Hemodynamic Responses to Resistance Exercise in Patients with Coronary Artery Disease

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ABSTRACT

GJØVAAG, T. F., P. MIRTAHERI, K. SIMON, G. BERDAL, I. TUCHEL, T. WESTLIE, K. A. BRUUSGAARD, B. B. NILSSON, and J. HISDAL. Hemodynamic Responses to Resistance Exercise in Patients With Coronary Artery Disease. Med. Sci. Sports Exerc., Vol. 48, No. 4, pp. 581–588, 2016. Purpose: Investigate hemodynamic responses of resistance exercise (RE) with moderate load (i.e., international guidelines for RE of patients) versus RE with high load in patients with coronary artery disease (CAD). Methods: Medically stable male (n = 11) and female patients (n = 4) treated with PCI or percutaneous coronary intervention, or coronary artery bypass surgery a minimum of 6 months before this study, performed three sets of 15RM and 4RM RE in a randomized order on separate days. Beat-to-beat systolic (SBP), diastolic (DBP) blood pressure, heart rate (HR), stroke volume (SV), cardiac output (CO), and systemic vascular resistance (SVR) were monitored at preexercise, and continuously during RE. Results: Compared with preexercise, SBP and DBP (mean of three sets) increased by 12% to 13% (both; P < 0.001) and 35% to 40% after 15RM RE (both; P < 0.001). 15RM SBP and DBP were higher than 4RM SBP and DBP (both; P < 0.001). The SBP of the fourth repetition of 15 RM RE was similar to the SBP of the fourth repetition of 4RM RE. Compared with preexercise, SV increased moderately after 4RM and 15 RM RE, respectively (both, P < 0.001). HR increased more after 15RM compared with 4RM RE (both, P < 0.05); thus, higher CO after 15RM compared with 4RM RE (P < 0.05) was mainly caused by higher HR. SVR decreased by 15% (P < 0.001) and 50% (P < 0.01) after 4RM and 15RM RE. Conclusions: SBP and DBP increased significantly more during moderate load RE; thus, the magnitude of the external load is not the prime determinant of the pressure response during RE. If management of blood pressure is of concern, high load/low rep RE is preferable to medium load/high rep RE. Key Words: BLOOD PRESSURE, CARDIAC OUTPUT, EXERCISE, SYSTEMIC VASCULAR RESISTANCE, VALSALVA, STRENGTH TRAINING

Participation in exercise rehabilitation programs is strongly recommended for patients with coronary artery disease (CAD) (e.g., 6,10,27), and traditionally, these programs have an emphasis on improving cardiovascular fitness. However, with the reduced level of physical activity and occurrence of sarcopenia often accompanied by coronary artery disease (CAD) and advancing age, these patients often experience a substantial loss of skeletal muscle mass and muscle strength (32). In addition, many CAD patients have impaired muscle function and increased muscle fatigability compared with sedentary healthy subjects (5). Relating to this, decreased muscle strength is an independent predictor of all-cause mortality (29), and it is demonstrated that muscle cross-sectional area and muscle strength are important predictors of clinical prognosis and long-term survival in patients with chronic heart failure (12). Consequently, to improve health, independent living, and long-term survival, it is important to implement effective resistance training protocols for patients with CAD.

Currently, there is a trend toward increasing use of resistance exercise in the rehabilitation and treatment of cardiovascular diseases, including CAD (14,15), peripheral arterial disease (33), and stroke (11). In all three studies mentioned previously (11,15,33), resistance exercises with
a high load/low repetition (3–5 RM, i.e., 85%–90% of 1RM) regime were used. However, international guidelines for resistance exercises for cardiac patients and healthy older individuals from, for example, American Heart Association (34), European Association for Cardiovascular Prevention and Rehabilitation (28), and others (2), do not recommend high load/low repetition resistance exercises, but rather endorse resistance exercises with low-to-medium load/medium-to-high number of repetition (10–15RM, i.e., 40%–60% of 1RM). The basis for these recommendations are probably the high blood pressure elevations previously reported during high load/low repetition resistance exercise (21,22) and with isometric exercise (e.g., 20). Thus, one of the primary reasons for restricting the magnitude of loading during resistance exercises of cardiac patients is the supposed increased risk of cardiovascular complications related to blood pressure elevations during high load/low repetition resistance exercises (2). It is also stated that there is a smaller pressure load on the cardiovascular system if the relative resistance is not too great (34). However, there are very few comparative studies of the pressure response in CAD patients after resistance exercise programs with different loadings, and in the light of the increasing use of resistance (SVR) are important determinants in the short-term regulation of arterial blood pressure. However, the effects of different resistance exercise protocols on CO and SVR has been little investigated in patients with CAD. Thus, there is a need to explore these responses during and after resistance exercises with different loads and number of repetitions. The aim of the present study was to investigate the relationship between resistance exercise with similar load but different number of repetitions to further clarify the effect of exercise load and duration on cardiovascular and hemodynamic responses in CAD patients. Hence, based on previous observations, our hypothesis was that the blood pressure would increase as a function of time and not only load during resistance exercise.

