Improved Efficiency in Cine DENSE using Low Resolution Phase Reference Images

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Introduction. DENSE is a quantitative myocardial wall motion imaging technique that encodes tissue displacement into the phase of the stimulated echo [1]. In addition to encoded displacement, the phase of the stimulated echo is also influenced by other factors such as B0 inhomogeneity. If phase shifts from sources other than the encoded displacement are not corrected for, they lead to errors in the measured myocardial motion. Therefore, unencoded phase reference images are typically acquired and used for phase correction [2]. While the use of phase reference images is straightforward and effective, this approach has the disadvantage of increasing the scan time significantly. For example, for a typical breathhold cine DENSE scan with an acquisition time of 18 heartbeats, 6 of the heartbeats are used to acquire phase reference data [2]. Since the background phase tends to vary slowly compared to the image spatial resolution, the purpose of the present study was to investigate whether low resolution phase reference images could be acquired in reduced scan times without significantly increasing the error in measured myocardial displacement and strain.

Methods. An echo-planar cine DENSE sequence that uses CSPAMM to acquire displacement encoded data in 10 heartbeats and acquires full resolution phase reference images in 5 heartbeats was modified to acquire low spatial resolution phase reference images in 0 – 5 additional heartbeats. The echo spacing of the low resolution phase reference images was adjusted as accurately as possible to ensure that off-resonance induced spatial shifts in the phase encoding direction matched those of the full resolution images. Also, the effective TE of the low resolution image matched the TE of the full resolution images. During image reconstruction, the low resolution data were filtered using a Hanning window to eliminate Gibbs ringing and then zero padded to the full matrix size. One set of displacement encoded images was reconstructed using the full resolution phase reference images and a second set was reconstructed using the low resolution phase reference images. Displacement measurements made using the low resolution phase reference images were evaluated by computing pixel-wise displacement and strain differences versus the images reconstructed using the full resolution phase reference data. For this study, the field of view was fixed at 27 x 36 cm and the full resolution matrix was 96 x 128. Other parameters included slice thickness = 8mm, flip angle = 15°, TR = 20 ms, TE = 10 ms, ETL = 9, segments = 18, phases = 20, and displacement encoding frequency = 0.1 cycles/mm. Low resolution matrix sizes were 72 x 96, 60 x 80, 48 x 64, 24 x 32, and 0 x 0, with acquisition times of 4, 3, 2, 1, and 0 heartbeats, respectively. Under protocols approved by our institutional review board, 5 volunteers were scanned using a 1.5T Avanto scanner (Siemens Medical Solutions) after informed consent was obtained.

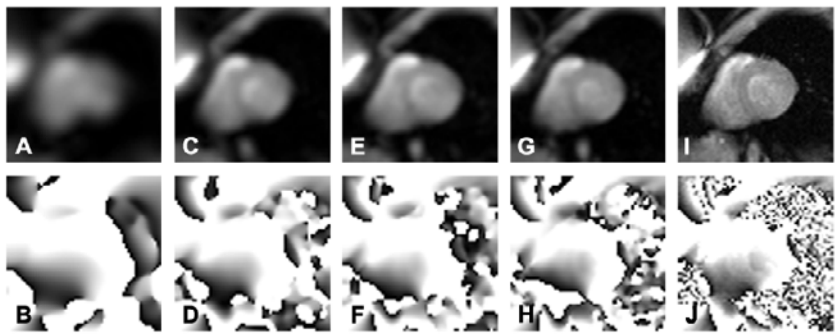

Fig. 1. Magnitude and phase reconstructed images at various spatial resolutions (low A, B – high I, J) acquired in 1 – 5 heartbeats, respectively. The background phase varies slowly compared to pixel size.

Results. Example low resolution and full resolution phase reference images are shown in Fig. 1, demonstrating the relatively slowly varying background phase. Displacement error summarized for all 5 volunteers as a function of cardiac phase is shown in Fig. 2, where large errors are seen when no phase reference images are acquired, and where the error decreases as the resolution of the phase reference images increases. The mean circumferential strain errors for all the volunteers were 0.0056±0.0034, 0.0057±0.0028, 0.0073±0.0032, 0.0147±0.0066, and 0.0800±0.0179 for low resolution reference scans acquired in 4 – 0 heartbeats, respectively, which also shows increase in error as the resolution of the phase reference images decreases. Peak circumferential strain is typically approximately 0.25.

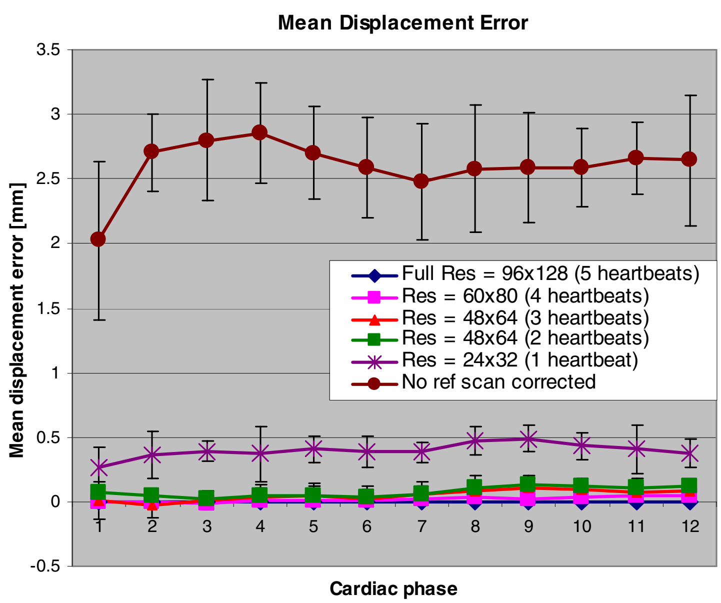

Fig. 2. Mean displacement error as a function of cardiac phase for phase reference scans of varying spatial resolution.

Conclusions. For the parameters investigated in this study, phase reference images acquired in 2 heartbeats with a matrix size of 48 x 64 provided the best tradeoff between measurement error and scan time. Replacing the full resolution phase reference scan with this low resolution scan decreases the scan time by 20% with minimal loss in accuracy. The time savings can be used to achieve shorter scan times or higher spatial or temporal resolution. These results also suggest that techniques such as HARP that do not account for background phase shifts likely have reduced displacement and strain accuracy.

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1. Aletras et al. Journal of Magnetic Resonance 1999; 137:247-252.

2. Kim et al. Radiology 2004; 230:862-871.