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Abstract

Background: Generally, the evaluation of the blood pressure response to resistance exercise has been limited to the evaluation of discontinuous casual blood pressure monitoring, often measured at the end of the exercise.
Design: To continuously evaluate the blood pressure response at different intensities of leg press exercise with the same duration and number of repetitions.
Methods: Seven normotensive healthy men performed an incremental test on the leg press machine at relative intensities of one repetition maximum (1RM). The blood pressure and heart rate were measured simultaneously to the incremental exercise by a photoplethysmographic method.
Results: The mean ± SD peak values of the heart rate, diastolic blood pressure (DBP) and systolic blood pressure (SBP) were obtained on 70% of 1RM and were 145 ± 20 bpm, 113.1 ± 15.4 mmHg, and 192.4 ± 20.0 mmHg, respectively. The SBP was characterized by a decrease followed by an increase during the sets of exercise. The decrease in the SBP was 12–22 mmHg and took approximately 25 seconds to reach the minimum value before the increase. It was observed for all participants in most of the intensities. The rate of increase in the SBP was not statistically different between the intensities.
Conclusions: Both duration and intensity of exercise have an impact on the blood pressure response. Above 30% of 1RM, the SBP decreases in approximately 20 seconds and starts to increase until the end of the set of leg press exercise.

Keywords
Diastolic blood pressure, finapres, photoplethysmographic, resistance exercise, systolic blood pressure

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Introduction

Dynamic resistance exercises, also called as strength training, are recommended as part of a comprehensive exercise programme to improve physical fitness in healthy adults and elderly subjects, with and without chronic diseases.[1,2] Although chronic dynamic resistance training decreases blood pressure,[3,4] some studies have provided evidences of an abrupt increase in the systolic and diastolic blood pressure (DBP) during the execution of exercises,[5–10] which can represent a risk for cardiovascular events, especially aneurism rupture.[11,12] MacDougall et al.[7] reported peak values of 320 mmHg for systolic blood pressure (SBP) and 250 mmHg for diastolic blood pressure during resistance exercises performed to fatigue.

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Blood pressure response is not only related to the intensity of exercises, but also to the number of repetitions and work duration, suggesting that the former is more important than intensity in determining the blood pressure increase.[6,8] Moreover, concentric failure, which is the moment when the subject is no longer able to produce contractions, is also a main factor for the increase in the blood pressure response even during low-intensity resistance exercises.[8,13] In the spectrum of intensity, when a skeletal muscle contracts at high percentages of its one repetition maximum (1RM), the intramuscular mechanical compression eventually becomes so high that the muscle blood flow is either reduced or stopped. Measurements of the point at which the local blood flow is reduced by the contraction range from 40 to 60% of 1RM and vary considerably between muscles. At values above 60–70% of 1RM, the blood flow is completely blocked.[7,14] The inadequacy of muscle perfusion triggers an increase in the systemic blood pressure, increasing the perfusion pressure to the exercising and fatiguing muscle.

Leg press is a popular exercise in weight training and also common in certain ordinary behaviours. Therefore, it is used in various situations of physical training in healthy and unhealthy individuals. Regarding leg press exercise, a large increase in the blood pressure during both high-intensity isometric exercises[7,15] and the concentric contraction phase of dynamic exercises with a heavy load has been found.[7] However, few studies have reported the behaviour of the blood pressure throughout the exercise performance, especially during the resistance incremental test.

The blood pressure response seems to be greater during resistance exercises that combine high intensity and long duration performed to exhaustion. Furthermore, the evaluation of the haemodynamic response to resistance exercise has been limited to the evaluation of a continuous heart rate monitoring and discontinuous casual blood pressure monitoring, often measured at the end of the exercise. In other words, the pressure response is limited to the magnitude of change between the rest and the end of the exercise, suggesting a linear increase. However, the blood pressure adjustments within the sets of exercise still need more explanation. A non-invasive, continuous blood pressure monitor would be necessary. The Finapres blood pressure monitor, which has been used in several clinical trials,[16–18] offers a continuous and noninvasive blood pressure monitoring similar to intra-arterial technique.[19] In light of these facts, the objective of this study is to continuously evaluate the blood pressure response at different intensities of leg press exercise with the same duration and number of repetitions.