MATERIALS AND METHODS

Participants

Fifteen revascularized CAD patients with moderately good ventricular function (ejection fraction, 42% ± 9%) (11 male and 4 female patients) volunteered to participate in the study. Their physical characteristics, treatments, and medicinal use are described in Table 1. Inclusion criteria were previous revascularization and stable CAD and regular participation in a cardiac exercise training program (25) for a minimum of 6 months before the start of this study. Exclusion criteria were smoking, percutaneous coronary intervention, or coronary artery bypass surgery less than 6 months before inclusion in this study. None of the participants participated in strength training before this study. The participants were closely monitored for any symptoms of distress and discomfort during testing. The participants were instructed to avoid exercise and alcohol 24 h before they reported to the laboratory. This study was approved by the Regional Committee for Medical Research Ethics in Norway, and written informed consent was obtained from all participants before participation.

Study Design

The present study is a randomized, crossover study, and the overall aim of the study was to examine the hemodynamic and cardiovascular responses of two different bouts of resistance training to voluntary failure and further to assess the effects of the load, volume (number of sets), and duration (number of repetitions) of the exercise. To evaluate the component of volume, the responses between the first and the fourth set within each exercise bout was analyzed. To examine the effect of load, the 4RM responses were compared with the fourth repetition of the 15RM protocol, and to examine the effect of duration, the fourth repetition of 15RM exercise was compared with the 15th repetition of the 15RM protocol. To study these objectives, the subjects reported to the laboratory on three different occasions, and the testing was performed at the same hour of the day on each occasion. Beat-to-beat hemodynamic and cardiovascular responses to the two different resistance exercise protocols were measured before and after each set of exercise. For the 15RM protocol, measurements were also completed at the fourth repetition of each exercise set. In addition, lactate levels and ratings of perceived exertion (RPE) (3) were measured before and after exercise.

Strength Testing and Bike Ergometry Testing

On the first test day, the participants’ VO2max were estimated based on a submaximal bicycle ergometer test according to the procedure of Okura and Tanaka (26). The formulae for calculation the VO2max is independent of heart rate, hence it is useful situations when the participants are using
beta-adrenergic antagonists. In addition, the participants were tested for the highest load that could be moved through the full range of motion for no more than one repetition (one repetition maximum; 1RM), and their 4 times (4RM) and 15 times (15RM) repetition maximum. The bilateral strength tests were conducted while seated in a leg extension apparatus (Steens Physical, Ski, Norway). Excessive movements were restricted using a strap across the hips fastened to the apparatus. The strength tests were performed in a standardized order; first the 1RM, then the 4RM, and finally, the 15RM. Pauses between tests were administered ad libitum but with a minimum of 3 min between trials. The participants were instructed to hold their hands open and to keep the arms folded across their chest during testing. Only attempts that could be lifted throughout the full range of motion while maintaining correct technique were approved.

