Cine DENSE MRI of Left Ventricular Dyssynchrony: Development and Initial Clinical Experience

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Introduction. Cardiac resynchronization therapy (CRT) for patients with end stage heart failure has been shown to improve hemodynamics, heart failure symptoms, exercise capacity, quality of life, and mortality (1). Current criteria for CRT include NYHA class III or IV symptoms, left ventricular ejection fraction (LVEF) <35%, and QRS duration >130msecs. However when these criteria are applied as many as 30% of patients are non-responders (1). Tissue Doppler data have shown that mechanical dyssynchrony is a better predictor of response to CRT than electrical dyssynchrony assessed by QRS duration and morphology (2). However, the specificity of tissue Doppler for predicting response to CRT remains only 75 – 80%. Cine DENSE (displacement encoding using stimulated echoes) MRI (3) can quantify myocardial strain with high spatial and temporal resolution, and, using semi-automated techniques, strain analysis of cine DENSE images is rapid and suitable for routine clinical application. In addition to assessing mechanical dyssynchrony, late gadolinium enhanced MRI can detect regional myocardial scar. The purpose of the present preliminary study was to establish the ability of cine DENSE and late gadolinium-enhanced MRI to detect mechanical dyssynchrony and scar, respectively, in heart failure patients, with the future goal of improving selection of patients for CRT.

Methods. Eight patients followed by the University of Virginia Health System cardiology division for congestive heart failure were enrolled. Entry criteria were documented LVEF <35%, NYHA class III symptoms, and no contraindication to MRI. Patients were imaged on a 1.5T Avanto scanner (Siemens Medical Solutions). Cine SSFP imaging of the heart in 2, 3, and 4 chamber views was obtained followed by short axis slices from the base to apex. Cine DENSE images were obtained next in 3 short-axis planes (base, midventricle, apex). In each slice, cine DENSE images encoded for displacement in orthogonal in-plane directions were acquired in separate 15 heartbeat breathholds. Using TR = 20 ms, TE = 11, FOV = 360 x 252, matrix = 128 x 90, ETL = 9, segments = 18, slice thickness = 8 mm, flip angle = 15°, and rate 2 view sharing, the spatial resolution was 2.8 x 2.8 mm^2 and the temporal resolution was 20 ms. Patients were then injected with Gd-DTPA 0.2 mmol/kg and phase sensitive inversion recovery image acquisition commenced after 10 minutes in the same slice positions imaged with cine DENSE. Left ventricular systolic function (volumes and ejection fraction) was calculated using Argus analysis software (Siemens Medical Solutions). Circumferential strain (E_{cc})–time curves were computed in 16 cardiac sectors using custom written software developed in MATLAB. Delayed onset of shortening was used as a metric of dyssynchrony, and the time to onset of contraction (t_{onset}) in ms for each segment was defined as the time at which the $E_{cc}(t)$ slope became negative. The extent of late gadolinium enhancement was also measured in each segment (percent per sector) using a custom written MATLAB program.

Results. Of the 8 patients studied, the etiology of heart failure was ischemic in 4 and nonischemic in 4. Three of the patients had left bundle branch block and 2 had right bundle branch block. QRS duration ranged from 84 – 151 ms and the mean ejection fraction was 22 ± 8%. Cine DENSE images from all patients were determined to be of analyzable quality. Example E_{cc} – time curves for one patient demonstrating normal onset and delayed onset of shortening are shown in Fig. 1. Example bullseye plots of onset time and extent of hyperenhancement are shown for patients without (Fig. 2) and with (Fig. 3) myocardial scar. In the patient without scar (Fig. 2), the inferior and posterior walls demonstrate delays in the onset of shortening from 20 – 60 ms, suggesting that this patient with a narrow QRS duration of 107 ms may indeed respond to CRT. In the patient with scar (Fig. 3), most segments of delayed onset are co-localized with heavily scarred segments, with only the apical inferior wall demonstrating delayed onset of shortening in a mildly infarcted sector. This pattern suggests that CRT might lead to only mild functional improvement in this patient. For patients with ischemic heart disease, the mean delay to onset of shortening was 26.2 ± 17.6 ms and the average of the within-subject standard deviations of the delay to onset, which reflect the distribution of onset times per subject, was 38.9 ± 20.6 ms. For patients with nonischemic disease, the mean delay was 53.2 ± 39.0 ms and the standard deviation was 68.7 ± 52.0 ms

