Comparison of SNR Efficiencies and Strain for Cine DENSE Images Acquired using Conventional EPI, Flyback EPI and Spiral *k*-space Trajectories

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Introduction. Displacement encoding with stimulated echoes (DENSE) is a quantitative myocardial wall motion imaging technique that encodes tissue displacement into the phase of the stimulated echo (1). Two-dimensional (2D) cine DENSE provides a time series of pixel-wise displacement and strain measurements for the myocardium through the cardiac cycle. The original implementation of 2D cine DENSE employed a rectilinear bottom-up interleaved echo-planar (EPI) *k*-space trajectory for rapid data sampling (2). Follow-up studies used a flyback EPI *k*-space trajectory to reduce ghosting artifacts at a slight cost of temporal resolution (3). More recently a spiral *k*-space trajectory was utilized for improved SNR (4). The purpose of this study was to evaluate and compare the SNR efficiencies and the strain results of these three techniques for 2D cine DENSE imaging.

Methods. All studies were performed on a 1.5T MRI system (Avanto, Siemens Medical Solutions, Germany) with a four-channel chest coil. Cine DENSE pulse sequences were developed that employed three different *k*-space trajectories, namely conventional bottom-up interleaved EPI, flyback bottom-up interleaved EPI, and interleaved spiral. These techniques were compared in volunteers using a protocol of two-breath-holds per slice (one breath-hold per encoding direction). In accordance with protocols approved by the local institutional review board, and with informed consent, 5 healthy volunteers were imaged. Identical parameters used for the three techniques included pixel size = 3.8 × 3.8 mm^2, slice thickness = 8 mm, flip angle = 20°, cardiac phases = 15, displacement encoding frequency = 0.08 cycles/mm, and two-point phase cycling with through-plane dephasing frequency = 0.08 cycles/mm for artifact suppression (3). Other parameters for conventional/flyback EPI included image matrix = 72 × 96, TE = 8.57/10.57 ms, TR = 17.69/21.19 ms, EPI factor = 8, segments = 16, total sampling time per uncombined image = 99.8 ms, heartbeats per breath-hold = 21/20 (one heartbeat was used to acquire *k*-space centerlines for phase correction for the conventional EPI trajectory), and fat suppression by water excitation. For spiral, other parameters included image matrix = 96 × 96, TE = 1.08 ms, TR = 17 ms, number of interleaves = 6, interleaves per heartbeat = 2, total sampling time per uncombined image = 66.8 ms, heartbeats per breath-hold = 14 (two heartbeats were used to acquire low-resolution field maps for deblurring for the spiral trajectory), and fat suppression by chemically-selective saturation pulses applied prior to displacement-encoding pulses (5). The signal-to-noise ratio (SNR) was calculated using magnitude-reconstructed images, and the SNR efficiency was derived by dividing the SNR by the square root of the corresponding total sampling time of all images used for DENSE reconstruction. Lagrangian displacement and strain maps were also calculated (6).

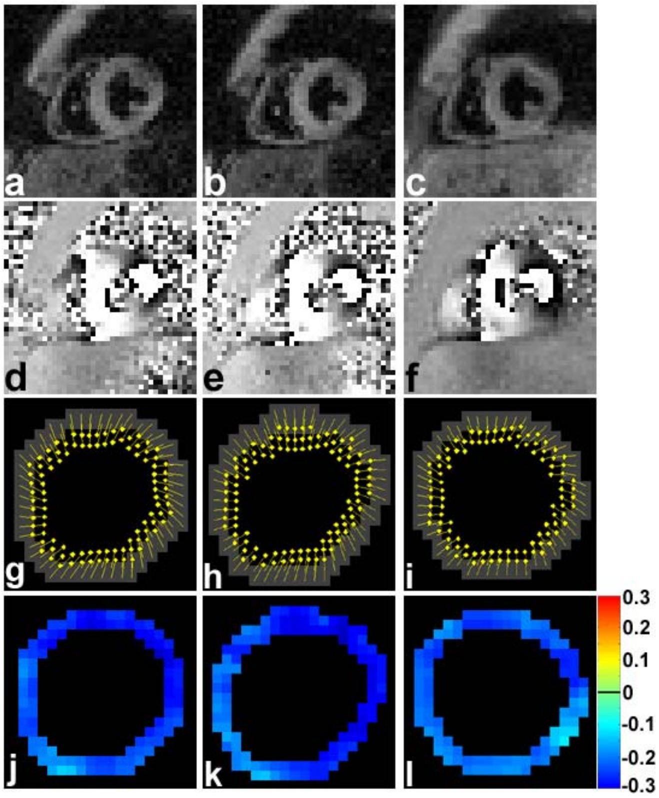

Figure 1 Example images of one volunteer. The rows of (a-c) and (d-f) are magnitude- and phase-reconstructed images with displacement encoded in the horizontal direction, respectively. The rows of (g-i) and (j-l) are Lagrangian displacement and circumferential strain maps, respectively. The columns of (a, d, g, j), (b, e, h, k) and (c, f, i, l) are measured using conventional EPI, flyback EPI and spiral cine DENSE, respectively.

Results. Example images using these three techniques for one volunteer are shown in Figure 1. SNR efficiencies summarized for all 5 volunteers as a function of cardiac phase are shown in Figure 2. The small difference between the SNR efficiencies of conventional and flyback EPI is due to their small TE and TR differences. In contrast, the SNR efficiency of spiral increases by about 33% at early phases and about 79% at late phases compared to the EPI techniques, which is attributed to shorter TE and more efficient sampling. The circumferential strain (Ecc) was calculated for mid-ventricular segments at end-systole (Table 1). One-way ANOVA analysis showed no statistically significant difference among these three techniques.

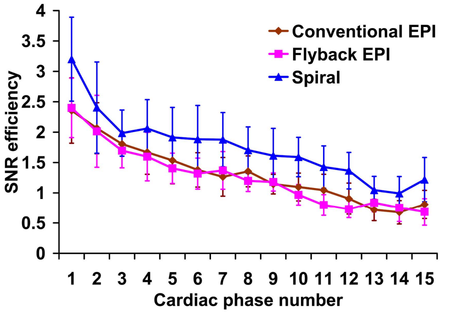

Figure 2 Mean SNR efficiency curves of the conventional EPI, flyback EPI and spiral cine DENSE as a function of cardiac phase summarized for 5 volunteers.

Table 1 Ecc of mid-ventricular segments measured with three techniques.

	Mid anterior	Mid lateral	Mid posterior	Mid inferior	Mid septum	Mid anterior septum
Conventional EPI DENSE	-0.20 ± 0.02	-0.22 ± 0.04	-0.19 ± 0.05	-0.18 ± 0.02	-0.17 ± 0.01	-0.17 ± 0.02
Flyback EPI DENSE	-0.19 ± 0.03	-0.22 ± 0.05	-0.21 ± 0.03	-0.18 ± 0.02	-0.14 ± 0.01	-0.15 ± 0.02
Spiral DENSE	-0.19 ± 0.03	-0.21 ± 0.03	-0.21 ± 0.02	-0.17 ± 0.02	-0.15 ± 0.03	-0.15 ± 0.03

Conclusions. Conventional, flyback EPI and spiral cine DENSE imaging produce similar strain results for the protocols tested. Spiral cine DENSE provides improved SNR efficiency compared to the other two techniques.

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