Exercise Testing

The 4RM and 15RM exercise protocols were performed on the second and third day of the experiments. The exercise bouts were performed in a randomized order and with a minimum of 48 h (range, 2–7 d) between bouts. The participants first completed a general warm-up routine using a stationary ergometer bicycle (Lode Excalibur Sport, Groningen, The Netherlands) for 10 min at a load that corresponded to a rating of 11 (“fairly light”) on the Borg Scale (RPE 6–20). After the warm up, testing immediately progressed with 4RM or 15RM resistance exercise in the leg extension training apparatus. For both exercise protocols, the participants were instructed to execute the leg extensions in a controlled manner without dropping the weight in the eccentric phase. The exercise was completed in a continuous manner without pauses between repetitions, using 1 s for the concentric phase (extension) and 1 s for the eccentric phase (flexion). The concentric and eccentric phases of each repetition were paced by a metronome (60 bpm). To control the effect of breathing on the blood pressure responses (24), both the previous strength tests and the 4RM and 15RM exercise testing sessions were performed without breath holding (Valsalva maneuver), that is, with exhalation during the extension phase and inhalation during the flexion phase of the movement. The participants were extensively coached to ensure correct execution of the breathing technique and synchronization of the concentric/eccentric lifting phases with the metronome rhythm. The participants were instructed not to clench their fists and to keep their arms folded across their chest both during the strength assessment and during the exercise sessions. There was a 4-min recovery period between each set of resistance exercise. Hemodynamic and cardiovascular parameters were recorded before set 1 (preexercise), in recovery periods between each set, and at the last repetition in each set. RPE were recorded preexercise and immediately after the last repetition in set 3, whereas lactate levels were measured preexercise and 60 s after the last repetition in set 3 of the 4RM and 15RM exercise.

Measurements and Instrumentation

Blood pressure measurements. Both preexercise and during 4RM and 15RM resistance exercises, continuous systolic (SBP) and diastolic (DBP) blood pressure (mm Hg) were measured noninvasively beat-to-beat by a Finometer Pro (FMS, Amsterdam, The Netherlands). This method provides finger-cuff measurements of peripheral arterial blood pressure, similar to intra-arterial values both at rest and during resistance exercise (9,31). Intra-arterial measurements (IAM) of blood pressure (BP) is considered to be the “gold-standard” of BP measurements, and the finger photoplethysmographic method of the Finometer Pro has recently been compared with IAM during resistance exercise. Evaluation of agreement between the two methods show that the average bias in absolute increases in SBP during resistance exercise was +2 mm Hg, and the limits of agreement were −28 and +32 mm Hg (9). The authors conclude that the two methods provide similar values of BP increments during resistance exercise.

Baseline (preexercise) blood pressures of each participant were measured with the Finapres PRO with the participants seated in the training apparatus, before the first bouts of 4RM and 15RM exercises. The participants rested in the apparatus for 5 min, and preexercise values are average values of the last 10 s of this period. Recovery blood pressures were measurements from the last single heart cycle of the 4-min recovery periods. Exercise blood pressure was recorded during the last repetition of each set of leg-extension exercise and measured with the leg fully extended and before the weight was lowered (lockout phase).

During all measurements, the participants were instructed to hold their hands open and to keep the arms folded across their chest in a fixed position and the finger-cuff at the heart level at all times (13).

Variability of resting blood pressure values. The variation of day-to-day resting BP was evaluated by comparing BP values after 5 min of quiet rest in the training apparatus, just before the 4RM and 15RM exercises.

Cardiovascular measurements. Heart rate (HR, bpm), stroke volume (SV, mL per beat), cardiac output (CO, L·min⁻¹), left ventricular end-diastolic volume (EDV, mL), and ejection fraction (EF, %) was assessed noninvasively by impedance cardiography (PhysioFlow Enduro; Manatec, Folschviller, France). Calculations of stroke volume are based on the assumption that changes in aorta blood volume induce opposing changes in electrical impedance (23). A detailed description of the impedance cardiography methodology is found in Richard et al. (30). The reliability and accuracy of this system has not been investigated during resistance exercise but has been compared with the direct Fick method both at rest and during moderate and maximal endurance exercise. Mean difference between the two methods was 0.04 L·min⁻¹ at rest and 0.29 L·min⁻¹ during moderate endurance exercise (4). During maximal incremental endurance
exercise testing, the correlation coefficient of the two techniques was 0.946 \((P < 0.01)\) with an average difference of \(-2.78\%\) \((30)\). In the present study, six PF-50 electrodes (Physioflow; Manatec) were attached to the upper body of the participants, carefully adhering to the manufacturer’s instructions regarding skin preparation and electrode placement. SV and HR were measured continuously beat-to-beat throughout each test and later reduced to 4-s averages.

Registrations of time per repetition during RE was done using a MuscleLab unit (Ergotest Innovation, Porsgrunn, Norway), connected to the leg-extension apparatus by a linear encoder. Lactate levels (La, mmol \(\cdot L^{-1}\)) in capillary whole blood were measured using a Lactate Pro LT-1710 apparatus (Arkay Inc., Kyoto, Japan). The Borg Scale (RPE, 6–20) was used to investigate the subjects’ rating of perceived exertion during the experiments \((3)\).

