High Resolution Strain Analysis of the Human Heart with Fast-DENSE

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Introduction

Displacement Encoding with Stimulated Echoes (DENSE) was recently presented for high-resolution myocardial displacement mapping (1,2). This work presents single breath-hold myocardial contraction measurements in the human heart, using a rapid version of DENSE (fast-DENSE). DENSE cardiac functional data combine desirable characteristics of both myocardial tagging and phase contrast (PC) velocity imaging. These include high spatial resolution, black-blood contrast and small encoding gradient strength. With DENSE, pixel phase is directly proportional to the displacement incurred over the encoding period. DENSE data may be used to compute accurate strain maps of the heart. Fast-DENSE is used to sample the stimulated echo multiple times in order to speed-up the acquisition process. This is accomplished via a low flip angle multi-shot segmented EPI sampling scheme (3). A modified centric k-space sampling scheme was implemented to increase SNR and reduce image artifacts. Planar functional data from the human heart were collected in 24 heartbeats within a single breath-hold and strain maps were computed. In addition, the overall error of in-vivo DENSE measurements was quantified in two normal volunteers.

Methods

In-vivo short axis data from the human heart at 2.5x2.5 mm^2 in-plane resolution were collected at 1.5 Tesla with the following parameters: Encoding for 1.6mm/π, Slice = 7-8mm, TE = 4.2ms, encoding interval TM = 105ms. The position encoded magnetization was recalled via a segmented EPI imaging scheme (centric ordering, 8 segments, six 30° RF pulses per segment, 2 gradient echoes per RF pulse, TR=6.4ms). In 24 heartbeats, a reference image along with the x and y encoded images were collected for a single slice. Eigenvector strain analysis was performed with in-house software. As expected, the principal direction of fiber shortening was circumferencial whereas dilation was radial. To quantify the accuracy of strain maps, the variability of each phase map in the DENSE data set was measured by acquiring the same image three times instead of acquiring a reference and the two encoded images. The strain estimated from these control DENSE data sets is the error in such strain measurements.

Results

A typical displacement short-axis arrow plot is shown in Figure 1. Each arrow-head corresponds to the position of the pixel at end-systole while each arrow-tail corresponds to the pixel's position (in mm) 100ms earlier. Figures 2 and 3 present short-axis strain maps computed from the arrow plots and correspond to dilation and contraction respectively. The bars represent the principal direction of strain while the grayscale depicts upto 20% of dilation or contraction. With the control DENSE studies, the absolute error in strain was measured to be 3%. In the human heart, this represents a relative error of 15% in strain.

Discussion

High resolution strain maps were collected with fast-DENSE. In theory, the SNR of the strain maps can be increased by utilizing larger encoding gradient strength. However, with the current pulse sequence, it was clear that 1.6mm/π encoding strength was optimal. Higher values resulted in regional signal loss. Clinical applications of DENSE will be feasible when total acquisition time is limited to less than 15 heartbeats. DENSE provides high spatial resolution and accuracy in strain estimation; however, it sacrifices temporal resolution. Compared to tagging techniques, data processing is straightforward.

References

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3. J. Frahm, W. Hanicke, H. Bruhn, M.L. Gyngell, K.D. Merboldt, Magn. Reson. Med. 22, 133-142, 1991.

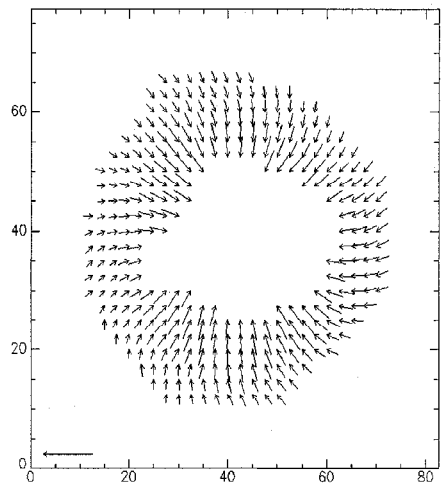

Figure 1.
Short-axis displacement arrow plot of the human heart.

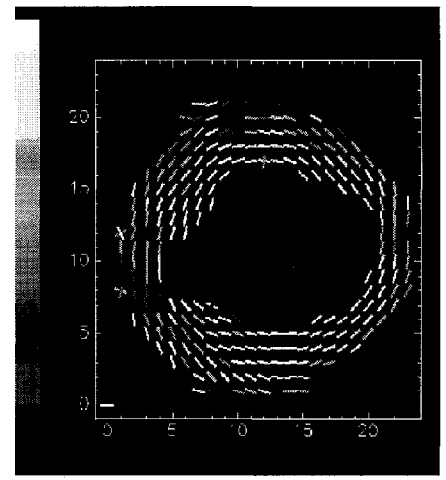

Figure 2.
Short-axis strain map of the human heart: dilation.

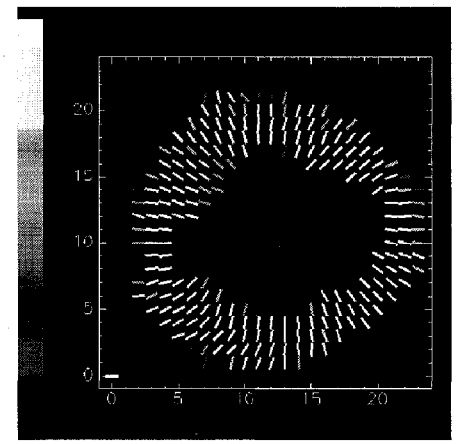

Figure 3.
Short-axis strain map of the human heart: contraction.