

INTRODUCTION Congestive heart failure (CHF) is a major cause of morbidity and mortality in the western world and is the leading cause of hospitalization in older patients (1). However, over one third of patients with decompensated heart failure have normal left ventricular (LV) systolic function (heart failure with normal ejection fraction (HFNEF)). This condition occurs when LV filling and relaxation are impaired during the diastolic phase of the cardiac cycle. It has been shown that aortic stiffening closely correlates with exercise intolerance in older patients with HFNEF (2). However, the relationship between aortic compliance and diastolic LV dysfunction has not yet been demonstrated. In this work, patients with HFNEF are imaged with MRI to measure the degree of aortic stiffness and diastolic dysfunction. The relationship between the resulting measurements is studied and compared to normal volunteers.

METHODS Eight human subjects (four HFNEF patients and four healthy volunteers) were scanned on a 3T Siemens MRI scanner. Three sets of cardiac images were acquired. The first set consists of a series of short-axis cine slices covering the LV to calculate the LV blood volume and filling rate during the cardiac cycle. The second set consists of three short-axis (base, mid, and apical) and one four-chamber cine tagged images to calculate myocardial strain throughout the cardiac cycle. Finally, a sagittal velocity-encoding (venc) phase image covering the whole aorta was acquired to calculate the blood pulse wave velocity (PWV) as a measure of aortic stiffness.

The imaging parameters for the cine short-axis images were: TR=40ms; TE=1.2ms; flip-angle=90°; slice-thickness=8mm; pixel-size=1.8x1.8mm². The tagged images were acquired with ECG triggering every other heart beat to cover the whole cardiac cycle. The imaging parameters were: TR=48ms; TE=4ms; flip-angle=15°; #cardiac phases=22; tag-sep=7mm; slice-thickness=8mm; pixel-size=1.4x1.4mm². The imaging parameters for the venc images were: TR=40ms; TE=2.8ms; flip-angle=15°; temporal-resolution=15ms; venc= 150cm/s; slice-thickness=7mm; pixel-size=1.8x1.8mm². The venc value was adjusted per patient to avoid velocity aliasing.

The cine short-axis images were semi-automatically analyzed using the Argus software, provided by the scanner manufacturer. The grid-tagged images were analyzed using Diagnosoft software to compute myocardial strain. Finally, the aortic PWV was calculated from the velocity-encoded images using the method described in (3).

RESULTS Figure 1 shows the venc image and different sites at which PWV is measured. The PWV was significantly ($P<0.01$) higher in HFNEF patients compared to normals (7.2 ± 2.2 and 3.9 ± 1.1 (mean \pm sd) in HFNEF and normals, respectively). Figure 2 shows the LV blood volume and blood filling rate through the cardiac cycle. The curves show diastolic dysfunction in HFNEF patients, where a major part of LV filling occurs later in the atrial filling phase. LV relaxation is impaired during most of the diastolic phase, compared to normals. Figure 3 shows myocardial strain throughout the cardiac cycle. The strain dynamic range (between systole and diastole) is reduced in HFNEF with less relaxation during LV diastolic filling phase.

DISCUSSION and CONCLUSIONS The proposed work introduces a comprehensive MRI exam for HFNEF patients to measure the aortic PWV, ventricular filling rate, and LV strain. The work shows that abnormal LV diastolic function in HFNEF, represented by incomplete and delayed LV relaxation and increased myocardial diastolic strain, is accompanied by less aortic compliance. In HFNEF patients, aortic stiffness (measured by PWV) is higher than in normals, and correlates with diastolic dysfunction. In conclusion, aortic stiffness is a major input in HFNEF and it has to be considered when studying different treatment options and for patient follow-up.

REFERENCES

- [1] Zile et al, Progress CD, 47:307-313.
- [2] Hundley et al, JACC 38:796-802.
- [3] Fielden et al, JMIR 27:1382-1387.

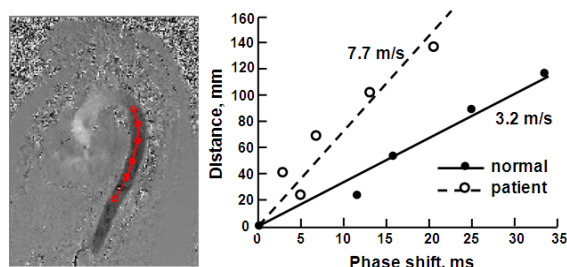


Fig1. Calculating PWV. Phase MRI image along the aorta and the sites at which velocity waveforms are measured. The part on the right shows the data recorded from a patient (open circles) and a volunteer (black circles). Lines are fitted to the data to estimate PWV (patient = 7.7 m/s, volunteer = 3.2 m/s).

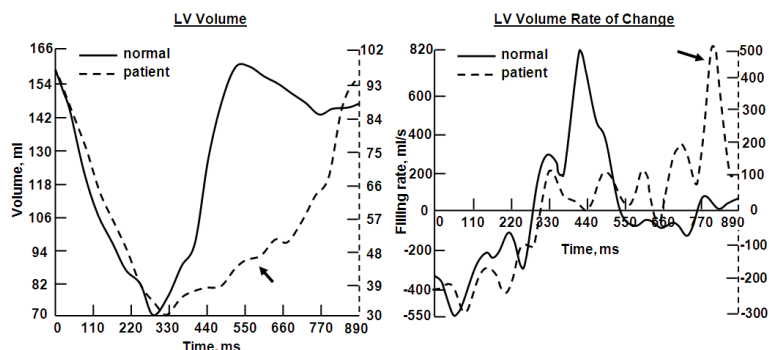


Fig2. Left and right panels show LV volume and filling rate, respectively, during the cardiac cycle for a patient (dashed line) and a volunteer (solid line). The patient shows reduced LV relaxation during the early diastolic phase (arrow on the left), where a major part of the filling occurs later at the atrial filling phase (arrow on the right).

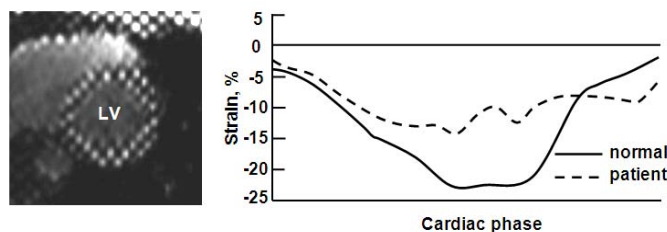


Fig3. Myocardial strain. The figure shows a short-axis tagged MRI image of the heart, from which strain is calculated. The curves show circumferential myocardial strain during the cardiac cycle for a patient (dashed line) and a volunteer (solid line). The patient has reduced strain range (between systole and diastole), with less relaxation during diastole.