### Calculations

Systemic vascular resistance (SVR, \(\text{dyn} \cdot \text{s}^{-1} \cdot \text{cm}^{-5}\)) was calculated according to the following formulae: \(\text{SVR} = \frac{\text{MAP}}{\text{CO}} \times 80\).

### Statistical Analyses

The data were analyzed using the SPSS version 18.0. Comparisons between treatments (4RM vs. 15RM loadings) were done with paired samples \(t\) test. Within-group differences between means for different exercise series (sets 1–3) were analyzed with one-way repeated measures ANOVA and the Sidak post hoc test when significant differences between series were found. The significance level was set at \(P < 0.05\). Results are presented as means \(\pm\) standard deviations.

### RESULTS

None of the patients reported any discomfort during the resistance training, and no adverse events occurred during the study. At the time of enrollment in the present study, all participants were partaking in an ongoing cardiac rehabilitation maintenance exercise training program (phase 3). The average number of years \((\pm SD)\) of participation in this program was 5.1 \(\pm 5.1\).

**Variability of resting BP measurements.** The mean \(\pm\) SD range (15RM SBP minus 4RM SBP) of resting SBP was 5.0 \(\pm\) 22 mm Hg. The corresponding range of DBP values was 2.1 \(\pm\) 13 mm Hg. Resting SBP and DBP values did not differ across testing days. The coefficient of variation (CV, \%) was 10.3 and 11.4 for the systolic and diastolic blood pressures, respectively.

**Peak SBP and DBP exercise responses.** 4RM preexercise SBP was 124 \(\pm\) 14 mm Hg. Compared with preexercise values, exercise SBP (mean of three sets) increased approximately by 18\% to 147 \(\pm\) 12 mm Hg after 4RM resistance exercise \((P < 0.001)\). 15RM preexercise SBP was 128 \(\pm\) 17 mm Hg and not different from 4RM preexercise values. Exercise SBP increased by 37\% to 176 \(\pm\) 16 mm Hg after 15RM resistance exercise (compared with preexercise and exercise SBP at 4RM; \(P < 0.001\); Figs. 1 and 2). In addition, the SBP for set 3 during 15RM resistance exercise was significantly higher compared with SBP values for set 2 \((P < 0.001)\). During the 4-min recovery period between sets of resistance exercise, both SBP and DBP recovered to preexercise values and were not different from preexercise values.

4RM preexercise DBP was 67 \(\pm\) 11 mm Hg and exercise DBP (mean of three sets) after 4RM RE increased by 13\% to 76 \(\pm\) 10 mm Hg, (compared with preexercise, \(P < 0.001)\). 15RM preexercise DBP was 69 \(\pm\) 12 mm Hg, and exercise DBP increased by 40\% to 94 \(\pm\) 13 mm Hg after 15 RM resistance exercise \((P < 0.001)\). 15RM exercise DBP was also significantly higher compared with 4RM exercise DBP \((P < 0.001)\). Also, the DBP values for set 3 during 15RM RT was significantly higher compared with DBP values for set 2 \((P < 0.01)\).

**Blood pressure, heart rate, and repetition number.** In addition to SBP and DBP recordings for 4RM
and 15RM resistance exercise, blood pressure responses were also recorded for the fourth repetition of 15RM exercise (Table 2). Compared with preexercise, the SBP of the fourth repetition of 15 RM exercise was increased ($P < 0.001$) but similar to the SBP of the fourth repetition of 4RM exercise. The SBP of the 15th repetition of 15RM RE was approximately 19% higher than the SBP of the fourth repetition of 15RM exercise ($P < 0.001$). Compared with preexercise, the DBP of the fourth repetition of 15RM exercise was increased ($P < 0.001$) but not different from the DBP of the fourth repetition of 4RM exercise. The DBP at the 15th repetition of 15RM exercise was 21% higher than the DBP of the fourth repetition of 15RM exercise ($P < 0.001$).

