MRI-Compatible Cardiac Exercise Device

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Abstract

In order to better understand the effects of exercise on patients with pulmonary hypertension, Professor Naomi Chesler would like to use MRI to accurately measure changes in pulmonary blood pressure and flow during exercise. Currently, there is no device on the market that allows a patient to exercise during a cardiac MRI scan. This device utilizes a stepping motion with adjustable weight resistance, and allows for the patient to exercise inside the MRI bore. The device was tested outside the MRI bore to determine the maximum achievable heart rate increase. Subjects were able to raise heart rates from initial values of 73, 74, 70, and 68 beats per minute (bpm) to 119, 143, 122, and 110 bpm, respectively. Subjects with a range in height from 5'7" to 6'3" effectively tested the exercise device in an actual MRI scanner. Real-time MRI scans were taken while a subject was exercising in the bore and provided evidence of pulmonary artery area change during exercise. These results demonstrate that this device can be used with pulmonary hypertension patients in the future to characterize, diagnose, and assess the progression and severity of the disease.

Problem Statement

Design an exercise device to be used in cardiac MRI scans in order to characterize, diagnose, and assess pulmonary hypertension.

Background

Pulmonary Hypertension:

- Abnormally high blood pressure in pulmonary arteries
- Chronic decreased systemic blood oxygen concentration
- 2-3 year median survival time if untreated

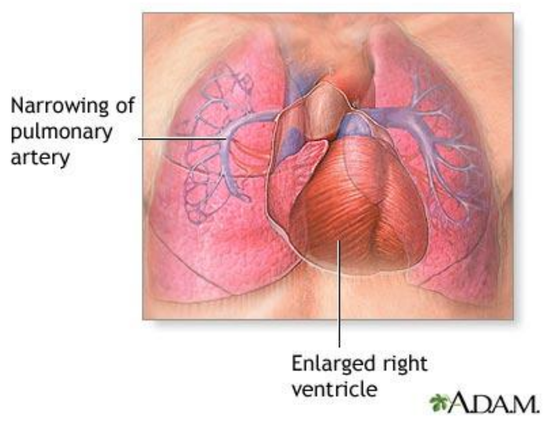

Figure 1 – Pulmonary Hypertension[1]

Competition:

- Lode BV MRI Ergometer[2]
  - (>$28,000)
- MRI-Compatible Treadmill[3]
- Previous UW BME Design Teams[4][5][6]

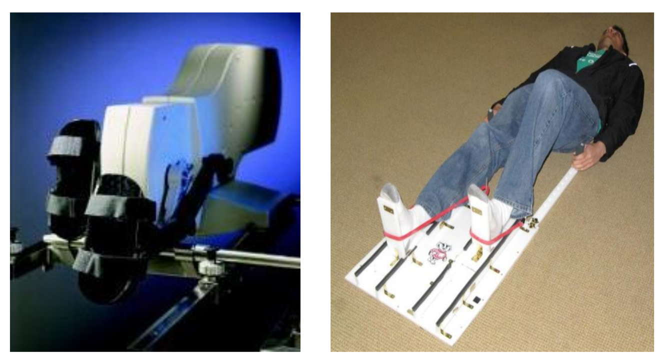

Figure 2 – Lode BV[2] (left) and Spring'10 BME Design[5] (right) competitive devices

Design Requirements

- MRI compatible material
- Comfortable supine exercise motion within bore
- No risk for patient injury
- Minimal upper body movement
- Accommodate various patient sizes
- Adjustable workloads
- Easy to operate
- Reasonable size and weight
  - 50 cm to the top of the bore
  - 150 kg (patient + device)
- Sufficient resistance to increase cardiac output
  - Enough to see physiological changes in pulmonary artery through real-time MRI

Final Design

Figure 3 – Device being set-up for use in MRI bore

Overview of Materials:

- HDPE structure
- Brass screws & brackets
- Glass/acetal bearings
- Aluminum rods
- Nylon straps
- Non-ferrous weights

Design Improvements:

Block housing for bearings:

- Two bearings/ lever arm
- Limits lateral motion
- Increased durability

Figure 4 – Block housing for bearings

Backpack straps:

- Secures patient to device
- Limits upper body motion

Stopping mechanism:

- Easy entry and exit
- Improved positioning of patient

Shortened lever arms

Foot straps

Hand straps

Base tracking:

- Rests only on sliding MRI couch
- Slides with patient

Figure 5 – Base tracking composed of HDPE cut at a 11.5° angle with yoga mat padding

Testing and Results

Power Calculation:

Table 1 – Power produced for various combinations of added mass and exercise cadence

Added Mass (kg)	Exercise Cadence (steps/min) 80	90	100	110	120
0	3.19	3.59	3.99	4.38	4.78
3.63	14.71	16.55	18.39	20.22	22.06
4.54	17.60	19.80	22.00	24.20	26.40
8.16	29.09	32.72	36.36	40.00	43.63

$$\boldsymbol{P} = \boldsymbol{R} * \left(0.03986\, J\frac{min}{sec} + 0.03967\, \frac{m^2}{sec^2}\frac{min}{sec} * \boldsymbol{M}\right)$$

