Measuring LV-RV Interventricular Dyssynchrony using Cine DENSE MRI

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Introduction: Cardiac resynchronization therapy (CRT) has been shown to improve symptoms, quality of life, left ventricular (LV) function, and mortality in patients with end stage heart failure [1]. However, approximately 30% of patients that meet the current criteria for CRT do not respond positively to this costly and invasive therapy [1]. Recent tissue Doppler echocardiographic studies have shown that measurement of mechanical dyssynchrony improves the ability to prospectively identify CRT responders compared to the current criteria which includes the ECG QRS duration as a measure of electrical dyssynchrony [2]. Moreover, while intraventricular LV dyssynchrony is superior to QRS duration, the additional measurement of interventricular dyssynchrony between the right ventricle (RV) and LV further improves the ability to prospectively identify CRT responders [2]. We are developing cine DENSE MRI methods [3] for quantifying mechanical dyssynchrony which may be superior to tissue Doppler in terms of spatial coverage and the ability to assess circumferential strain rather that longitudinal velocities, strain rate, and strain. In the present study we extended cine DENSE methods typically used to image the LV to measure RV strain-time curves. We subsequently acquired data demonstrating the detection of intra- and interventricular dyssynchrony in heart failure patients with left and right bundle branch block (LBBB and RBBB), respectively.

Methods: The RV is typically 2 – 3 mm thick, and spans only 1 – 3 pixels in cine DENSE images. This poses three main challenges to the analysis: phase unwrapping, through-plane motion and a suitable measure of strain. For this application, the phase unwrapping algorithm described in [4] was made more robust by using spatio-temporal phase quality maps, predefined myocardial contours, and by commencing the unwrapping at all myocardial pixels on the first cardiac phase.

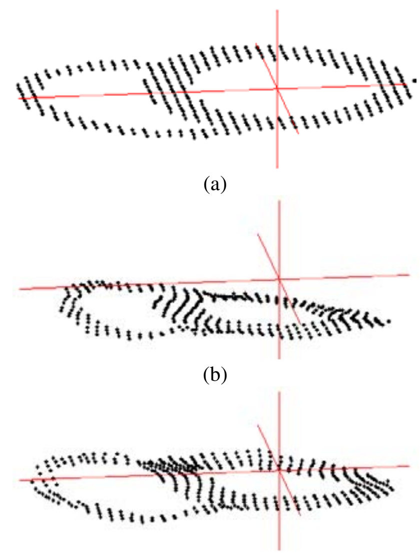
Slice-followed (SF) cine-DENSE [5] accounts for the high degree of longitudinal motion of the RV [6]. Figure 1 shows an example of 3D tracking using SF cine DENSE, where three cardiac phases of a normal volunteer are portrayed. Each point in Figure 1a represents the center of a voxel at end-diastole, and Figure 1b and c portray the position of these points along their trajectories at end-systole and mid-diastole, respectively. Variations in through-plane motion are evident, as is the LV radial thickening and circumferential shortening typically seen in tagged images. The volunteers were imaged using SF and the patients were imaged without SF.

Circumferential strain (Ecc) has previously been shown to be a sensitive metric of intraventricular LV dyssynchrony [7]. Ecc, which is the component of the 2D strain tensor in a direction circumnavigating the LV centroid, is a reasonable measure of strain for the annulus-shaped LV in the short axis view. The shape of the RV is more complex, and there are typically too few transmural pixels to reliably calculate the 2D strain tensor. We therefore propose using a measure of Lagrangian strain taken tangential to the midwall (Ett). Figure 2 shows 2D linearly interpolated DENSE displacement vectors along the midwalls of a normal volunteer at end-systole. The heads of the vectors refer to the position of the material points at the current time t, and the tails refer to the position at the time of displacement encoding, t=0. Ett at point p_n can be obtained using the two adjacent vectors along the midwall. If l_0, the undeformed length, is the distance measured by cine DENSE between the tails of the vectors at p_{n-1} and p_{n+1}, and l_t, the deformed length, is the distance between the heads of these two vectors at time t, then Ett at p_n is given by $\frac{1}{2}((l_t / l_0)^2 - 1)$. The LV midwall was divided into six standard segments. The anterior two-thirds of the RV midwall was classified as the RV free wall, and the remaining third was classified as the diaphragmatic RV wall.

