Cine DENSE for Assessment of Diastolic function: Pulse Sequence Development and Initial Results.

Bhairav Bipin Mehta[1], Andrew D. Gilliam[2], Frederick H. Epstein[1,3], and Michael Salerno[3,4]

[1]*Department of Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States,* [2]*A.D. Gilliam Consulting, Providence, Rhode Island, United States,* [3]*Department of Radiology, University of Virginia, Charlottesville, Virginia, United States,* [4]*Department of Medicine, Cardiology Division University of Virginia, Charlottesville, Virginia, United States*

Introduction Heart failure with preserved ejection fraction (HF-PEF) resulting primarily from diastolic dysfunction accounts for more than half of all heart failure cases[1]. Echocardiographic techniques such as transmitral inflow and tissue Doppler imaging are commonly used to assess diastolic function; however, limited acoustic windows, operator dependence, and the angular dependence of Doppler can limit the accuracy of these techniques. Strain and strain rate measurement using MRI may be preferable to existing techniques, since they do not have these limitations. Cine Displacement Encoding with Stimulated Echoes (DENSE) has been used to measure displacement, strain[2], and strain rate[3]. Typically, DENSE displacement encoding is performed at end diastole (ED), and images covering the first two-thirds of the cardiac cycle are acquired with high signal-to-noise ratio (SNR). This acquisition technique is not optimal for imaging diastole, as SNR in the later diastolic phases of the cardiac cycle is reduced due to the T1 decay of the stimulated echo and the cumulative effects of radio frequency pulses. We developed a cine DENSE sequence capable of imaging the entirety of diastole with sufficient SNR to compute accurate diastolic displacements, strains, and strain rates.

Method All studies were performed using a 1.5T scanner (Avanto, Siemens, Germany) and in accordance with protocols approved by our institutional review board. We modified a spiral cine DENSE sequence[4] (referred to here as systolic DENSE, figure 1A) to apply displacement encoding pulses after a fixed delay from the ECG R wave (referred to here as diastolic DENSE, figure 1B). We then compared diastolic displacements, strains, and strain rates between the two sequences in 7 healthy volunteers. The diastolic DENSE sequence was designed to detect the ECG R wave even during the readout period which allows data to be collected on every heart beat, significantly reducing the required breath-hold duration of the conventional gating scheme. A single short axis section of the left ventricle was acquired with each DENSE sequence. Specific imaging parameters included: field of view = 300-350 mm, matrix = 128 x 128 pixels, slice thickness = 8mm, flip angle = 15°, TR = 17 ms, TE = 1.08 ms, number of spiral interleaves = 6. View sharing was used to achieve an effective temporal resolution of 17 ms, and a two point displacement encoding strategy was used with displacement encoding frequency = 0.1 cycles/mm. Through plane dephasing (frequency = 0.08 cycles/mm) and 2-point phase cycling were used for artifact suppression. Lagrangian displacement and strain were estimated offline as described previously[5]. As strain values are dependent on the position of the myocardium during displacement encoding, strain values from diastolic DENSE were temporally shifted and scaled using reference data from a matched systolic DENSE scan. SNR was calculated as the average signal intensity of the entire myocardium from DENSE magnitude images divided by the average standard deviation over all frames in a noise region.

Results Figure 1 displays example Lagrangian 2D displacement maps, which illustrate that systolic DENSE measures displacement from end diastole (1A, C) while diastolic DENSE measures displacement from late systole (1B, D). Figure 2 shows that the SNR during diastole is uniformly low using the systolic DENSE method (panel A), but the SNR during much of diastole is higher using the diastolic DENSE method (panel D). Atrial systole (panels E and F, arrow) was captured with the diastolic DENSE sequence but not with systolic DENSE (panels B and C). Peak circumferential strain rate during early diastole and atrial systole were computed for each volunteer using diastolic DENSE strain rate data. Peak strain rate during early diastole was 0.87 ± 0.08 1/s, which agrees with the literature[6] and peak strain rate during atrial systole was 0.26 ± 0.05 1/s.