**Mean arterial pressure.** Preexercise mean arterial pressure (MAP) was 87 ± 11 mm Hg. Exercise MAP (mean of three sets) increased to 112 ± 8 and 135 ± 11 mm Hg after 4RM and 15RM exercise, respectively (compared with preexercise, both, $P < 0.001$). MAP after 15RM exercise was 21% higher than 4RM exercise MAP ($P < 0.001$).

**SV, HR, CO, SVR, EF, and EDV responses.** There were no differences in responses between sets for the above parameters; thus, for simplicity, these exercise responses are presented as means of three sets of resistance exercise (Table 3). Compared with preexercise, exercise SV after 4RM and 15 RM exercise increased by 20% ($P < 0.001$) and 50%, ($P < 0.001$), but there were no differences in SV comparing 4RM and 15RM exercise. However, HR increased more after 15RM resistance exercise in comparison to 4RM exercise ($P < 0.05$); thus, the higher CO after 15RM exercise (compared with 4RM exercise; $P < 0.05$) is mainly the result of increased HR. There was a concomitant decrease in SVR of about 15% and 50% after 4RM and 15RM exercise (compared with preexercise, $P < 0.001$ and $P < 0.01$, respectively), but there were no differences between 4RM and 15RM exercise. EF and EDV increased only moderately by exercise (~10%–20%), and there were no differences between the exercise protocols.

**Maximal strength, 4RM and 15 RM loading.** Mean ± SD, 1RM, 4RM, and 15RM of leg extension exercise were 44.2 ± 13.5, 38.2 ± 11.2, and 24.2 ± 7.5 kg, respectively. The 1RM load (kg) was heavier than both 4RM ($P < 0.001$) and 15RM loads ($P < 0.001$), and the 4RM load (kg) was heavier than the 15RM load ($P < 0.001$). The mean (SD) 4RM and 15RM loads corresponded to 87% ± 2.4% and 55% ± 4.9% of the subjects’ 1RM, respectively ($P < 0.001$). The time to complete one set of either 4RM or 15RM exercise was 7.5 ± 1.0 and 26.7 ± 3.5 s, respectively ($P < 0.001$).

**VO$_2$max.** Estimated $\text{VO}_2$max of the participants was 1.86 ± 0.13 and 2.87 ± 0.43 L·min$^{-1}$, that is, 29.8 ± 2.8 and 33.3 ± 3.9 mL·min$^{-1}$·kg$^{-1}$, for the female and male patients, respectively. In comparison, reported $\text{VO}_2$max values of healthy 60- to 69-yr-old Norwegian female and male patients from the HUNT Fitness study are 2.15 ± 0.4 and 3.23 ± 0.57 L·min$^{-1}$, respectively (1). The bike ergometer test was terminated when the participants scored “15” on the Borg scale (6–20 scale), and the mean watts produced at Borg 15 was 109 ± 23 and 191 ± 43 for the female and male patients, respectively. Statistical comparison of male and female patients’ measurements were not performed because of uneven numbers of men and women participants.

**Lactate and RPE responses.** From preexercise, lactate levels increased from 1.28 ± 0.4 to 2.54 ± 1.2 mmol·L$^{-1}$ after three sets of 4RM exercise ($P < 0.01$), whereas lactate levels increased to 6.61 ± 1.9 mmol·L$^{-1}$, after three sets of 15RM exercise (compared with preexercise; $P < 0.001$). The lactate levels after 15RM exercise was higher compared with 4RM exercise ($P < 0.001$). Preexercise ratings of perceived exertion (RPE) was 6.2 ± 0.4 and increased to 12.7 ± 1.5 and

