Imaging cardiac motion and flow simultaneously during exercise stress studies using SPAMM n' EGGS

S. Sampath[1], J. A. Derbyshire[1], M. J. Ledesma-Carbayo[2], and E. R. McVeigh[1]
[1]National Institutes of Health, Bethesda, MD, United States, [2]Universidad Polytecnica de Madrid

Introduction: The ability to simultaneously image transient, non-stable physiological manifestations in left ventricular dysfunction and trans-valvular blood flow under varying loading conditions may provide important prognostic information in patients with IMR. The availability of MR-compatible exercise bikes and open-bore magnet configurations has made supine exercise MR stress testing feasible. In this study, we apply a new MR imaging technique called SPAMM n' EGGS (spatial modulation of magnetization acquisitions with encoded gradients for gauging speed), that combines tagging and phase-contrast imaging principles to provide simultaneous measurements of longitudinal left ventricular compression and trans-mitral chamber blood velocity for any given long axis slice in a single, short, breath-held acquisition during exercise stress studies. Correlated measurements of these two quantities from two long-axis slices in six normal volunteers during rest, exercise stress and post-stress were obtained.

Experimental Setup: Experiments were conducted in the open-bore 1.5T Siemens Espree scanner (Siemens Medical Solutions, Erlangen, Germany). An MR-compatible bicycle ergometer (Lode Medical Technology, Groningen, Netherlands) was mounted at the furthest position on the foot-end of the patient table (see Fig. 1a). The volunteer was oriented head-first supine in the scanner and positioned with respect to the bike to ensure clearance of the knees from the upper shroud of the scanner bore during pedaling motion (See Fig. 1b).

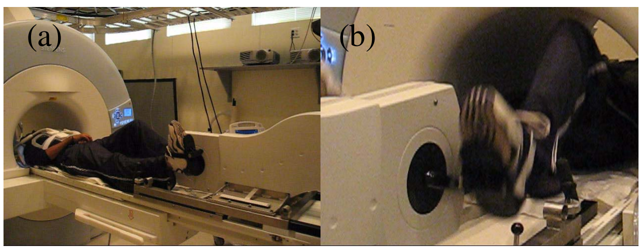

Fig. 1. (a) Bicycle ergometer mounted at the foot-end of the patient table. (b) Espree scanner provides good knee clearance during pedaling motion.

Pulse Sequence: The pulse sequence comprises a 1-1 SPAMM tagging preparation (tag separation=10mm, tagging flip angle=130°) followed by a gated, segmented, multi-phase 2-D gradient echo imaging module. During every even cardiac phase, a bipolar velocity encoding gradient (venc=90cm/s) was applied before the readout gradient to encode the velocity of the blood spins. The sequence of images obtained was subsequently post-processed to separate the myocardial motion and blood flow terms. Typical imaging parameters used were: imaging matrix: 192×160, resolution: 1.6mm × 1.6mm, slice thickness: 8-10mm, readout bandwidth: 400-700 Hz/pixel, TE: 4-5ms, TR: 7-8ms, views per cardiac phase: 3-5. To maintain an optimal compromise between tag persistence in diastole and early recovery of the flow signal in systole, a specifically designed train of imaging flip angles was employed.

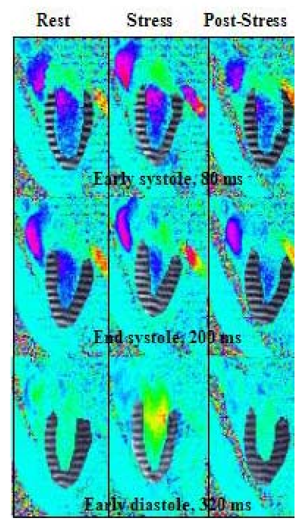

Fig. 2. Combined tag-flow images obtained at three time points using SPAMM n' EGGS from a normal volunteer during rest, stress and post-stress.

Experimental Methods: Two orthogonal long-axis slices were prescribed. For each long-axis slice, rest datasets using SPAMM n' EGGS were first obtained. The exercise bike was programmed to demand a fixed power level so that the volunteer would be forced to maintain a fixed work rate. The volunteer was then instructed to cycle for about 2 minutes until a steady-state heart rate for that workload was attained. A stress dataset for one long axis slice was then acquired in a single breath-hold. This procedure was repeated for the second long axis slice. The volunteer was then rested for 10 minutes before a post-stress dataset for each of the two slices was acquired.

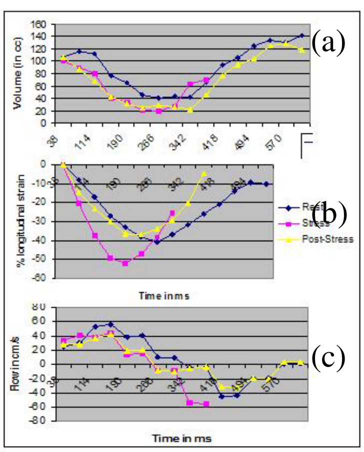

Fig. 3. Time-evolution curves of (a) estimated ventricular volume, (b) average septal longitudinal strain, and (c) average trans-mitral flow in a normal volunteer during rest, stress, and post-stress.

Data Analysis: Three measurements were quantified for each volunteer. 1. An estimate of ventricular volume was computed from the two long axis slices using a geometric hemisphere model [1], 2. Longitudinal strain was computed from the reconstructed tagged images using a non-rigid registration method [2] in regions of interest defined on the lateral and septal walls. 3. The average blood flow in regions of interest defined near the mitral inflow and the aortic outflow were computed from the reconstructed flow images.

Results and Discussion: Combined tag-flow images and quantitative analysis obtained from one volunteer are depicted in Figs. 2 and 3 respectively. The heart rate, systolic/diastolic blood pressures recorded during rest, stress and post-stress was (66bpm, 112/57), (107-95bpm, 120/55), and (74bpm, 99/66). From Fig. 2, it is evident that systolic outflow, maximum longitudinal shortening, and diastolic inflow are initiated earlier during stress. We also note increased longitudinal compression and greater mitral inflow velocities during stress. From Fig. 3, we observe that rate of change in ventricular volumetric compression and expansion, longitudinal septal shortening and elongation, and mitral diastolic in-flow velocity is higher during stress. We also observe that the peak amplitude of ventricular volume, longitudinal septal shortening and mitral diastolic inflow is higher during stress. Disease conditions sensitive to stress-induced changes in 1) elasticity of the underlying tissue, or 2) time to peak myocardial strain and time to peak trans-valvular flow relative to rest, or relative to one another may be detected using this method.

References:
[1] Dulce M. C. et. al., Radiology 1993; **188**:371-376. [2] Ledesma-Carbayo M. J. et. al., Magn. Reson. Med. 2007; *in press.*

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