Continuous blood pressure monitoring during high-intensity resistance training after myocardial infarction or percutaneous coronary intervention in a phase 2 cardiac rehabilitation setting

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ABSTRACT

The purpose of this study was to investigate the maximum rate-pressure product of cardiac rehabilitation participants after myocardial infarction, percutaneous coronary intervention, or both during high-intensity resistance training (HI-RT) using continuous blood pressure monitoring. Thirty-four individuals exercised on the leg press machine while being monitored with a continuous blood pressure monitor. The maximum rate-pressure product was significantly lower than the established safety threshold of 36,000 ($P < 0.001$), with a mean of 17,369 and standard deviation of 6634. Only 2% of observations had a value $\geq 36,000$. These results suggest that cardiac rehabilitation patients can perform HI-RT while keeping their rate-pressure products under the safety threshold of 36,000 after myocardial infarction/percutaneous coronary intervention. Performance of HI-RT exercises contributes to return to precardiac event occupations, and continuous blood pressure monitoring may be an effective tool in evaluating the safety of HI-RT in this patient population.

KEYWORDS Blood pressure monitoring; cardiac rehabilitation; high-intensity resistance training; leg press; rate-pressure product

In the United States, approximately 805,000 Americans have a heart attack each year.¹ Patients who experience a myocardial infarction are typically fearful about resuming demanding physical activity and strenuous jobs and lose skeletal muscle strength through their resulting inactivity. Resistance training (RT) improves skeletal muscle strength and endurance, which are essential for the safe return to activities of daily living and active or strenuous jobs. However, in the cardiac rehabilitation (CR) setting, RT is typically not performed until at least 4 weeks of aerobic activity is complete,² and, even then, is traditionally limited to light hand weights and elastic bands. High-intensity resistance training (HI-RT) is avoided, based on studies showing disproportionately large circulatory responses to static work.³ For example, one particularly influential HI-RT study (cited 976 times), conducted in five healthy bodybuilders aged 22 to 28 years, reported that one subject reached a blood pressure of 480/350 mm Hg.⁴ However, HI-RT studies

conducted in populations more relevant to CR report increases in arterial pressure within clinically acceptable ranges.⁵ This study sought to obtain noninvasive continuous hemodynamic data during performance of HI-RT for comparison to the myocardial work safety threshold (rate pressure product $< 36,000$).^{6,7}

METHODS

All participants aged 18 to 80 years old referred to CR at Baylor Scott and White Heart and Vascular Hospital in Dallas, Texas, from May 2013 until May 2017 with a history of coronary artery disease were eligible for this study. The presence of atherosclerosis was confirmed by patients either having experienced a myocardial infarction for which they were being treated medically or having undergone coronary catheterization in which an angioplasty was performed or a stent placed. Patients were excluded if they

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Figure 1. A patient using the leg press machine.

had a permanent pacemaker or defibrillator, coronary artery bypass surgery or valve surgery, unstable angina pectoris, history of acute hernia or aneurysm, physical disability that limited RT, uncontrolled hypertension (systolic 160 mm Hg or diastolic > 100 mm Hg), symptomatic dysrhythmias, regular participation in an RT program since cardiac intervention, or history of heart or lung transplant. A total of 40 patients were invited to participate and provided informed consent. The study protocol was approved by the Baylor Scott & White Research Institute's institutional review board.

Subjects performed a maximum of three 1-rep max testing sessions and 15 HI-RT sessions on the leg press machine while enrolled in the study (*Figure 1*). The study protocol is described in *Table 1*. Patients' characteristics were presented as mean and standard deviation for continuous variables and frequencies and percentages for categorical variables. The outcome of interest was the maximum myocardial work—measured by the rate-pressure product (calculated as heart rate $\times$ systolic blood pressure)—performed during each 1-rep max testing or HI-RT exercise session. The necessary data to calculate the rate-pressure product were obtained from the Finometer continuous blood pressure monitors worn by participants during their CR sessions as well as the lead 2 electrocardiogram monitor. To reduce technological error in the analysis, such as a false high reading resulting from excessive gripping on the extremity attached to the monitor, occurrences with a heart rate > 200 beats per minute were compared with max heart rate derived from electrocardiogram monitoring and, if inaccurate, excluded from the analysis. This method was not feasible for every data point, as thousands of data points were collected each occurrence. The maximum rate-pressure product, summarized according to the patient's demographics and diagnosis, was compared with the safety threshold of 36,000 using a one sample *t* test. All analyses were performed using STATA 14.

RESULTS

Table 2 shows the characteristics of the study participants. Thirty-four of the 40 individuals enrolled completed the study, with two withdrawing due to family obligations, one for medical necessity unrelated to his cardiac disease, and three for work obligations. A total of 1199 bouts of HI-RT with intensities of 85% to 100% 1-rep max were used for this analysis; 178 bouts with inaccurate measures of heart rate > 200 beats per minute in each patient were excluded from the analysis.

The mean maximum myocardial work in this population was significantly lower than 36,000 (mean 17,369, standard deviation 6634; $P < 0.001$ on one-sample *t* test). Only 2% (24 bouts) of this measurement had a value $\geq 36,000$.

DISCUSSION

Our results provide preliminary evidence that patients who have had a myocardial infarction or percutaneous coronary intervention and perform HI-RT during CR have a low risk of exceeding the safety threshold of a 36,000 rate-pressure product. They also demonstrate the utility of Finometer continuous blood pressure monitors in CR, providing a means of near real-time monitoring of myocardial work, which can be used to help ensure safety thresholds are not exceeded while enabling CR patients to obtain the benefits of HI-RT.

