for all 5 volunteers is v=(1.01 ± 0.03)*u+(0.03 ± 0.009) with R^2=0.993 ± 0.005. Circumferential strain (E_{cc}) from all 5 volunteers (C) showed typical values and patterns for healthy subjects.

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