Low encoding frequencies accurately quantify cardiac mechanics while minimizing phase wrapping in 2D cine DENSE with through-plane dephasing

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Background
Displacement Encoding with Stimulated Echoes (DENSE) encodes displacement into the phase of the MR signal to quantify cardiac mechanics. The encoding frequency (ke) links myocardial displacement to phase. Studies with 2D cine DENSE have used ke of 0.10 cycles/mm, which is high enough to remove the stimulated anti-echo from the sampled k-space and is partially responsible for dephasing the blood signal. This ke leads to wrapping in the phase images and causes intra-voxel dephasing. With the advent of through-plane dephasing, the unwanted echo can be removed without relying on high ke. This may allow the use of lower ke to simplify post-processing and increase SNR. Low ke, however, may be less sensitive to displacement and result in inaccurate measures of cardiac mechanics. We hypothesized that ke below 0.10 cycles/mm will 1) provide accurate measures of cardiac mechanics, 2) minimize phase wrapping, 3) dephase the blood signal, and 4) improve SNR.

Methods
Spiral cine DENSE was obtained on 10 healthy subjects and 5 patients with a history of heart disease on a 3T Siemens Tim Trio. For each subject, a mid-ventricular short-axis slice was acquired 5 times with respiratory navigation using a range of encoding frequencies: 0.02, 0.04, 0.06, 0.08, and 0.10 cycles/mm. The acquisition with 0.10 cycles/mm was repeated to assess inter-test reproducibility. Other DENSE parameters included: 6 spiral interleaves, 2.4x2.4x8 mm voxel size, 1.08/17 ms TE/TR, constant 20° flip angle, CSPAMM echo suppression, and through-plane dephasing of 0.08 cycles/mm. Twist, circumferential strain, and radial strain were compared between acquisitions employing different ke using Bland-Altman analyses, coefficient of variation (CoV), and paired t-tests. The percentage of wrapped pixels in the phase images at end-systole was calculated for each ke. The magnitude of the blood pool signal was measured through the cardiac cycle to follow dephasing. SNR was calculated at end-systole to assess intra-voxel dephasing.

Results
Figure 1 contains end-systolic images from a representative subject. Negligible differences were seen in the strains and twist for all ke between 0.04 and 0.10 cycles/mm (Table 1). These differences were of the same magnitude as the inter-test differences. For 0.02, 0.04, 0.06, 0.08, and 0.10 cycles/mm: 1) the percentage of wrapped pixels in the phase images at end-systole was 0, 0, 6, 19, and 35%, 2) the percent of blood pool signal remaining 68 ms after encoding was 30, 28, 25, 24, and 22%, and 3) the mean SNR at end-systole was 26, 26, 26, 25, and 24, respectively.

Conclusions
For 2D cine DENSE with through-plane dephasing, the encoding frequency can be lowered to 0.04 cycles/mm without causing changes in measures of twist or strain. The amount of wrapping and reliance on un-wrapping algorithms can be substantially reduced with this lower
Figure 1: End-systolic, short-axis images from a patient with heart disease. Five separate acquisitions employing different $k_e$ yielded unique magnitude and phase images. The prevalence of phase-wrapping in both the x- and y-phase images decreased as $k_e$ decreased.
value. The use of lower $k_e$ marginally decreases the rate of blood pool dephasing and provides small improvements in SNR.

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