Conclusion A cine DENSE sequence was developed to improve strain and strain rate measurement during the diastolic part of the cardiac cycle. This method allows quantitative comparisons of diastolic function by measuring diastolic strain and strain rate. Since strain and strain rate provide direct information on myocardial mechanical properties, their measurement using DENSE MRI may improve the evaluation of diastolic dysfunction. In the future we will investigate using ramped flip angles to achieve a more uniform SNR throughout diastole.

References [1] Owan et al NEJM 2006; 355(3) :251-259. [2] Kim et al Radiology 2004 ; 230 :862-871. [3] Vandsburger et al AJPHCP 2011(in press). [4] Zhong et al Proceedings of 15th ISMRM 2007 ; p. 756. [5] Spottiswoode et al. IEEE Trans Med Imag. 2007;26. [6] Ennis et al MRM 2003; 50:638-642.

Acknowledgements This work was funded by Siemens Medical Solutions and NIH R01 EB 001763.

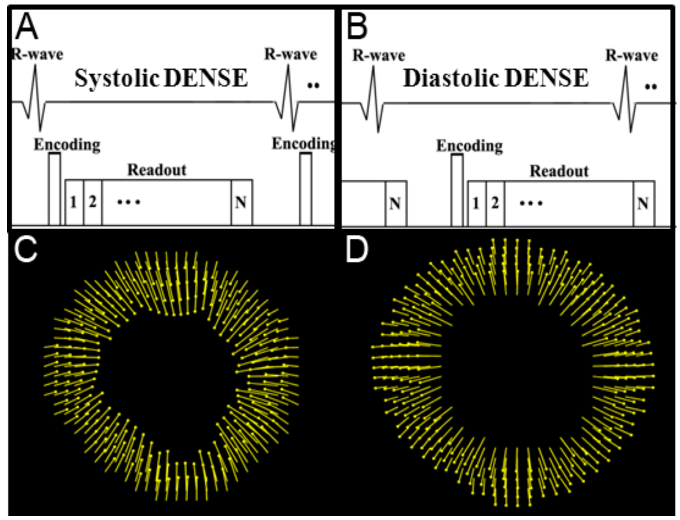

Fig. 1. Example Lagrangian 2D displacements (bulk corrected) maps. A: Acquisition strategy for systolic DENSE, B: Acquisition strategy for diastolic DENSE, C: Displacements using systolic DENSE, D: Displacements using diastolic DENSE. Image C shows radially inward movement of the myocardium while image D shows radially outward movement of the myocardium.

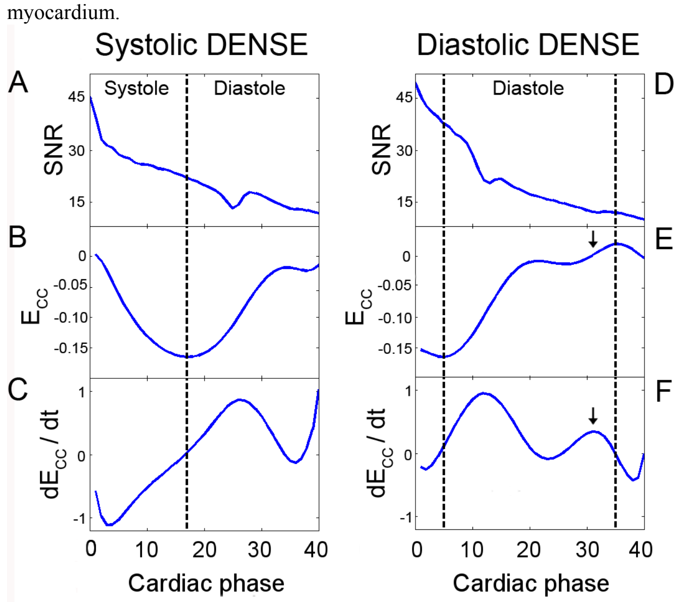

Fig. 2. Example SNR vs time (A,D) , normal circumferential Lagrangian strain (Ecc) vs time (B,E), and normal circumferential Lagrangian strain rate (dEcc/dt) vs time (C,F) curves acquired using systolic DENSE (A-C) and diastolic DENSE (D-F). With systolic DENSE, the SNR is low during the diastolic part of the cardiac cycle but with diastolic DENSE, SNR is relatively high during diastole.