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**Table 3. Responses of stroke volume (SV), left ventricular ejection fraction (EF), and end diastolic volume (EDV), heart rate (HR), cardiac output (CO), and systemic vascular resistance (SVR) to 4RM and 15RM resistance exercise.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rest</th>
<th>Exercise</th>
<th>% Change, Pre-Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR, bpm</td>
<td>4RM</td>
<td>64 ± 7</td>
<td>89 ± 18**</td>
</tr>
<tr>
<td></td>
<td>15RM</td>
<td>67 ± 7</td>
<td>113 ± 21***</td>
</tr>
<tr>
<td></td>
<td>4RM</td>
<td>73 ± 13</td>
<td>89 ± 24*</td>
</tr>
<tr>
<td></td>
<td>15RM</td>
<td>68 ± 13</td>
<td>103 ± 27**</td>
</tr>
<tr>
<td>CO, L·min$^{-1}$</td>
<td>4RM</td>
<td>4.68 ± 0.84</td>
<td>7.90 ± 2.64***</td>
</tr>
<tr>
<td></td>
<td>15RM</td>
<td>4.60 ± 0.98</td>
<td>11.66 ± 4.34***</td>
</tr>
<tr>
<td>EF, %</td>
<td>4RM</td>
<td>42 ± 9</td>
<td>45 ± 9**</td>
</tr>
<tr>
<td></td>
<td>15RM</td>
<td>42 ± 8</td>
<td>47 ± 9**</td>
</tr>
<tr>
<td>EDV, mL</td>
<td>4RM</td>
<td>175 ± 32</td>
<td>211 ± 50***</td>
</tr>
<tr>
<td></td>
<td>15RM</td>
<td>167 ± 32</td>
<td>199 ± 28**</td>
</tr>
<tr>
<td>SVR, dyn·s$^{-1}$·cm$^{-5}$</td>
<td>4RM</td>
<td>1415 ± 242</td>
<td>1191 ± 403**</td>
</tr>
<tr>
<td></td>
<td>15RM</td>
<td>1451 ± 380</td>
<td>958 ± 322*</td>
</tr>
</tbody>
</table>

Values are means ± SD. Exercise values are means of 3 sets of exercise. $N = 15$. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$; rest versus exercise, ****$P < 0.05$; 4RM versus 15RM exercise.
to 15.5 ± 1.7 after 4RM and 15 RM exercise, respectively (compared with preexercise, both, P < 0.001). 15RM exercise was rated as harder training than 4RM exercise (P < 0.01). On the Borg scale, a score of 13 is subjectively described as “somewhat hard,” whereas a score of 15 is described as “hard.” All participants stated that they preferred the 4RM to the 15RM exercise.

**DISCUSSION**

In the present study, we have examined the separate effects of the exercise load, set duration, and the number of sets on important hemodynamic and cardiovascular parameters in revascularized CAD patients with moderately good ventricular function. The main finding of the present study is that the pressure response is higher after 15RM compared with 4RM resistance exercise. Because the mean external load per repetition was about 38 kg for 4RM exercise, but only ~24 kg for 15RM exercise, the implications are that the magnitude of the external load is not the prime determinant of the blood pressure response during resistance exercise. This is further emphasized by the fact that the pressure responses were similar during exercise with similar duration but different loads (Table 2). Moreover, when the 15RM exercise was performed to voluntary exhaustion (15 reps), the exercise lasted about 27 s, and the blood pressure was significantly elevated compared with the fourth repetition of 15RM exercise (duration about 7.5 s). Thus, during submaximal RE, the blood pressure increases with the duration of exercise. Collectively, these results indicate that the total duration of the exercise set perhaps is more important than the magnitude of the external loading in determining the pressure response during resistance exercise.

The effect of multiple sets of resistance exercise on the pressure response is little investigated. In the present study, peak blood pressures of set 1, 2, and 3 of 4RM resistance exercise were similar; thus, performing multiple sets does not have an accumulative effect on the blood pressure during 4RM exercise. In contrast, when performing 15RM exercise, peak blood pressures of set 3 were significantly higher compared with those of set 2, despite the fact that the blood pressure in the recovery phase was similar to preexercise levels. Interestingly, in a study of healthy young individuals performing resistance exercise, we found the same response (8). Hence, this effect is probably related neither to age nor to CAD. Relating to this, Lamotte et al. (18) compared the pressure responses to resistance exercise with different loads (40% and 70% of 1RM) but similar volume of exercise (kilograms per repetition per number of repetitions) in cardiac patients. Each set of 40% and 70% of 1RM resistance exercise lasted 34 and 20 s, respectively, and similar to the present study, blood pressure responses were significantly higher after the exercise regimen with the longest duration (40% of 1RM). Because the exercise volume was similar for the two loading conditions, this emphasizes that the pressure response during resistance exercise possibly is governed by the exercise duration. In contrast to our findings, Lamotte et al. (18) observed an accumulative effect of multiple sets of resistance exercise on the blood pressure, both when exercising at 40% and at 70% of 1RM. This may be explained by the fact that recovery periods between sets were only 60 s and too short for blood pressures to completely return to baseline values between sets. Hence, each new set of resistance exercise started on a higher blood pressure level than the previous set. In summary, it seems that several sets of high load/low rep resistance exercise is well tolerated by CAD patients without an additive increase in the blood pressure, provided sufficient recovery time between sets.