Methods

Subjects

Seven normotensive healthy men (mean ± SD age 26 ± 3 years; height 1.80 ± 0.05 m; body mass 82.7 ± 7.0 kg) participated in the study. The subjects had a minimum experience of 6 months in hypertrophy-type resistance training, with typical load corresponding to 6–12 RM. They also answered the Physical Activity Readiness Questionnaire. The following exclusion criteria were adopted: use of any kind of medication or anabolic steroids and cardiovascular, metabolic, neurological, pulmonary, or orthopaedic complications that could limit the performance of the exercises. The experiments were carried out in a climatically controlled room at 22–24°C and relative air humidity of 50–60%. Each subject was instructed to avoid caffeinated and alcoholic beverages and any other stimulants the night before and the day of the data collection. They were also instructed to not perform activities requiring moderate to heavy physical exertion the day before the application of the protocols. Lastly, they were instructed to avoid heavy meals 2 hours before the tests. The participants gave their written consent prior to the study, which was approved by the local Ethics Committee and complies with the Helsinki Declaration.

Experimental design

The participants accomplished two morning sessions of exercise on different days. In the first session, 1RM was determined. After 48 hours, an incremental test was performed in order to analyse the blood pressure response.

The tests were performed on a leg press machine (Leg Press 45°; Reforce, Brazil). The volunteers were instructed to perform the correct biomechanics of the movement in all sessions: (1) each movement cycle lasted approximately 3 seconds, with 1.5 seconds for the concentric phase and 1.5 seconds for the eccentric phase, controlled by visual and verbal commands; (2) motion angle of knee between 90 and 180 degrees, which was controlled by an eletrogoniometer (EMG system; Brazil).

One-repetition maximum test

The volunteers performed a 1RM test on leg press, as described by Kraemer and Fry.[20] Initially, the resistance load for 1RM was estimated before the test by multiplying the volunteer's body weight by 4, based on previous pilot tests and maximum strength perceived. A warm-up set of 7–10 repetitions was performed using 50% of the estimated resistance load for

1RM. After a 1-minute rest period, a set of 3–5 repetitions was performed at 80% of the estimated resistance load for 1RM. Subsequently, 3–6 maximal trials (one-repetition sets) with 5-minute periods between them were performed to determine the one-repetition maximum strength. The rate of the gradual increase in load was dependent on the participant's self-perceived capacity. When the pre-1RM had been determined, a second attempt with an additional 10% above the load was performed to verify the load value. If the participant did not succeed, the previous load would be considered his 1RM.

Resistance incremental test

Participants went to the laboratory 1 hour before starting the test. The resistance incremental test consisted of incremental stages at different percentage of 1RM. The test started with 10% of 1RM and the next stages were 20, 25, 30, 35, 40, 50, 60, 70, and 80% of 1RM or until exhaustion, with each stage lasting 1 minute with 2-minute passive recovery between stages. The subjects performed 20 3-second movements and during the passive recovery the intensity (%1RM) was increased. The end of the test was determined by either the subject's incapacity to perform the movement within the previously established correct biomechanics or his incapacity to perform the number of movements established for the stage.

Photoplethysmographic blood pressure and heart rate measurement and analysis

Photoplethysmographic measurements were obtained simultaneously to the incremental exercise with Finapres (Ohmeda 2300; Monitoring Systems, Englewood, CO, USA). This technique consists in adapting a pneumatic cuff to the phalange of the middle finger of the left hand. The cuff inflates until it senses the pulse in the digital artery. A pneumatic regulator continuously adjusts, by a servo-controlled system, the cuff pressure to keep the digital artery volume constant. This adjustment is proportional to the blood pressure values[21] and permits measuring the blood pressure beat-by-beat. The waveform generated by the equipment was recorded on a computer at a sampling frequency of 1000 Hz, using a data acquisition system (WinDaq DI-720; Dataq Instrumentes, Akron, OH, USA).

After arriving at the laboratory, the participants rested in the supine position (45 degrees) and the Finapres cuff was adjusted to the middle finger of the left hand, which was positioned on an armrest elevated to the level of the 4th intercostal space, so that the automatic calibration and the nulling procedure could be performed. This position was maintained during the resistance incremental exercise and the signal was recorded at rest and during the entire protocol. The participants were encouraged to avoid the isometric contraction of the left arm.