An ECG-gated 2D EPI cine-DENSE sequence [8] was run on a 1.5 T Siemens Avanto scanner. Imaging parameters included FOV = 360 × 252 mm; TE = 11 ms; TR = 20 ms; slice thickness = 8 mm; pixel size = 2.81 × 2.81 mm^2; temporal resolution = 20 ms (rate 2 view sharing); and displacement encoding frequency = 0.1 cycles/mm. In accordance with protocols approved by our institutional review board, and with informed consent, 2 normal volunteers, 2 patients with LBBB, and 2 patients with RBBB were imaged.

Results: Midwall Ett strain-time curves for two segments in a normal volunteer are presented in Figure 3a, depicting synchronous onset of contraction for both ventricles. Strain-time curves for patients with LBBB and RBBB are shown in Figure 3b and c, demonstrating delayed onsets of strain of 60 – 80 ms in the LV and RV respectively. The results for the remaining subjects were similar.

Conclusions: A cine DENSE technique suitable for imaging both the LV and RV was developed. Initial results in volunteers and heart failure patients suggest that this technique can be used to assess RV strain and interventricular dyssynchrony. Higher spatial resolution would simplify the phase unwrapping and tissue tracking algorithms. When used in conjunction with delayed contrast enhanced MRI and cine DENSE measurements of intraventricular LV dyssynchrony, the additional measurement of interventricular RV-LV dyssynchrony may improve our ability to prospectively identify CRT responders.



(a) (b) (c)

Figure 1. Three dimensional trajectory positions of a mid-ventricular short-axis slice of a healthy volunteer at (a) end-diastole, (b) end-systole, and (c) mid-diastole.

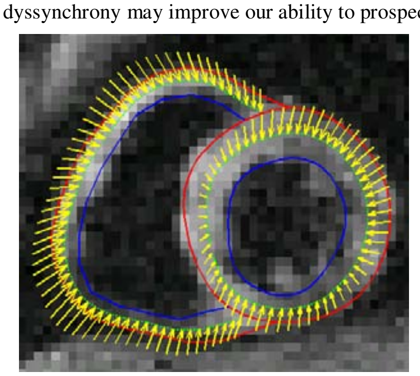
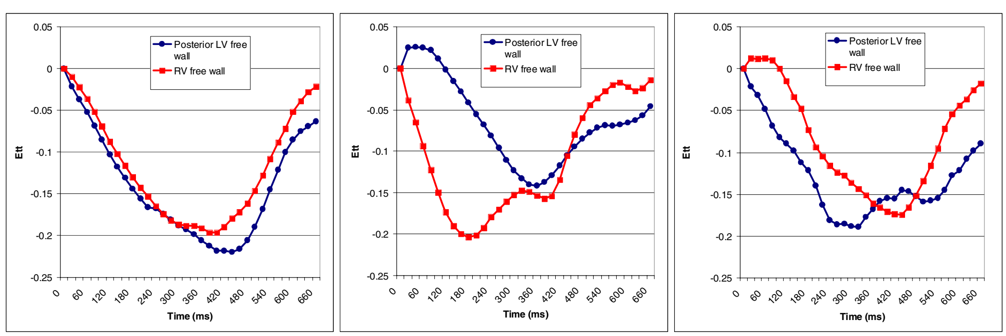


Figure 2. Interpolated midwall DENSE displacement vectors.



(a) (b) (c)

Figure 3. Ett versus time for (a) a normal volunteer, (b) a patient with LBBB, and (c) a patient with RBBB.

1. Bristow MR. NEJM 2004; 350:2140-2150.
2. Penicka M. *et al.* Circulation 2004; 109:978-983.
3. Patel R. *et al.* Submitted to ISMRM 2006.
4. Spottiswoode B.S. *et al.* Proc. ISMRM 2005; #2786.
5. Spottiswoode B.S. *et al.* Proc. SCMR 2006.
6. Haber I. *et al.* Am J Physiol Heart Circ Physiol 2005; 289: H1826–H1833.
7. Helm R.H. *et al.* Circulation. 2005; 111(21): 2760-2767.
8. Kim D. *et al.* Radiology 2004; 230:862-871.

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