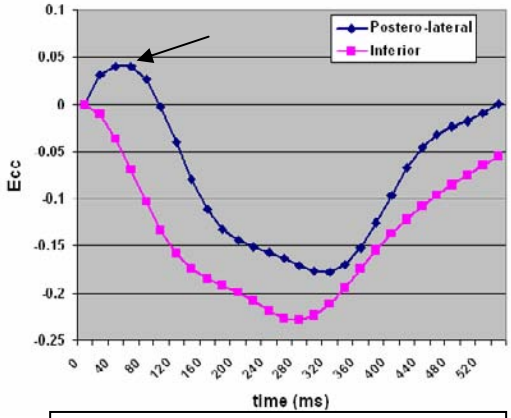

Fig. 1. Example strain-time curves demonstrating delayed onset of circumferential shortening in the posterolateral wall (arrow) and normal time to onset in the inferior wall.

Conclusions. Cine DENSE and Gd-enhanced MRI can non-invasively quantify areas of delayed onset of shortening and determine whether they are co-localized with scar. These techniques can be applied in a single imaging study in heart failure patients with ischemic and non-ischemic cardiomyopathies who have a wide range of QRS durations. The current temporal resolution achieved using cine DENSE of 20 ms is adequate to detect delays of greater than 40 ms, but methods with higher temporal resolution to more finely sample the strain-time curve are in development. The assessment of mechanical dyssynchrony by cine DENSE and viability by late Gd-enhanced MRI holds promise for improving the ability to select patients for CRT.

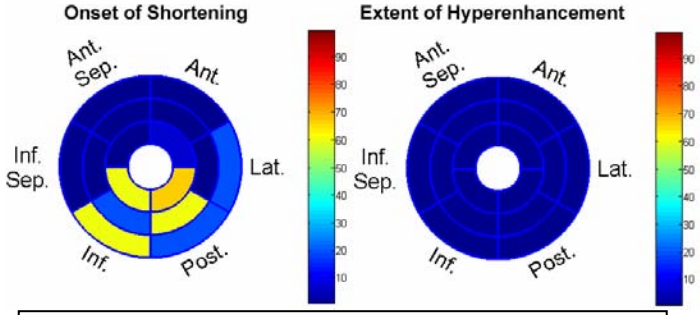

Fig. 2. Bullseye plots of the time to onset of shortening in ms (left) and the percent hyperenhancement (right). In this patient with nonischemic cardiomyopathy, cine DENSE detects delays in the onset of shortening from 20 – 60 ms in the inferolateral wall with the greatest delay at the apex. No hyperenchancement was detected.

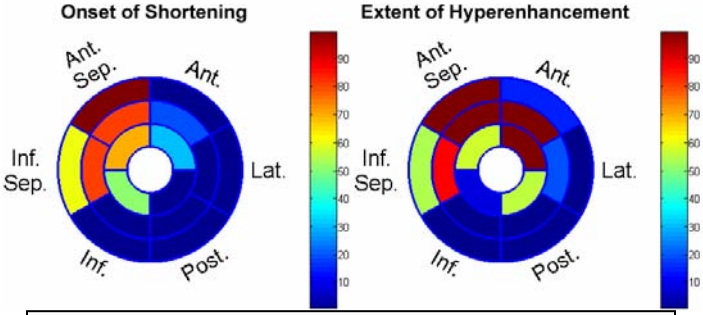

Fig. 3. Bullseye plots of the time to onset of shortening in ms (left) and the percent hyperenhancement (right). In this patient with a large region of scar due to previous myocardial infarction, sectors with delayed onset of shortening from 20 – 100 ms are mainly co-localized with heavily hyperenhanced sectors.

1. Bristow MR. *NEJM* 2004;350:2140-2150. 2. Penicka et al. *Circulation* 2004;109:978-983. 3. Kim et al. *Radiology* 2004; 230:862-871.

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