The SBP and DBP were continuously recorded before and during the resistance incremental test. The resting blood pressure value was calculated as the mean of the 2-minute data immediately before the exercise. The blood pressure values during the recovery moments between the intensities of the exercise were excluded. The values obtained during the 60 seconds of each exercise intensity were divided into means of 5 seconds. The mean of the first 5 seconds was considered the initial blood pressure value of the corresponding intensity and the mean of the last 5 seconds represented the final blood pressure.

Statistical analysis

Results are expressed as mean $\pm$ SD or mean and 95% confidence intervals, as appropriate. In the statistical analysis, the blood pressure and heart rate presented a normal distribution, tested by the Shapiro–Wilk normality test. The coefficient of variation for blood pressure and heart rate was calculated as the ratio of the standard deviation to the mean. The paired sample t-test was performed to analyse the differences between the initial and the final blood pressures and heart rate at each intensity. A repeated measures ANOVA was performed to establish the differences in the blood pressure and heart rate between the intensities. A linear regression analysis was conducted between the lower and the higher values of SBP, followed by repeated measures ANOVA on the slope of the equation to verify the increasing response of the SBP. The significance level was $p < 0.05$ and SPSS version 17.0 (Somers, NY, USA) software was used.

Results

The characteristics, resting blood pressure, and resting heart rate of the participants are shown in Table 1.

An example of a simultaneous heart rate, DBP and SBP signals during the execution of the leg press exercise at 50% of 1RM are shown in Figure 1. The mean $\pm$ SD of the heart rate and blood pressure of the participants during the exercise is illustrated in Figure 2. The coefficient of variation was 0.15 for heart rate, 0.17 for DBP, and 0.15 for SBP. During the sets of exercise, the final heart rate at the end of 25% of 1RM, the DBP at the end of sets 20, 25, 40, 50, 60, and 70% of 1RM and the SBP at the end of sets 25, 30, and 50% of 1RM were significantly higher than the initial values ($p < 0.05$). The mean $\pm$ SD peak values of

Table 1. Characteristics of the participants

Parameters	Study population ($n = 7$)
Age (years)	26 ± 3
Height (m)	1.80 ± 0.05
Body mass (kg)	82.7 ± 7.0
Body mass index (kg/m^2)	25.5 ± 2.0
One repetition maximum (kg)	291.3 ± 34.0
Resting heart rate (beat/min)	69 ± 12
Resting systolic blood pressure (mmHg)	126.2 ± 9.6
Resting diastolic blood pressure (mmHg)	71.2 ± 8.5

the DBP (113.1 ± 15.4 mmHg) and SBP (192.4 ± 20.0 mmHg) were achieved during 70% of 1RM. The increase from rest to maximal exercise was approximately 150% for the DBP and SBP. At the final of the stage 10% of 1RM, the heart rate was 38.9 ± 10.2% of maximal heart rate (72 ± 21 bpm) and at the final of the stage 70% of 1RM was 74.7 ± 10.5% of maximal heart rate (145 ± 20 bpm).

The SBP response was evaluated in more detail due to its 'v-shape' during the sets above 30% of 1RM (Figure 2). The 'v-shape', achieved above 30% of 1RM, is characterized by a decrease followed by an increase in the SBP during the sets of exercise. The mean differences between the initial SBP and the lower value achieved is shown in Table 2. Repeated-measures ANOVA determined that the difference of pressure was not statistically significant between the intensities ($F(5,30)=1.490$, $p = 0.223$). The decrease in the systolic pressure was 12–22 mmHg and took approximately 25 seconds to reach the minimum value and start increasing. The time to start increasing the SBP was not statistically different between the intensities ($F(5,30)=0.813$, $p = 0.550$). The 'v-shape' was observed for all participants in most intensities. During 30% of 1RM, no decrease in SBP was observed in two subjects. No decrease in SBP was observed during 35 and 60% of 1RM in one subject.

In order to analyse the increase in the SBP after the lower value had been achieved during the set of exercise, a linear regression analysis was conducted between the lowest and the highest values. This procedure was performed above 30% of 1RM for each participant, where the 'v-shape' response was achieved. Table 3 shows the linear regression parameters. The slope value reflects the increase in the SBP between the minimum and the peak values. Repeated measures ANOVA revealed that the difference of slopes was not statistically significant between the intensities ($F(5,34)=1.093$, $p = 0.385$). Although there were no statistically different between the intensities, the

