Quantification of left and right ventricular kinetic energy using four dimensional intracardiac magnetic resonance imaging flow measurements

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INTRODUCTION: Intracardiac flow can be visualized and quantified with three-dimensional, three-component, time-resolved (4D) velocity encoded phase contrast (PC) MRI. The kinetic energy content of the blood in the left ventricle (LV) and right ventricle (RV) during the cardiac cycle has previously not been described. Therefore, the aim was to develop a method to calculate the kinetic energy during the cardiac cycle of the ventricles from 4D PC-MRI and to investigate if the energy patterns of the LV and RV differ.

MATERIALS AND METHODS:. Ten volunteers (age 33±13 SD, 3 females) underwent CMR-imaging using a 1.5T Philips Achieva. One patient with ischemic cardiomyopathy and decreased ejection fraction <30% was included for comparison of kinetic energy. The local ethics committee approved the study**.** MRI was acquired with retrospective ECG-triggering **4D flow:** A 4D PC turbo field echo (TFE) sequence with respiratory navigator was used to quantify intraventricular flow. Typical imaging parameters were: TE/TR: 3.7/6.3 ms, α:8º, SENSE factor 2, spatial resolution 3 mm isotropic voxels and a temporal resolution of 50 ms interpolated to 25 ms. Scan time was 45-55 minutes. **2D flow:** A phase sensitive fast field echo (FFE) sequence was used to measure flow of the aorta and main pulmonary artery. Typical imaging parameters were: TR/TE: 5.3/8.6 ms, α:15°, in-plane spatial resolution 1.2x1.2 mm; slice thickness 6.0 mm, temporal resolution 30 ms, velocity encoding 200 cm/s. **Cine imaging:** A balanced steady state free precession sequence was used to delineate the endocardial contours of the LV and RV throughout the cardiac cycle. Typical imaging parameters were: TR/TE: 1.4/2.8 ms, α:60°, in-plane spatial resolution 1.3x1.3mm; slice thickness 8.0 mm, no gap; temporal resolution 30 ms. Images were analyzed using a novel in-house developed module to the imaging software Segment (http://segment.heiberg.se). This comprises a linear phase correction and the possibility to reconstruct the 4D-dataset into any 2D plane or imaging stack. Also, quantitative flow can be calculated from the reconstructed 2D images and kinetic energy over the cardiac cycle can be quantified from the imaging stack. The endocardial contours were imported from the cine images to the reconstructed 4D-PC images and manually corrected when needed. Flow was measured by outlining the aorta and pulmonary trunk in the velocity encoded 2D-images and these contours were transferred to the reconstructed 4D-images and manually corrected when needed. The kinetic energy of the LV and RV was calculated as the squared velocity times the mass divided by two for all voxels within the ventricles for each time point resulting in a milliJoule (mJ) value for each time point. Continuous variables are presented as mean±SEM and compared using Wilcoxon´s matched paired sign rank test.

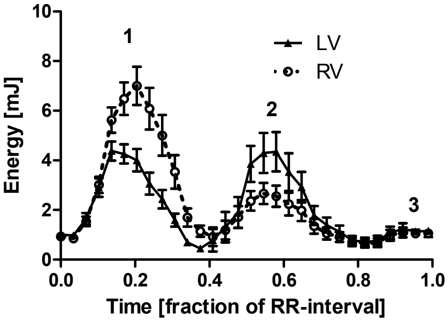

Figure 1. Kinetic energy (mean±SEM) of 10 volunteers. Three peaks were seen in both the LV and RV: 1 systole, 2 early diastole and 3 late diastole.

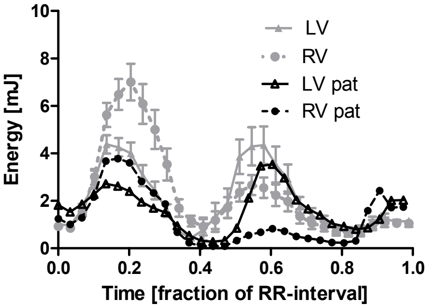

Figure 2. Kinetic energy of one patient with ischemic cardiomyopathy. Energy peaks from healthy volunteers are shown in grey for comparison.

RESULTS: Three distinct kinetic energy peaks during the cardiac cycle were seen in all subjects in both the LV and RV (Figure 1). The first kinetic energy peak was found in systole, the second peak in early diastole and the third in late diastole corresponding to atrial contraction. The early diastolic LV peak (5.8±0.6 mJ) did not differ from the systolic LV peak (4.8±0.4 mJ, P=0.13) but was larger than the late diastolic LV peak (1.4±0.2 mJ, P=0.002). The kinetic energy peaks in the RV (7.2±0.8, 3.4±0.4 and 1.3±0.2 mJ) differed from the LV having a larger systolic RV peak (P=0.002) compared to the early diastolic RV peak. Similar to the LV, the early diastolic RV peak was larger than the late diastolic RV peak (P=0.002). When comparing the RV and LV energy patterns the early diastolic peak was larger in the LV (P=0.004) and the systolic peak was larger in the RV (P=0.006). The kinetic energies of the patient with cardiomyopathy were smaller during systole and early diastole compared to healthy subjects in both the RV and LV and the late diastolic peaks were larger. The repeatability/bias between the two CMR acquisitions for the three peaks were 0.9±1.1, -0.5±1.2 and 0.1±0.2 mJ, respectively (*P*=ns). 2D-flow measurements of the SV in the aorta and pulmonary artery showed a strong correlation (r^2=0.92) and low bias (3.8±6.2 ml). 4D measurements of SV showed a high correlation with 2D measurements (r^2=0.80) and a low bias (2.6±10.6 ml).

CONCLUSION: This study has demonstrated the feasibility of a new method for non-invasive quantification of biventricular kinetic energy using 4D phase contrast velocity encoded CMR. Three energy peaks of the LV and RV were seen in healthy subjects. Interestingly, the systolic energy was higher in the RV compared to the LV and in contrast the energy during early diastole was higher in the LV compared to the RV. This can be used to enhance our understanding of cardiac pumping in healthy conditions and disease.