Two-dimensional Spiral Cine DENSE

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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 echo-planar (EPI) k-space trajectory for rapid data sampling in one breath hold, where the SNR and the temporal resolution were relatively low and ghosting artifact was sometimes problematic (2). More recently flyback EPI was used to reduce artifacts, but generally two breath-holds were needed for 2D displacement encoding (3). The purpose of this study was to evaluate the use of a spiral k-space trajectory for single breath-hold 2D cine DENSE imaging with improved SNR, temporal resolution, and artifact reduction.

Methods. All studies were performed on a 1.5T MRI system (Avanto, Siemens Medical Solutions, Germany). An ECG-gated EPI cine DENSE sequence was modified to use a spiral k-space trajectory (4). Single-shot images with two different TEs were acquired for each slice and at each cardiac phase to estimate field maps. Image reconstruction was performed on-line using gridding and linear inhomogeneity compensation. Spiral cine DENSE was first compared to cine DENSE with flyback EPI using a 2-breath-hold protocol, and spiral cine DENSE was also evaluated for single breath-hold imaging. For cine DENSE with an EPI readout, the EPI readout gradient waveform was modified using the flyback technique (5). In accordance with protocols approved by our institutional review board, and with informed consent, 6 healthy volunteers were imaged using both sequences. In order to compare the SNR, whenever possible, identical parameters were used for both sequences, including pixel size = 2.8×2.8 mm^2, slice thickness = 8 mm, flip angle = 15°, TR = 17 ms, breath-holds = 2, heartbeats per breath-hold = 16, and cardiac phases = 22. Also, both sequences used displacement encoding frequency = 0.1 cycles/mm, through-plane dephasing frequency = 0.08 cycles/mm for improved artifact suppression (3), and fat suppression pulses applied prior to the displacement-encoding pulses (6). Other parameters for spiral included TE = 1.9 ms, number of interleaves = 10, interleaves scanned per heartbeat = 2, and total sampling time per image = 112 ms. Other parameters for EPI included TE = 8.9 ms, ETL = 9, segments = 18, and total sampling time per image = 74 ms. The SNR of both sequences was calculated using magnitude-reconstructed images. For single breath-hold 2D spiral cine DENSE, the parameters different from above include number of interleaves = 6, and total heartbeats = 19. Lagrangian displacement and strain maps, as well as the strain-time curves were calculated for all cine DENSE images as described in (7).

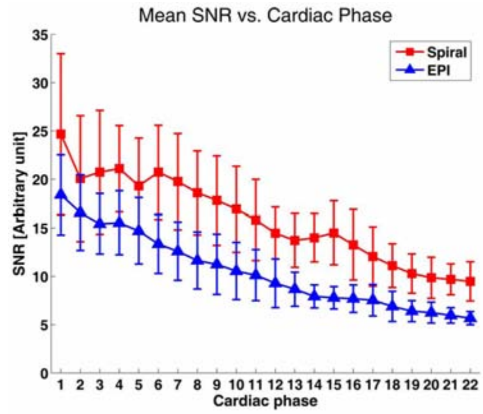

Fig. 1 Mean SNR of spiral and EPI cine DENSE as a function of cardiac phase for 6 volunteers.

Results. SNR results summarized for all 6 volunteers as a function of cardiac phase are shown in Fig. 1, where the SNR of spiral increases by about 34% at early cardiac phases and about 67% at late cardiac phases compared to flyback EPI. Approximately 20% of the SNR difference is attributed to the difference in sampling time, with the remaining difference attributed to shorter TE. Example data from single breath-hold 2D spiral cine DENSE is shown in Fig. 2(A), where no ghosts and good suppression of flow artifacts can be observed. The circumferential (Ecc) strain-time curve of the anterior free wall is shown in Fig. 2(B), where the temporal resolution was improved to 34 ms, compared to 60 ms in the original EPI cine DENSE (2). Lagrangian displacement and Ecc strain maps at end systole are shown in Fig. 2(C,D), respectively.

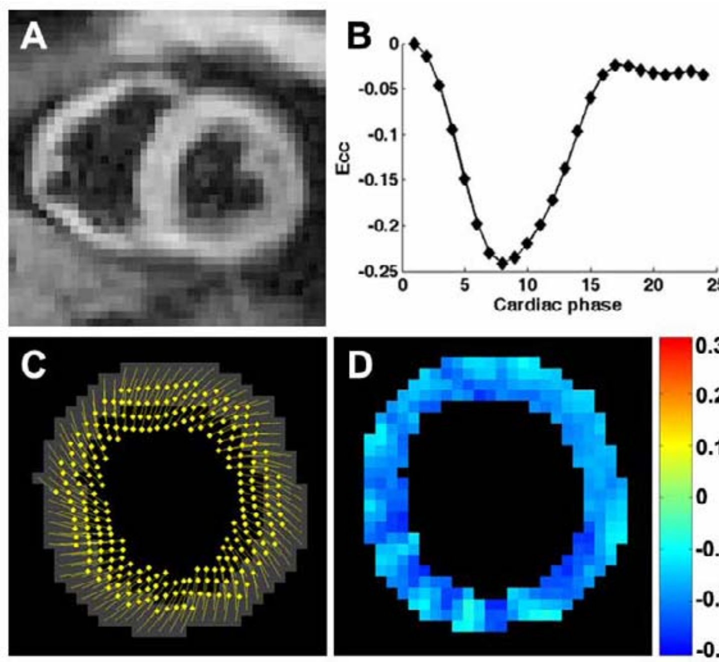

Fig. 2 (A) Short-axis magnitude image. (B) Ecc strain-time curve of the anterior free wall. (C) Lagrangian displacement map at end systole, where the line tail represents the position of the myocardium element at the beginning of the cardiac cycle (end diastole), and the line head represents the current position of this element. (D) Lagrangian Ecc strain map at end systole. Data were acquired in a single breath hold using spiral cine DENSE.

Conclusions. The use of a spiral k-space trajectory in cine DENSE provides increased SNR, high-temporal resolution, and reduced artifacts. Using the parameters in this study, 2D spiral cine DENSE can quantify displacement and strain with a spatial resolution of $2.8 \times 2.8 \times 8$ mm^3 and temporal resolution of 34 ms in a single breath-hold.

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