- **M** is added mass (kg)
- **R** is the exercise cadence (steps/min)

Exercise Testing:

- Performed outside the bore to determine the maximum attainable heart rate
- Subjects exercised with maximum weight according to individual fitness levels
- Exercised at cadence of ~110 steps/min for 10 min
- Heart rate measured with digital pressure monitor

Table 2 – Exercise testing results for four subjects

Subject	Resting HR (bpm)	Post Exercise HR (bpm)	% Max. HR
1	73	119	59.80
2	74	143	71.86
3	70	122	61.31
4	68	110	55.28
Average	71.25	123.50	62.06

MRI Testing:

- Obtained cardiac MR images from one subject
- Real-time imaging during exercise

Real-time MRI:

- Continuously scans
- Allows for assessment of:
  - Pulmonary artery area
  - Right ventricle function
- Comparison of relative area change (RAC) between systole and diastole can be used to determine arterial distensibility (stiffness)

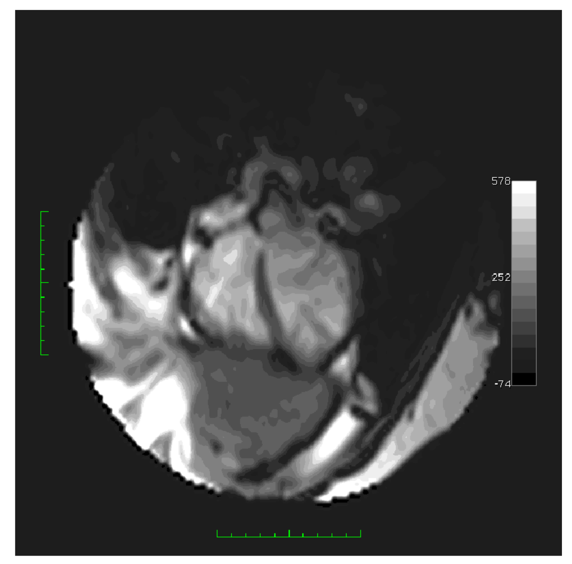

Figure 6 – Real-time MRI four-chamber view of the subject's heart

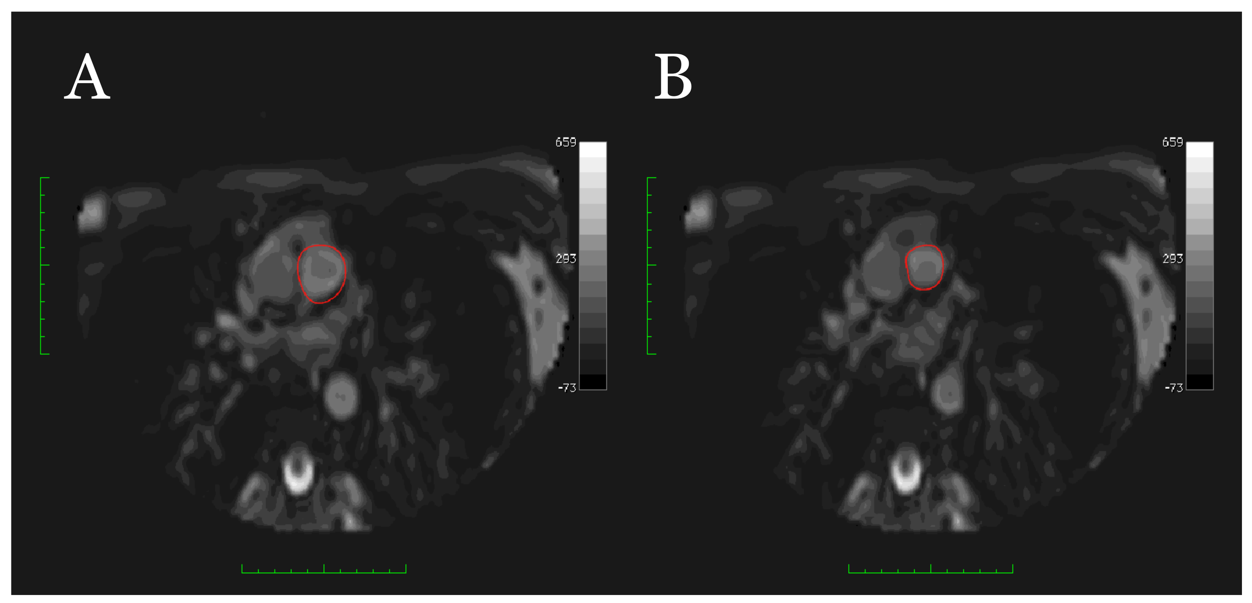

Figure 7 – Real-time MRI images of systole(A) and diastole (B) of the subject's heart during exercise; red circles indicate the pulmonary artery

- Pulmonary artery systolic area = 7.6 cm²
- Pulmonary artery diastolic area = 4.6 cm²
- RAC = 39.5%

Future Work

- Limit base movement
- Better weight interface
- Improved support durability
- Eliminate unwanted strap loosening during exercise
- Employ electronic measurement and feedback system
  - Measure exercise cadence
  - Calculate power
  - Feedback to user
- Synchronized alternating arm movement
- Obtain IRB approval

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