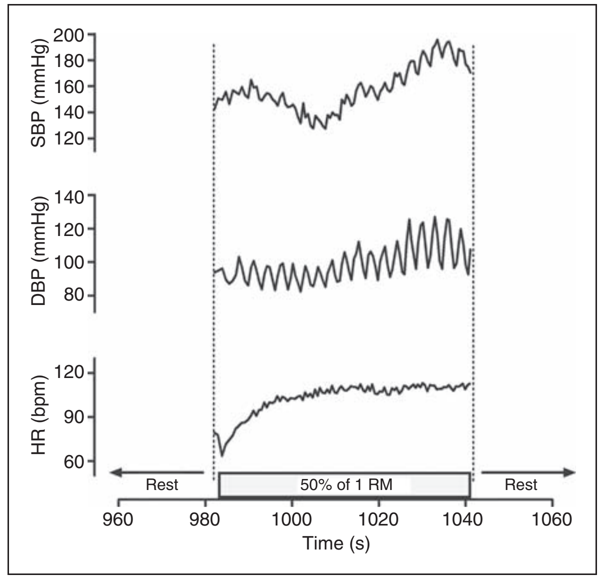

Figure 1. Example of the signals obtained during one set of leg press exercise performed at 50% of 1RM for subject number 2. 1RM, one repetition maximum; DBP, diastolic blood pressure; HR, heart rate; SBP, systolic blood pressure.

increase in SBP was approximately 60% higher in 70% of 1RM (1.27 ± 0.34 mmHg/s) than in 40% of 1RM (0.78 ± 0.43 mmHg/s).

Discussion

The main finding of this study was the surprising 'v-shape' response of the SBP during the sets above 30% of 1RM. Although the DBP and SBP were higher at the end of each set, in comparison to the initial values, the increase was not linear since the beginning of the sets. The low coefficient of variation suggests a standard response for SBP. Moreover, the mean peak values of SBP were lower than 200 mmHg, suggesting a slight increase in the blood pressure, instead of an abrupt one.

Many previous studies have shown blood pressure increases during resistance exercises;[5,7–10,22] however, no data on the response of blood pressure within the set of resistance exercise at different intensities have been reported. The elevation in the blood pressure is attributable to greater vascular resistance as well as the cardiac output achieved at the end of the exercise. The increase of vascular resistance seems to produce a rapid increase in the blood pressure and impose a greater pressure than volume load on the left ventricle.[23] Also, the increased intramuscular pressure promotes significant restriction of blood flow to the muscles,[14,24–26] resulting in the accumulation of metabolites, triggering the metabolic reflex and activating the sympathetic nervous system.[26] The breathing technique is another factor that could influence the

