Accelerated Three-Dimensional Cine DENSE Strain Imaging in Three Minutes

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Target audience: Researchers, cardiologists and radiologists interested in imaging cardiac function.

Purpose: Imaging myocardial strain is of growing importance for the clinical assessment of heart disease. A 3D measurement can provide a complete assessment of the heart with regard to spatial coverage and a comprehensive evaluation of the strain tensor. Cine DENSE (Displacement ENcoding with Stimulated Echoes) has emerged as a strain imaging technique that, compared to tagging, offers high spatial resolution, equivalent accuracy and better reproducibility, and where strain analysis is less time consuming[1,2,3]. Previously, a navigator-gated 3D spiral cine DENSE sequence was developed which provided broad coverage and comprehensive strain quantification[4]; however, the scan time was approximately 25 minutes, which is too long for routine clinical use. In the present study, we accelerated 3D spiral cine DENSE and shortened the scan time to 2~4 minutes.

Methods:

Pulse sequence: The previously-described navigator-gated 3D stack-of-spirals cine DENSE sequence[4] was modified to achieve acceleration using compressed sensing and parallel imaging (CS-PI). Data undersampling was performed both in the in-plane (k_x-k_y) and through-plane (k_z) directions. For in-plane acceleration, 2 out of 6 variable-density spiral interleaves were used (rate-3 acceleration). The 2 spiral interleaves were uniformly distributed within each cardiac phase and rotated by the golden angle through different cardiac phases. For through-plane acceleration, 7 out of 14 partition encodings (rate-2 acceleration) were acquired following a variable density k_z-t sampling pattern where the center 3 k_z partitions were fully sampled and higher spatial frequency k_z partitions were randomly sampled.

Data collection: Prospectively rate-6 (3x2) accelerated 3D cine DENSE data were collected from 6 healthy volunteers on a 1.5T scanner (Siemens Avanto) using a 5-channel RF coil. The imaging protocol included: voxel size ~2.5x2.5x5.0mm^3, temporal resolution 32msec, cardiac phases ~22, displacement-encoding frequency k_e=0.06 cycles/mm, end expiration navigator acceptance window width of ±3mm. Fully-sampled 3D cine DENSE scans were also attempted for each volunteer but only 4 cases were completed. The other 2 scans were not completed due to drifting respiratory patterns.

Data reconstruction and analysis: A CS Block LOw-rank Sparsity with Motion-guidance (BLOSM)[5] and SENSE[6] technique was previously developed in our lab for reconstruction of accelerated 2D cine DENSE imaging[7]. This technique was extended for 3D imaging (3D BLOSM-SENSE). Multi-channel data were combined into images using sensitivity maps calculated from temporally-averaged data. The dynamic 3D images were divided into small cubes and matrix low-rank sparsity was exploited inside these cubes to remove artifacts. Three-dimensional strain analyses were performed using a previously published semi-automatic method[8].

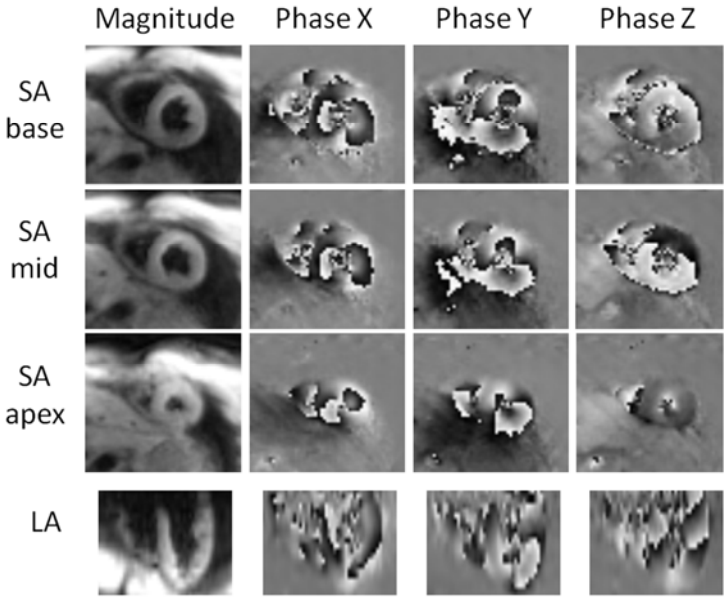

Figure 1: Example CS-accelerated 3D cine DENSE images. Three short-axis (SA) views at base, mid and apex locations, along with one long axis (LA) view are shown in different rows. The magnitude images (col 1) show clear delineation of the myocardium. All the phase images with displacement encodings in x (col 2), y (col 3) and z (col 4) show clear phase information that can be utilized for strain analysis.

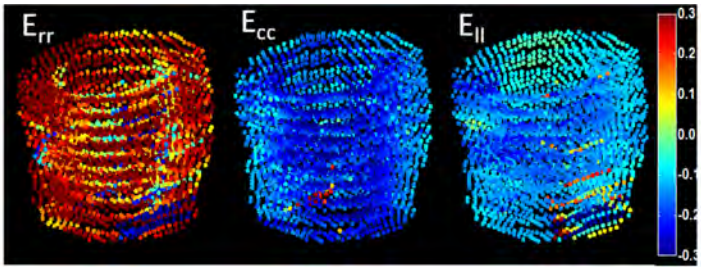

Figure 2: Example 3D voxel-wise strain maps of the LV at end systole. Radial (Err), circumferential (Ecc) and longitudinal strain (Ell) maps show values in the range of normal subjects.

Results: Example reconstructed images from rate-6 prospectively-accelerated 3D DENSE data show high image quality in both magnitude and phase through the whole heart (Fig 1). The strain analysis obtained from the reconstructed images agreed well with historical strain values[1] (Fig 2). The average accelerated scan time for all volunteers was **3.0±1.4 minutes** with navigation acceptance of 58±28%.

Conclusions: In this study, we have accelerated 3D cine DENSE imaging and have shortened the scan time from ~25 minutes to ~3 minutes. High image quality was achieved and strain analysis showed expected values for normal subjects. These results suggest that acceleration will make it feasible to routinely employ 3D cine DENSE for clinical comprehensive myocardial strain imaging with scan times of around 3 minutes.

References: [1] Simpson RM et al. JMRI 2013;37(3):576-599. [2] Spottiswoode BS et al. Med Image Anal 2009;13(1):105-115. [3]Young AA et al. MRM 2012;67(6):1590-1599. [4] Zhong XD et al. MRM 2010;64(4):1089-1097. [5] Chen X et al. MRM 2013;72(4):1028-1038. [6] Pruessmann KP et al. MRM 1999;42(5):952-962. [7] Chen X et al. JCMR 2014;16(Suppl 1):W16. [8]Auger D et al. JCMR 2014;16(1):8

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