

MRI Compatible Treadmill

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Introduction: Treadmill exercise stress testing in conjunction with cardiac imaging is an essential tool in the detection and treatment of heart disease. Over ten million of these tests are performed in the USA each year with either single photon emission tomography (SPECT) or cardiac ultrasound (echocardiography). Both modalities suffer from image quality limitations, and SPECT imaging involves significant radiation exposure. Furthermore, neither of these methods provides combined assessment of both cardiac function and perfusion at stress. Cardiac magnetic resonance (CMR) already offers a complete cardiac evaluation in a single examination; however, treadmill exercise stress CMR (EXCMR) has not been feasible to date because:

- AHA guidelines suggest that images must be obtained within one to two minutes (preferably < 1 minute) after exercise [1].
- Traditional treadmills cannot be safely placed in the same room as the MRI due to the strong magnetic field of an MRI system.
- Rapid acquisition of cardiac function and myocardial perfusion immediately post-exercise is not feasible with a remotely located treadmill.

To address these limitations, a completely MR compatible treadmill was designed to operate safely and reliably immediately adjacent to a MRI scanner without affecting image quality. The goal was to conduct the Bruce Stress Test Protocol, a prescribed series of speed and elevation changes up to 5.5 MPH and 11.3° elevation used in cardiac stress testing, immediately adjacent to a 1.5T MRI system (MAGNETOM Avanto, Siemens Healthcare, Malvern, PA).

Materials and Methods: All ferromagnetic structural components and fasteners from a commercial rehabilitation treadmill (Landice 8700, Randolph, NJ) were replaced with aluminum and non-ferromagnetic stainless steel equivalents (Figure 1). Hydraulic drive and elevation systems were developed to power the treadmill

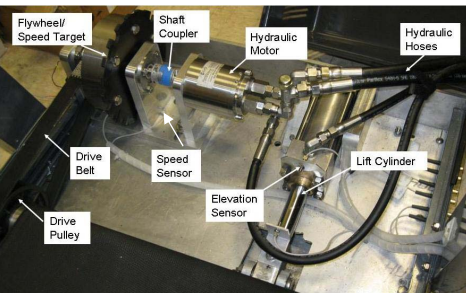


Figure 1: Hydraulic Drive and Elevation Systems

using tap water. The running belt was powered by a hydraulic motor, driven by an electric pump located outside the MRI room (Figure 2). A hydraulic cylinder was used to elevate the treadmill (Figure 1). Fiber optic sensors were used for speed and elevation feedback and a Labview (National Instruments, Austin, TX) program used for control. All components were constructed of non-ferromagnetic materials and tested for MR safety using a 0.32T hand magnet (Next Generation Science, Lafayette, IN). The treadmill was placed immediately adjacent to the 1.5T MRI system and connected to the pump via hydraulic hoses routed through a wave guide (Figure 3). MRI

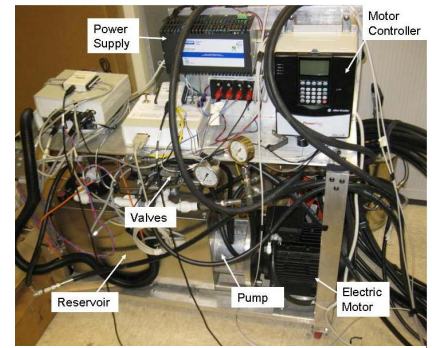


Figure 2: Hydraulic power unit remotely located in MRI equipment room

service software tools were used to test for RF interference and image artifacts introduced by the treadmill. Static field homogeneity, image artifact level, RF noise level over a range of frequencies ($f_0 \pm 250\text{kHz}$), and data spikes were all evaluated. Each test was performed first without the treadmill in the MRI room, then with the treadmill adjacent to the magnet but not running, and finally with the treadmill running.