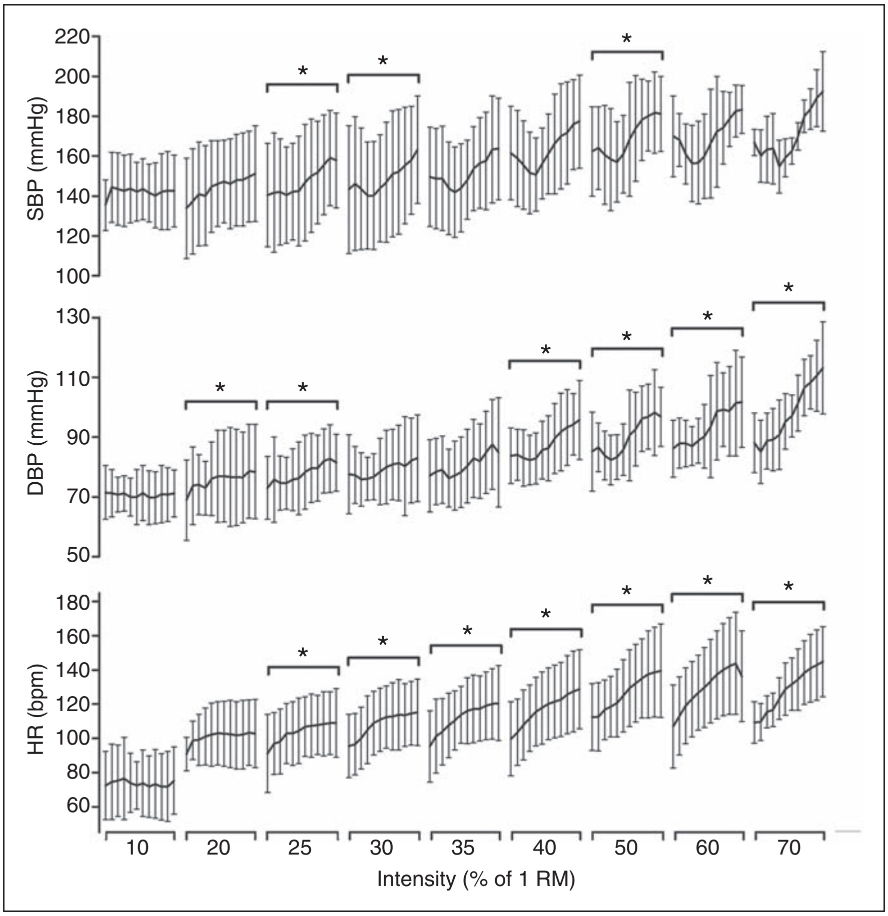

Figure 2. Heart rate (HR), diastolic (DBP), and systolic blood pressure (SBP) in each 5 seconds at different intensities of leg press exercise.

Values are mean ± SD. HR coefficient of variation, 0.15; DBP coefficient of variation, 0.17; SBP coefficient of variation, 0.15. *Significant difference between the first and the last five seconds of the set. 1RM, one repetition maximum.

Table 2. Decrease in systolic blood (ΔP) pressure and time to reach the lowest value during each intensity

% of 1RM	ΔP (mmHg)	Time (s)	*n*
30	14.7 (0.4–27.5)	28 (20–40)	5
35	13.9 (2.5–29.6)	23 (10–35)	6
40	12.7 (4.1–24.5)	25 (15–30)	7
50	12.2 (1.2–37.0)	20 (10–30)	7
60	22.5 (2.7–33.7)	27 (15–35)	6
70	17.3 (6.7–29.0)	25 (20–30)	6

Values are mean (95% CI). No statistical differences for ΔP and time between the intensities.; 1RM, one repetition maximum.

Table 3. Linear regression parameters for systolic blood pressure results after achieving the lowest value in the incremental test

% of 1 RM	Slope (mmHg/s)	r^2	*n*
30	0.85 ± 0.47	0.82 ± 0.17	5
35	0.78 ± 0.26	0.91 ± 0.03	6
40	0.78 ± 0.43	0.88 ± 0.12	7
50	0.87 ± 0.36	0.87 ± 0.06	7
60	0.91 ± 0.45	0.82 ± 0.13	6
70	1.27 ± 0.34	0.85 ± 0.14	6

Values are mean ± SD.; 1RM, one repetition maximum.

haemodynamic responses. When the exercise is performed with a closed glottis, the increase in blood pressure is extreme. Arterial hypertension produced during heavy weight lifting (85–100% of 1RM) with Valsalva manoeuver could reach values of 300 mmHg and remains elevated for 3–8 seconds after strain.[27]

Despite the evidence about the increased blood pressure during resistance exercise, the mechanisms for this behaviour are commonly elucidated during isometric exercise. Measurements of the point at which the local blood flow becomes impeded by the contractions is approximately 40% of the maximal voluntary contraction.[26,28] Such evidences suggest a linear increase in the blood pressure during isometric contractions, which is usually generalized to resistance exercises. Indeed, resistance exercises are isotonic and not isometric, therefore the comparison between them must be careful.

To our knowledge, the systemic vascular resistance has never been measured during resistance exercises. Nevertheless, we may hypothesize that a systemic vascular resistance response during resistance exercises is more similar to isometric than to dynamic exercises due to the continuous contraction of the muscles involved in resistance exercises. The intramuscular mechanical compression of both concentric and eccentric contractions may either stop or hinder the muscle blood flow during exercises. Our results are in accordance with Baum et al.,[29] showing that both duration and intensity of contraction have an impact on the blood pressure response. As in isometric exercise, a marked increase in the blood pressure is an inevitable result of exercising for 1 minute on leg press, whatever the intensity. Interestingly, above 30% of 1RM, the SBP response is not a linear increase, as expected. The response achieved during the sets of leg press above 30% of 1RM show that before the SBP increase, there is a decrease that could last between 20 and 30 seconds, independently of the intensity. The decrease during leg press exercise, in our study, reached approximately 15 mmHg for all intensities above 30% of 1RM.

