Intra-scan and inter-scan reproducibility and variability of left ventricular 4D flow kinetic energy values in healthy volunteers.

Victoria Stoll[1], Aaron Hess[1], Malenka Bissell[2], Jonatan Eriksson[3], Petter Dyverfeldt[3], Andrew Lewis[2], Tino Ebbers[3], Saul Myerson[2], Carl-Johan Carlhäll[3], and Stefen Neubauer[2]

[1]Division of Cardiovascular Medicine, OCMR, Oxford, United Kingdom, [2]OCMR, Oxford, United Kingdom, [3]Division of Cardiovascular Medicine and Center for Medical Imaging Science and Visualization (CMIV), Linköping University, Linköping, Sweden

Target audience: Researchers interested in 4D flow and Cardiologists.

Purpose: Left ventricular (LV), intra-cardiac flow as assessed by retrospectively ECG gated 4D flow, can be divided into 4 functional components; direct flow, delayed ejection flow, retained inflow and residual volume[1]. The kinetic energy (KE) of these flow components can be calculated throughout the cardiac cycle by utilising $KE = \frac{1}{2} \cdot \rho_{blood} \cdot V_{pathline} \cdot v^2_{pathline}$, where ρ_{blood} is blood density, $V_{pathline}$ the volume that one pathline represents and $v_{pathline}$ the velocity of the pathline. Previous studies have demonstrated differences in the proportions and kinetic energy of flow components between healthy volunteers and patients with dilated cardiomyopathy[2]. This study aims to assess the inter-scan and intra-scan reproducibility and variability of the kinetic energy of the LV flow components in healthy volunteers.

Methods: 15 participants were prospectively enrolled. 5 participants underwent consecutive 4D flow MRI and anatomical data acquisitions within the same scanning session in order to assess for reproducibility of the data acquisition and post processing. The other 10 participants underwent 2 data acquisitions separated by an interval of between 2-8 weeks in order to assess for physiological variability. All CMR scans were undertaken at 3 Tesla (Trio, Siemens, Erlangen, Germany) using a 32 channel cardiac coil. The 3D time resolved, phase contrast sequence was retrospectively gated with a respiratory navigator. The echo times were around 2.75 with a repetition time of around 52ms. The flip angle was 7, read field of view 390 and voxel size 3x3x3 mm^3. The velocity encoding value was between 0.9-1.1m/s based upon an estimate of the LV flow velocity. The datasets were analysed via the methods previously described by Eriksson *et al*[1, 3]. Manual segmentation of the LV from the short axis cines at end diastole (ED) and end systole (ES) was undertaken. From the centre of each voxel in the LV segmentation a pathline was emitted. Pathlines were created backwards and forwards in time until the preceding or subsequent ES, respectively. In combination the pathlines represent the entire LV end diastolic blood volume tracked over one complete cardiac cycle. The positions of all pathlines at the time of end systole relative to the cardiac chambers defined by the end systolic segmentation was then used to separate them into the four flow components. These components are direct flow; blood that enters the LV during diastole and leaves during systole in the analysed cardiac cycle, retained inflow; blood that enters during diastole but does not exit during systole in the analysed cardiac cycle, delayed ejection flow; blood that starts in the LV during diastole and leaves during systole of the analysed cardiac cycle and residual volume; blood that remains within the LV for at least 2 cardiac cycles. The kinetic energy values obtained for each flow component at ED from the two visits were compared by Pearson's correlation.

Results: As shown in Figure 1 the correlation of the kinetic energy values for the four flow components at end diastole was good; direct flow (r^2 0.6, p 0.0007), retained inflow (r^2 0.58, p 0.001), delayed ejection flow (r^2 0.65, p 0.0003) and residual volume (r^2 0.76, p<0.0001). The end diastolic KE values for the four flow components showed no significant difference, as assessed by paired t-test, between the volunteers scanned twice within the same session and those scanned at an interval of a few weeks (p all >0.05).

Discussion and Conclusions: The end diastolic kinetic energy of the four LV flow components is a stable measurement in healthy volunteers which can be reliably reproduced by 4D flow data acquisition and post processing. No changes in KE values attributable to physiological variability were seen over a number of weeks; ongoing studies will assess the stability of this parameter in an increased number of healthy volunteers and patients with impaired systolic function. In conclusion the kinetic energy of the four components of flow are reproducible both intra and inter-scan.

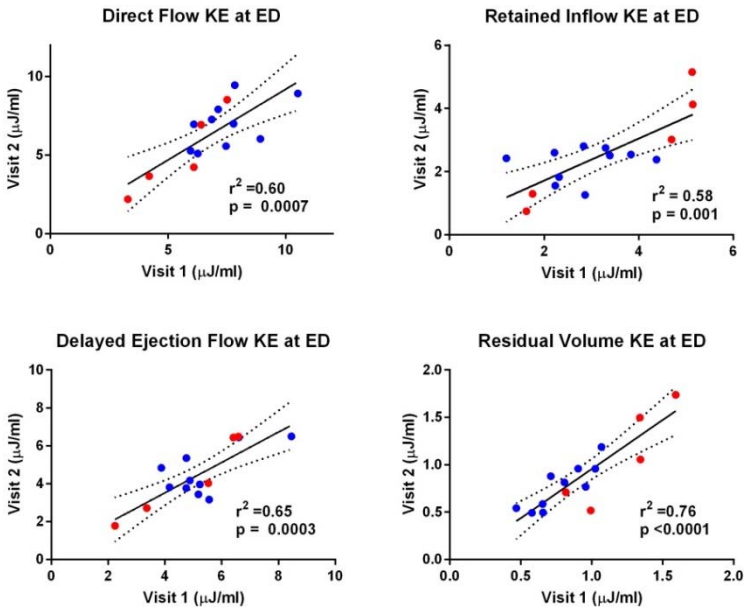

Figure 1: Scatterplot showing Pearson correlation's for the kinetic energy at end diastole for the four LV flow components at the two study points. Red dots are volunteers scanned in the same session, blue dots are volunteers scanned with an interval of 2-8 weeks. Dotted lines are 95% confidence intervals of the mean.

References:

1. Eriksson, J., et al., *Semi-automatic quantification of 4D left ventricular blood flow.* J Cardiovasc Magn Reson, 2010. 12: p. 9.
2. Eriksson, J., et al., *Four-dimensional blood flow-specific markers of LV dysfunction in dilated cardiomyopathy.* Eur Heart J Cardiovasc Imaging, 2013. 14(5): p. 417-24.
3. Eriksson, J., et al., *Quantification of presystolic blood flow organization and energetics in the human left ventricle.* Am J Physiol Heart Circ Physiol, 2011. 300(6): p. H2135-41