Assessment of diastolic dysfunction in hypertensive patients using full-cycle cine DENSE

Bhairav Bipin Mehta[1], Sujith Kuruvilla[2], Michael Salerno[1,2], and Frederick H Epstein[1,3]

[1]Department of Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States, [2]Department of Medicine, Cardiology Division, University of Virginia, Charlottesville, Virginia, United States, [3]Department of Radiology and Medical Imaging, University of Virginia, Charlottesville, Virginia, United States

Target audience: Clinicians and scientists working on assessment of diastolic dysfunction or patients with hypertension.

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]. Diastolic dysfunction is independently associated with increased cardiovascular morbidity and mortality[2]. 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. Speckle tracking techniques have been used to assess diastolic strain but robust application of this technique requires high image quality which may not be routinely obtainable in a clinical setting. 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 systolic displacement, strain[3], and strain rate[4]. We previously developed a full-cycle cine DENSE sequence[5] to image the entire cardiac cycle with sufficient signal-to-noise ratio (SNR) to compute accurate systolic and diastolic displacements, strains, and strain rates. Diastolic dysfunction is known to be present in half of patients with hypertension[1]. In the present study we assess diastolic function in hypertensive patients using the full-cycle cine DENSE sequence by comparing results with healthy volunteers.

Methods: A spiral cine DENSE sequence[6] was modified to continually acquire data until the next ECG R wave was detected (fig. 1). Full-cycle DENSE (fig. 1) was designed to detect the ECG R wave, even during the readout period, allowing data to be collected throughout the cardiac cycle. A ramped flip angle, which compensates for the cumulative effect of radio frequency pulses and myocardial T1 decay of the stimulated echo, was used to achieve a more uniform SNR throughout the cardiac cycle. We imaged six hypertensive patients and seven healthy volunteers as controls using full-cycle cine DENSE. All studies were performed using a 1.5T scanner (Avanto, Siemens, Germany) in accordance with protocols approved by our institutional review board. A single mid-ventricular short-axis section of the left ventricle was acquired. Specific imaging parameters included: field of view = 300-350 mm, matrix = 128 x 128 pixels, slice thickness = 8mm, variable flip angle with last flip angle=14-16°, TR = 17 ms, TE = 1.08 ms, and 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 RF phase cycling were used for artifact suppression. Lagrangian displacement and strain were computed offline as described previously[7]. Peak systolic circumferential strain rate (SR_S), early diastolic strain rate (SR_E) and atrial systolic strain rate (SR_A) were computed for each study and were compared between hypertensive subjects and normal controls.

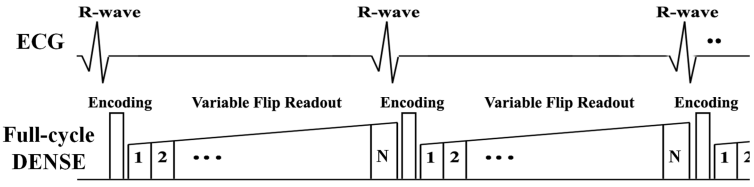

Figure 1. Acquisition strategy for full-cycle DENSE. Fully-cycle DENSE uses variable flip angles and continuous monitoring of the ECG R wave to capture entire cardiac cycle with sufficient SNR.

Results: Figure 2 shows example circumferential strain (fig. 2A) and strain rate (fig. 2B) time curves from a hypertensive patient and a healthy volunteer. All phases of diastole can be distinguished from the strain-time curves, including early filling, diastasis and atrial systole. Figure 3 shows a comparison of SR_S, SR_E and SR_A between hypertensive patients and healthy volunteers. The SR_E was significantly lower in patients compared to volunteers ($p<0.01$), implying impaired early diastolic relaxation. The SR_A was significantly higher in patients compared to volunteers ($p<0.01$), implying an increased filling rate during atrial systole. The SR_S values were similar in patients and healthy volunteers (p=NS), implying preserved systolic function in these hypertensive subjects. The echocardiography results (transmitral inflow and tissue Doppler imaging) showed that all the patients possessed diastolic dysfunction based on ASE guidelines[8], which is in agreement with our CMR findings.

