Mechanical Activation Time Mapping in Heart Failure Patients with and without Myocardial Scar using Cine DENSE MRI

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Target audience: Researchers and clinicians interested in cardiac MRI and cardiac activation.

Purpose: The purpose of this study was to use MRI and other methods to evaluate the relationship between mechanical and electrical cardiac activation in patients with heart failure (HF), a wide QRS complex, and the absence or presence of myocardial scar. These factors are clinically relevant in the setting of cardiac resynchronization therapy (CRT) using biventricular pacing, as understanding the electromechanical properties of the underlying substrate is critical to achieve optimal implementation of CRT. We have previously developed MRI strain imaging methods to detect regions of delayed mechanical activation in patients with HF and left bundle branch block (LBBB) [1]; however this patient cohort excluded patients with myocardial scar. The presence of myocardial scar makes the myocardial substrate more complex and can alter electromechanical coupling. The present study applied cine DENSE (Displacement Encoding with Stimulated Echoes) MR strain imaging [2] to assess the delay in mechanical activation time in patients with and without scar, and compared the relationship between mechanical and electrical activation between these patient cohorts.

Methods: Cine DENSE MRI was performed on a 1.5T MRI system in standard short-axis planes in 6 healthy subjects and 2 cohorts of HF patients all of whom were referred for CRT treatment: 16 patients with LBBB and no myocardial scar; and 11 patients with LBBB and myocardial scar. Late gadolinium enhanced (LGE) MR imaging was used to detect scar, and Hammer projection maps were used to illustrate the distribution of scar [3]. Circumferential strain (E_{cc}) was computed from cine DENSE images using previously described semiautomatic methods [4]. Midwall E_{cc} was arranged into a matrix form (Fig. 1(a)), and singular value decomposition (SVD) was applied to denoise the spatiotemporal strain data. An active contour (AC) method automatically detected the mechanical activation time (defined as the onset of circumferential shortening) based on the patient's E_{cc} pattern (Fig. 1(a)). During the CRT implementation procedure, the electrical activation time (QLV) was assessed at the LV lead implantation site. Registration methods between MRI and fluoroscopy were used to determine the LV lead position on the MR images [5], and mechanical and electrical activation times at that location were subsequently compared.

Results: The mean time of the latest mechanically activated segment was 26 ± 7 ms in healthy subjects, 70 ± 19.8 ms in HF patients with no scar (p<0.01 vs. healthy subjects), and was 76 ± 48.4 ms in HF patients with scar (p<0.01 vs. healthy subjects). Fig. 1(a) shows a mid-ventricular E_{cc} matrix (as a function of cardiac phase and left ventricular segment) of a patient with HF-LBBB and no scar. The figure illustrates the AC (black line) depicting the times of mechanical activation (onset of shortening), including the region of pre-stretch / delayed mechanical activation (arrow). A corresponding DENSE activation time map is shown in Fig 1(b), where mechanical activation in the inferolateral wall is delayed by 75 ms. Fig 1(d) illustrates the scar distribution using a Hammer projection map for a second patient with HF-LBBB and scar. The corresponding DENSE mechanical activation time map for a basal slice is shown in Fig 1(e). The region of scar for this slice was located in the lateral wall of the LV while the region of delayed mechanical activation occurred adjacently, in the anterolateral segment of the LV. The latest mechanical activation delay in this slice was 135 ms. As shown in Fig 1(c) and (f), the plots of mechanical vs. electrical activation times at matched locations for patients with no scar versus those with scar at the LV lead implantation site, respectively, demonstrate that the slope of the regression line is greater in patients with scar vs. patients without scar, suggesting altered electrical-mechanical coupling due to scar.

Conclusions and Discussion: Cine DENSE strain MRI detects regions of late mechanical activation in HF patients referred for CRT. Good correlations between mechanical and electrical activation times were found in HF patients without and with myocardial scar, and the slope of the regression line was greater in patients with scar, likely representing altered electro-mechanical coupling in patients with scar compared to those without scar. Noninvasive imaging of cardiac mechanical activation and scar are likely to provide insights useful for optimal implementation of CRT in HF patients.

References: [1.] Auger et al. AHA Scientific sessions, 2014. [2.] Kim et al. Radiology, 2004; 230:862-71 [3.] Herz et al. Ann Biomed Eng, 2005; 33:912-9. [4.] Spottiswoode et al. MIA, 2009; 13:105–15. [5.] Parker et al. PACE, 2014; 37:757-67.

Acknowledgements: AHA Grant-in-Aid 12GRNT12050301, Siemens Medical Solutions, NIH RO1 EB 001763

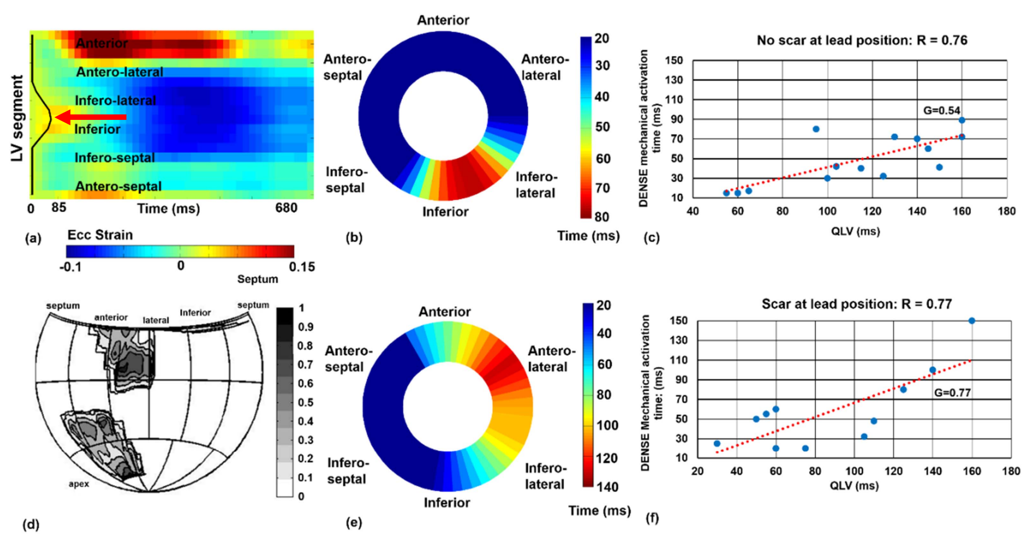

Figure 1: (a) Strain matrix showing region of late activation (red arrow) depicted by the AC in a patient with HF-LBBB. (b) The corresponding DENSE mechanical activation time map. (c) Correlation of mechanical and electrical activation times for patients with no scar. (d) Hammer map showing regions of myocardial scar in a different patient. (e) DENSE mechanical activation time map. (f) Correlation of mechanical and electrical activation times for patients with myocardial scar.