

MRI-compatible exercise device for use in cardiac stress tests

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Target Audience: Those interested in cardiopulmonary physiology and stress-rest cardiac MRI.

Purpose: Assessment of cardiac function during exercise can be used as a diagnostic tool in the investigation of a wide range of cardiovascular diseases¹. Cardiac magnetic resonance (CMR) imaging is the reference standard for non-invasive measurement of global and local cardiac function². However physical exercise stress in conjunction with CMR poses significant challenges due to the limited space in the MR bore, the horizontal position of the subject during imaging, incompatibility of standard exercise equipment with MRI and the sensitivity of MRI to motion artifacts. The purpose of this study was to develop a low-cost exercise device that could be used within the confines of an MRI bore during a cardiac MR scan. Herein, we describe the design and construction of our prototype device, exercise CMR scanning protocol, and pilot data from a healthy subject.

Methods: Our design uses a stepping motion with adjustable weights as the source of resistance. It is constructed mainly of high-density polyethylene (HDPE), aluminum, brass, and nylon, all non-ferrous materials. The stepping motion is accomplished through the use of two L-shaped lever arms that are held up with three vertical supports. Both the lever arms and vertical supports were constructed as I-beams using 1.27 cm (½ in) thick HDPE, with a 7.62 cm (3 in) web and 5.08 cm (2 in) flanges. The base of the device is a 1.27 cm (½ in) thick HDPE sheet that sits on the MRI couch allowing both the device and subject to slide on the MRI couch as needed to adjust for subject body size (Figure 1). An optical sensor (Sharp Microelectronics of the Americas, Camas, WA) to measure the distance from the base to one of the moving lever arms was incorporated into the design in order to measure stepping power and cadence. As the subject exercises, the angular rotation of the lever arm is calculated for each step based on the distance sensor output. Additionally, the time between each peak distance is recorded and used for the calculation of stepping cadence. Using the values for angular rotation, stepping cadence, and weight in each enclosure, along with the geometry of the device, the power output can be calculated as a function of work and time.

The total cost of parts and materials used in the construction of this device, not including software or labor, was less than \$200 (USD).

Pilot testing was performed on one healthy adult female subject (age 25, weight 73 kg, height 165 cm) using an institutional review board (IRB)-approved protocol after written informed consent was obtained. MR images were obtained using a 1.5 Tesla scanner (HDxt, GE Healthcare, Waukesha, WI) with a bore diameter of 55 cm and an eight-element phased array cardiac coil (GE Healthcare, Waukesha, WI). Cardiac output was obtained with a retrospectively ECG-gated, two-dimensional (2D) phase contrast (PC) flow-sensitive MR images through the ascending aorta and main pulmonary artery (MPA). 2D PC parameters were: field-of-view: 24 x 36 cm, acquired spatial resolution = 1 x 1.5mm, 4 views per segment, VENC 200cm/s. Scans were performed before exercise as a baseline and during a brief cessation from 4–5 minutes of 50 watts physical exercise. Exercise was suspended during imaging because residual movements caused motion artifacts and unreliable gating off the ECG signal despite the hand straps and other torso movement stabilization features.

Results: Heart rate increased with exercise by 85%, from a baseline of 65 beats per minute (bpm) to 120 bpm. Flow rates through the ascending aorta (Fig. 2A) and MPA (Fig. 2B) substantially increased following physical exercise. Specifically, ascending aorta mean flow rate and peak flow rate increased by +65% and +32%, respectively. MPA mean flow rate and peak flow rate increased by 101% and 48%, respectively. Cardiac output was doubled from 5 L/min to 10 L/min.

Discussion: Cardiac stress-rest testing is an important diagnostic and prognostic tool for a wide range of cardiovascular pathologies. The design of our device allowed the subject to exercise inside the MRI bore, thereby minimizing the intermission between exercising and imaging. The pilot testing demonstrated that our device was successful at inducing a cardiac stress state, while simultaneously allowing high quality 2D PC MR imaging. The main advantage of our exercise device is the minimal intermission between exercising and imaging that allows accurate capture of hemodynamic changes in the cardiovascular system. The addition of single breath-hold, whole heart CINE SSFP sequences should allow for assessment of changes in ventricular wall motion and function with exercise as well. CMR is currently considered as the reference standard for both left and right ventricular structure and function assessment³. Hence, our device has a great potential for diagnosis and prognosis of cardiovascular diseases such as pulmonary hypertension and ischemic heart disease.

Conclusion: We designed, constructed and tested a relatively inexpensive MRI-compatible exercise device for the purpose of cardiac stress testing. We performed a pilot test with a healthy young adult subject and demonstrated the feasibility of using the exercise device within the confines of the MRI bore. The results of the pilot test subject showed substantial increases in cardiac output and flow with exercise. The use of exercise in the MR scanner offers great potential in clinical practice to accurately assess cardiovascular function under stress.

- References:** 1. Torpy JM et al. JAMA 2008; 33(15), 1386.
 2. Wieben O et al. Eur J Radiol 2008; 65(1), 15-28.
 3. Valsangiacomo Buechel ER et al. Eur Heart J 2012; 33(8), 949-960.

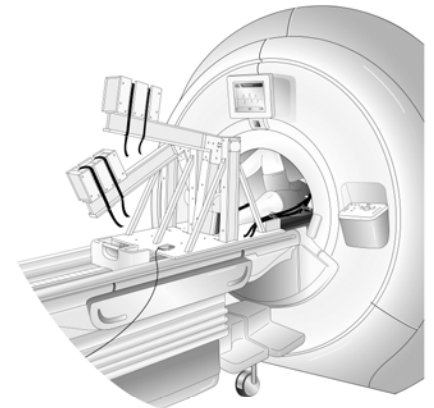


Figure 1. MRI-compatible stepper exercise device illustrating its use during CMR. As the subject extends and then flexes alternating knees, the L-shaped lever arms are raised and then lowered in a dynamic stepping motion.

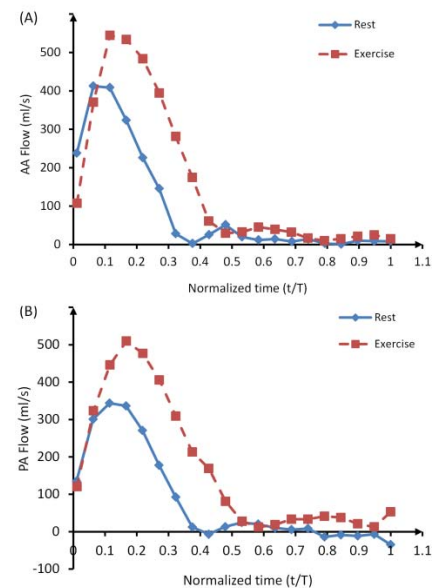


Figure 2. Blood flow rates in the ascending aorta (AA) (A) and pulmonary artery (PA) (B), showing both rest and a brief cessation from physical exercise stress. The time component was normalized with respect to the total period of the cardiac cycle for each curve.