Although current literature examines the benefit of low- to moderate-intensity RT in patients with coronary artery disease,^{8,9} investigation into the safety and efficacy of incorporating HI-RT into CR is scarce. Currently, the recommendation for RT for patients after myocardial infarction or percutaneous coronary intervention is light intensity (30%–40% 1-rep max) to moderate intensity (50%–60% 1-rep max) resistance exercise such as elastic bands and hand weights, in which the load is not to exceed 60% to 80% of their 1-rep max in low risk stratified patients.² For patients who have occupations or endeavors that require high-intensity work, training as suggested by the current guidelines leaves them ill-prepared mentally and physically.

It is important to note the impact of atherosclerosis on resting and exercising blood pressure when prescribing HI-RT. The disease process can be cyclical, in which chronic increased blood pressure causes increased plaque buildup in the arteries, which causes the lumen to become narrowed, thus driving hypertension further.¹⁰ Patients who have coronary artery disease and hypertension may benefit from real-time continuous blood pressure monitoring using noninvasive devices such as the Finometer to ensure HI-RT is performed with rate-pressure products within the safety threshold of 36,000.

Some limitations need to be kept in mind when interpreting our results. First, this was a small study conducted in a single CR program, which may limit the generalizability of the results. This is particularly true for the portions of the

Table 1. High-intensity resistance training cardiac rehabilitation protocol activities and data collection

	Day 0	Days 1, 3, 7 (1RM testing sessions)	Days 2-6, 8-12, and 14-18 (HI-RT sessions; completed 3 times per week)
Data collected	<ul style="list-style-type: none"> • Medical history form and patient demographics (age, sex, diagnosis) • Medications • HR • BP • Height • Weight 	<ul style="list-style-type: none"> • Resting lead 2 EKG^a • HR • BP 	<ul style="list-style-type: none"> • Resting lead 2 EKG^a • HR • BP
Activities	<ol style="list-style-type: none"> 1. Case manager reviewed medical history and medications, introduced CR program 2. RN assessed patient for signs of edema, incision infection, and any other heart or lung problems 3. Informed consent obtained for study participation 	<ol style="list-style-type: none"> 1. CR warm up^b 2. Review of RT breathing technique and double leg press technique 3. Application of Finometer continuous BP monitor 4. RT test protocol to estimate double leg press 1RM 5. RT warm up: 5-10 light double leg press repetitions, then light stretching 6. 3-5 double leg press repetitions at 60%-80% maximum 7. Conservative increase in weight and 1RM lift attempted^c 8. Repeat of steps 5 and 6 until a failed attempt occurs (with one 1RM lift obtained within 4 sets to avoid excessive fatigue) 9. Warm down^b 	<ol style="list-style-type: none"> 1. CR and RT warm ups 2. Review of RT breathing technique and double leg press technique 3. Application of Finometer continuous BP monitor 4. 4 sets of 6 double leg press repetitions at 85% of the final 1RM obtained at the most recent 1RM testing session 5. Warm down^b

1RM indicates one repetition maximum; BP, blood pressure; CR, cardiac rehabilitation; EKG, electrocardiograph; HI-RT, high-intensity resistance training; HR, heart rate; RT, resistance training.

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^bOne slow lap around the 0.1-mile track.

^cIf unsuccessful, a 3-minute rest was allowed before a second attempt.

Table 2. Characteristics of the 34 subjects

Variable	N (%)
Age (years) mean ± standard deviation	59.8 ± 11.0
Female	10 (29.4%)
Male	24 (70.6%)
Black	6 (17.6%)
White	28 (82.4%)
Hispanic	2 (5.9%)
Not Hispanic	32 (94.1%)
Myocardial infarction	11 (32.4%)
Myocardial infarction with percutaneous coronary intervention	7 (20.6%)
Percutaneous coronary intervention	16 (47.0%)

population underrepresented in our sample (i.e., women and minorities). Additionally, we considered only a small subset of CR diagnoses in this study. Further research is needed to investigate the feasibility of using HI-RT with patients with

coronary artery bypass surgery, valve repairs/replacements, congestive heart failure, and orthotopic heart transplant. Lastly, our small sample had wide variation in age. Since age influences blood pressure¹¹ at rest and during exercise, it would be beneficial for age groups to be analyzed separately in a larger future study. Likewise, a larger study is needed to investigate differences in response to HI-RT that may occur in women vs. men.

An important strength of this study was use of the Finometer blood pressure monitors to provide continuous monitoring during the HI-RT sessions. It is not feasible to use the gold standard of intra-arterial measurements during exercise sessions due to the invasive risks such as pain, arterial spasm, blood clots, bleeding, and vaso-vagal syncope.¹² The dynamic nature of the blood pressure response to RT makes intermittent measurements by the standard arm cuff and auscultation method poorly representative of the characteristic physiological response.³ Despite this fact, most of the available information on the blood pressure response during CR has been collected this way.¹³⁻¹⁵ In contrast, the Finometer blood pressure monitors we used have been shown to achieve continuous blood pressure monitoring similar to intra-arterial recordings.³

Due to the overwhelming prevalence of myocardial infarction and percutaneous coronary intervention,¹ it is essential for health care professionals and clinicians to provide patients a safe and effective method of training for returning to work, as returning to work and previous activity is an important predictor of the quality of life of this patient population.¹⁶ The CR setting provides an opportunity to monitor and progress patients as they perform HI-RT so they can return to their lives safely and successfully.

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