MRI of Longitudinal Myocardial Strain using Multislice Cine DENSE with Through-plane Displacement Encoding

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Introduction Cine DENSE (Displacement Encoding with Stimulated Echoes) is a quantitative MRI method for imaging myocardial displacement and strain. Typically, cine DENSE images of the heart are acquired in a short-axis plane, and the in-plane circumferential and radial displacements and strains are measured. However, quantitative imaging of longitudinal myocardial motion is also important, as is routinely performed in echocardiography, the most common modality for imaging cardiac function. The purpose of the present study was to develop a cine DENSE pulse sequence for quantitative imaging of longitudinal motion, where two adjacent short-axis slices are encoded for through-plane (longitudinal) displacement and are simultaneously acquired. Displacement trajectories measured from the two slices are used to calculate longitudinal strain.

Methods. A slice-interleaved cine DENSE pulse sequence (Fig. 1) was implemented on a 1.5T Avanto MRI system (Siemens Medical Solutions, Erlangen, Germany). After the application of nonselective displacement-encoding pulses, a multiphase and multislice data acquisition module was applied, where the slices loop was placed inside the phases loop. Using this method, two slices with through-plane displacement encoding can be acquired within a single breathhold. The acquisition of both slices within a single breathhold is a critical design feature, because the distance between slices remains fixed and determined by the user-selected slice locations. In contrast, if the two slices were acquired in separate breathholds, then inconsistencies between breathholds would add variability to the distance between slices. Maintaining a known and fixed distance between slices enables the accurate calculation of strain from the measured displacement fields. The modified cine DENSE sequence was evaluated in normal volunteers after informed consent was obtained and in accordance with protocols approved by the IRB at our institution. Specific pulse sequence parameters included: field of view = 340 - 400 mm^2, matrix = 128 x 128, slice thickness = 8 mm, slice gap = 0 mm, flip angle = 20°, TR = 12 ms, TE = 1.3 ms, number of spiral interleaves = 4, fat suppression, temporal resolution = 24 ms, and displacement encoding frequency = 0.08 cycles/mm. Images were exported to a PC and computation of Lagrangian displacement trajectories was performed as previously described (1).

Results. Example displacement-encoded phase-reconstructed images of two adjacent slices at selected cardiac phases acquired during the same breathhold are shown in Fig. 2. Decreasing phase values are observed over time, as longitudinal displacement decreases through systole. Greater phase decreases are seen for the more basal slice (A-C) compared to the adjacent slice (D-F), reflecting the development, over time, of longitudinal shortening. Mean longitudinal displacement and strain are plotted in (H,I) for the slices shown in (A-F), and further demonstrate the pattern of differential longitudinal displacement and the resulting longitudinal strain. Similar results were obtained from additional normal volunteers.

Conclusions. A slice-interleaved cine DENSE pulse sequence was developed to acquire two slices with through-plane displacement encoding in a single breathhold. By acquiring both slices within a single breathhold, a fixed and consistent distance between the slices is maintained, which enables the accurate calculation of longitudinal strain from the measured longitudinal displacement fields. Furthermore, once a region of interest is identified, the calculation of displacement and strain is automatic, and does not require manual intervention. This method may be ideally suited for applications such as quantifying mechanical dyssynchrony in heart failure, where, in a single breathhold, strain may be measured in the septum and lateral wall, and where the septal-lateral delay may be a diagnostic parameter. The multislice cine DENSE sequence with through-plane encoding has both similarities and differences as compared to strain-encoded (SENC) MRI (2). In SENC, through-plane spatial modulation of magnetization is also employed, however much higher spatial frequencies are used, and longitudinal strain is estimated from signal intensity changes on magnitude-reconstructed images. For the present cine DENSE method, lower encoding frequencies are used and longitudinal displacement and strain are calculated from phase-reconstructed images. The direct phase-based measurements of DENSE may provide improved accuracy compared to the magnitude-based estimations of SENC.

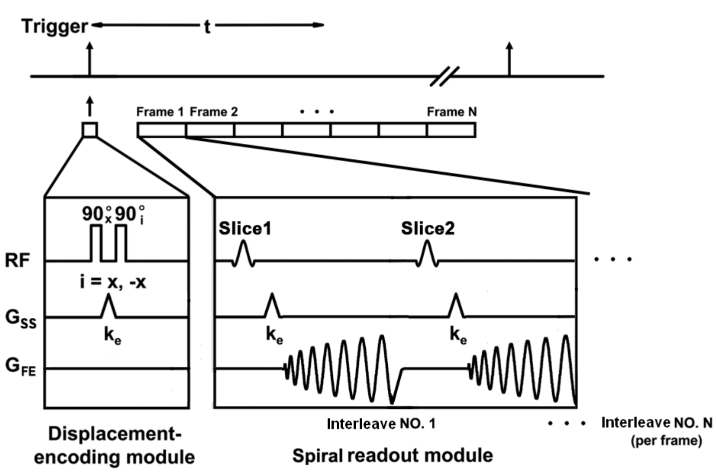

Fig. 1. Pulse sequence timing diagram for multislice cine DENSE. For clarity, slice select gradients for the RF pulses are not shown.

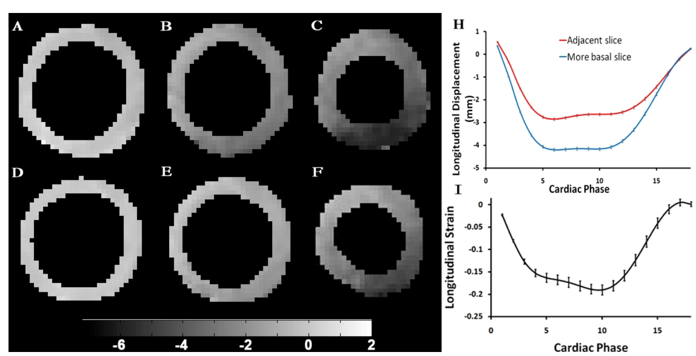

Fig. 2. Selected displacement-encoded phase-reconstructed images from basal (A-C) and adjacent (toward the apex) (D-F) slices at end diastole (A,D), mid systole (B,E), and end systole (C,F). These images measure longitudinal displacement as a function of time. More longitudinal displacement is seen in the more basal slice (H), leading to the development of longitudinal shortening during systole (I).

References (1) Spottiswoode et al. IEEE Trans Med Imag. 2007;26(1):15-30. (2) Osman. MRM 2003;49(3):605-8.
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