In this perspective, one may question the rationale for advising against high load/low rep resistance exercise for cardiac patients. Pioneering studies have shown extreme blood pressure elevations with arterial systolic blood pressures well above 300 mm Hg during double-leg press exercise with a load of 90% of 1RM (22). The latter study is frequently cited to warrant caution for letting cardiac patients perform resistance exercise with high or maximal loads (e.g., 2,7,16). Arterial blood pressure during resistance exercise in cardiac patients is considered to be within a clinically acceptable range at 40% to 60% of 1RM (34). However, the caution against high load resistance exercise may not be entirely warranted. With a relative load of 90% of 1RM, the subjects in the MacDougall study (five male body builders) lifted 11 to 17 repetitions (i.e., 11RM and 17RM resistance exercise) before exhaustion, and this is rather uncommon for an exercise load that is close to maximal. In comparison, the subjects in the present study were unable to perform more than 4 to 5 repetitions at approximately 90% of 1RM. By inspecting the actual traces of the blood pressure response in the MacDougall study (22), it is quite clear that the blood pressure of the body builders increased repetition-by-repetition and reaching peak values at the last repetitions. However, this finding is less communicated than the extreme blood pressure responses reported from this study. Thus, similar to the present study, the blood pressure responses observed in the study of MacDougall et al. (22) are probably more related to the duration of the exercise than the magnitude of the exercise load. In line with this, it is also stated that the highest blood pressure values are reached when multiple sets of 70% to 95% of maximal voluntary contraction are performed to voluntary exhaustion (2). Furthermore, it is argued that the pressure load on the heart will be lower the smaller the resistance (% IRM) (28). Our results are not in agreement with these arguments. The 15RM load in the present study correspond to about 55% of 1RM and clearly demonstrate that when a submaximal load is lifted to exhaustion, the blood pressure can indeed rise to very high values and even higher values than when a near maximal load (4RM) is lifted to exhaustion. In this respect, our findings are also in contrast to the statement that patients should increase the number of repetitions performed in each set before increasing the resistance or weight lifted (34,35). On the contrary, if the increase in blood pressure is of
concern, one should perhaps limit the total number of repetitions during each set of resistance exercise.

**Cardiovascular responses.** Physiologically, the pressure that is primarily regulated from the blood pressure center in the medulla oblongata is the mean arterial pressure. In the present study, and compared with preexercise, there was a larger increase in MAP after the 15RM exercise (55%) compared with 4RM exercise (28%). The MAP is the product of cardiac output (CO) times the systemic vascular resistance (SVR); thus, it is important to examine the different components affecting the MAP during exercise, and especially so, given the different pressure responses after 15RM and 4RM exercise. Relating to this, CO increased only moderately after exercise, and our data are comparable to data reported on young, normotensive men during repeated sets of isokinetic leg extensions (17). Similar to previous studies (19), the SV contributed very little to the increases in CO. In this respect, an increased afterload due to increased systemic vascular resistance and reduced preload due to decreased venous return could explain the relatively small changes in SV after dynamic resistance exercise. However, we observed a significant decrease in SVR (16% to 34%) for both RE protocols; thus, it is unlikely that venous return was compromised during exercise. Furthermore, the repeated forceful contraction of the leg muscles may provide a powerful muscle pump that enhances venous return and ventricular filling (22), as shown by the increase in the end-diastolic volume (EDV) after both exercise protocols. Hence, we assume that the small changes in SV in the present study are mainly caused by increases in EDV and that the moderate elevations in CO after RE are mainly caused by the increases in heart rate, as shown also by previous studies (17,19). In summary, the present results suggest that high load/low rep resistance exercise is well tolerated and results in a significantly lower blood pressure than low load/high rep exercise. Consequently, to reduce the hemodynamic response during resistance exercise in a risk population, we suggest shortening the duration of the exercise sets. We also suggest that one should preferably increase resistance before increasing the number of repetitions, if management of blood pressure responses is of concern. However, in the present study, the pressure response was only investigated for a limited number of loads and repetitions; thus, the relationship between blood pressure, exercise duration, and external load during resistance training needs to be examined in more detail using a wider range of loadings and repetitions (14).

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