Conclusions: Full-cycle cine DENSE detects diastolic dysfunction in hypertensive patients. It enables measurement of strain and strain rate during the entire cardiac cycle, allowing a more comprehensive quantitative assessment of both systolic and diastolic function.

References [1] Owan et al NEJM 2006. [2] Bella et al Circ 2002. [3] Kim et al Radiology 2004. [4] Vandsburger et al AJPHCP 2011. [5] Mehta et al Proc. of 21st ISMRM 2013. [6] Zhong et al MRM 2010. [7] Spottiswoode et al IEEE TMI. 2007. [8] Nagueh et al JASE 2009.

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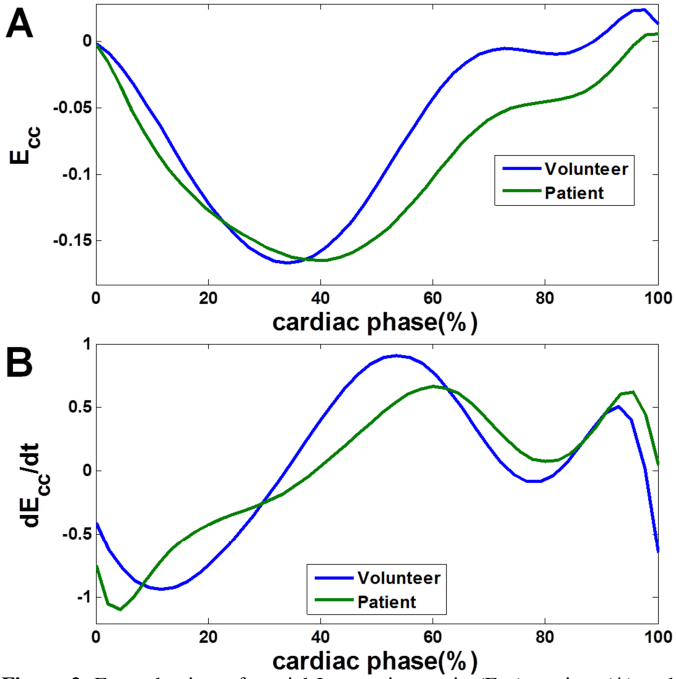

Figure 2. Example circumferential Lagrangian strain (Ecc) vs time (**A**) and circumferential Lagrangian strain rate (dEcc/dt) vs time (**B**) curves acquired using full-cycle DENSE from a healthy volunteer and a hypertensive patient. Different phases of diastole viz. early filling, diastasis, and atrial systole can be determined from the strain and strain rate curves.

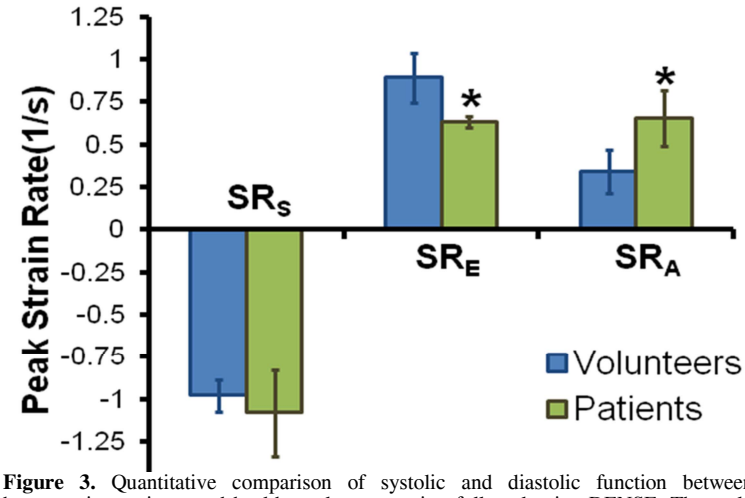

Figure 3. Quantitative comparison of systolic and diastolic function between hypertensive patients and healthy volunteers using full-cycle cine DENSE. The early diastolic strain rate (SR_E) was significantly lower and the atrial systole strain rate (SR_A) was significantly higher in patients compared to volunteers, implying impaired diastolic function. The systolic strain rate (SR_S) was similar between patients and healthy volunteers, implying preserved systolic function. (* $p<0.01$ v.s. Volunteers)