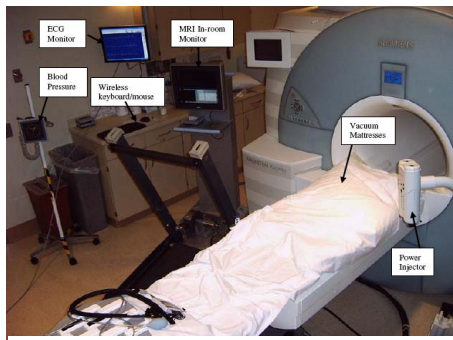


Figure 3: MR compatible treadmill prototype system located within MR environment

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To test whether the magnetic field of the MRI system affected treadmill performance, three subjects (weight = 125, 177, and 203 lbs) walked/ran on the treadmill at speeds and elevations corresponding to the first 6 stages of the Bruce Stress Test protocol both outside and inside the MR room. A photo-tachometer and inclinometer were used to verify that the treadmill achieved and maintained desired speed and elevation at each stage of the test. An additional six healthy subjects (Age 19-36) were then exercised to peak cardiovascular stress with the treadmill positioned adjacent to the MRI system as shown in Figure 3. Upon reaching target heart rate, the subjects were quickly transferred to the MRI table and cardiac function images acquired using a real-time cine sequence (32-channel cardiac array coil, TGRAPPA parallel acceleration rate 4, TR/TE 2.3/1.0 ms, temporal resolution 47.6+/-1.3 ms, matrix 84x160).

Results: MR safety testing with a hand magnet confirmed that no components demonstrated any perceptible magnetic attraction. MRI system diagnostic tests showed that homogeneity and image quality remained within specification with the treadmill both stationary and operating directly adjacent to the MRI table. All imaging test results were within manufacturer's specification. The treadmill achieved and maintained all desired speeds and elevations both inside and outside the MRI room. Comparison of results inside and outside the MRI room for all three subjects showed that speed deviated by no greater than 1.08% and elevation by no greater than 1.43%. All subjects completed the EXCMR study, reaching an average of 13.7 ± 0.3 minutes of the Bruce

Protocol; each subject achieved target heart rate. The average time to transfer the subject to the MRI table and start imaging was 26.7 ± 6.4 s, and real-time cine imaging covering three short-axis and two long-axis views was completed within 12 s, or an average of 38.7 ± 6.4 s after end of exercise (Figure 4).

Conclusions: MR safety and compatibility testing confirmed that the treadmill may be safely placed in the MR environment without affecting image quality. Treadmill speed and elevation were unaffected by the magnetic field of the 1.5T MRI system. Cardiac function imaging of healthy volunteers was completed within a time 36% below AHA guidelines for stress testing.

References: [1] Gibbons, R.J., et al., *ACC/AHA 2002 guideline update for exercise testing: summary article*. J Am Coll Cardiol, 2002. **40**(8): p. 1531-40.

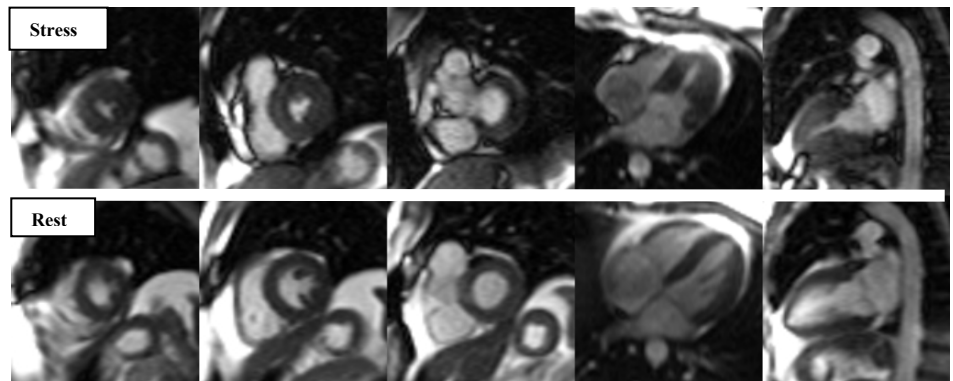


Figure 4: End-systolic cardiac function images obtained at stress and rest