The reasons for this drop could not be elucidated; however, some speculations can be made. Resistance exercise is not an isometric exercise, thus, the blockage of blood flow is not continuous due to the joint movement and the transition between eccentric and concentric phases. We can assume that in the first seconds of each set, the dynamic movement of the limbs allows an appropriate blood flow to the muscles, differently to isometric exercises, even with the increase in the intramuscular pressure during the set. At the same time, the accumulation of metabolites also increases. The increase in the intramuscular pressure and accumulation of metabolites can reach a point that promotes significant restriction to the blood flow to the muscles, triggering the metabolic reflex and activating the sympathetic nervous system.[14,25] The key point is that during leg press exercise, the critical peripheral vascular resistance that promotes increased blood pressure could occur after 20 seconds of exercise, supposedly due to the dynamic movement of the lower limbs. However, this mechanism would be responsible only for the maintenance of SBP and not for its fall. Therefore, other mechanisms should explain the decrease in the SBP during the first seconds of leg press. The position on the leg press machine may contribute to the drop of SBP in the start of the exercise. The premovement to move the legs from the resting position to the exercise position (lower limbs elevated) and the isometric contraction performed due to the position adjustment before the beginning of the exercise, which could last approximately 3 seconds, would raise the SBP even before the start of isotonic contractions. Baum et al.[29] showed that lifting the feet to the device promotes a raise in the blood pressure in elderly people. As previously discussed, isometric contractions cause a progressive increase in the blood pressure.[30] Immediately after the beginning of the set, there may be a downward adjustment of the SBP to compensate for the initial disturbance. Unfortunately, we do not have previous data of the sets to support this idea.

Possibly, below 30% of 1RM, the load that each subject had to sustain was not enough to cause a prompt increase in the SBP before starting the set. Above 30% of 1RM, the load is enough to cause changes in the vascular system. It has been shown that loads higher than 30% of 1RM can promote a high intramuscular pressure, reducing the blood flow.[31–33] Furthermore, this intensity is characterized by a metabolic transition between the aerobic and anaerobic metabolism – the anaerobic threshold[31,33] – which can also influence the blood pressure.

The results of the linear regression model between the lower and the peak values of SBP at each stage show that the rate of increase is similar between the intensities, although the rate of increase in 70% of 1RM is 60% higher than 40% of 1RM. This model was used due to the difficulty in calculating the baroreceptor reflex sensitivity in our experimental model. However, a linear regression analysis permits observing the rate of SBP increase at different intensities. According to the parameters (Table 3), the linear regression model showed a high correlation coefficient, adequately representing the rate of blood pressure increase after the decrease phase. If we consider the increase rate of 1.27 mmHg/s (slope in 70% of 1RM), after 30 seconds, the SBP will increase approximately 40 mmHg. This information is critical because an earlier study showed that the main factor affecting the cardiovascular response is the length of the set.[34]

As the objective of this study was to describe blood pressure response during leg press exercise at different intensities, the results provided at least two important evidences that should be explored, especially with cardiac patients: (a) the isometric contraction performed at the beginning of the movement should be minimized to prevent the fast increase in the blood pressure; and (b) exercise time until 30 seconds seems to avoid significant increases in the SBP, independently of the intensity. For clinical aspects, it does not seem reasonable to impose long durations of exercises, which could contribute to an excessive burden to the myocardial function. As well as the number of repetitions or length of the set, rest period intensity and rhythm of contraction are important for determining the degree of blood pressure increase during resistance exercises in hypertensive patients.[8,34] The increased SBP was more pronounced when the rhythm of contraction was slow or when the recovery period was short.[34] This increased SBP may represent a risk to hypertensive subjects, who are more prone to aneurysms than normotensive subjects, because an abrupt increase in the blood pressure may cause the rupture.[35] In this sense, shorter lengths of the set were recommended to prevent arterial hypertension during the exercise for cardiac patients. However, it is not certain that patients would present a similar response.

There are some limitations in this study that should be considered. The method and the protocol did not permit the evaluation of the blood pressure responses above 70% of 1RM for three specific reasons: (a) the subjects could not perform 20 movements above 70% of 1RM because of exhaustion; (b) above 70% of 1RM the subjects performed intense isometric contractions of the left arm, increasing signal noising; and (c) 70% of 1RM is an intensity at which the blood flow is completely blocked.[7,14] Furthermore, different intensities of exercise should be performed on different days to enable the complete recovery of blood pressure between the stages and to avoid the cumulative effect of blood pressure during the sets. All results found in this study are specific to the leg press machine and conclusions regarding other resistance exercises must be careful. The Finapres blood pressure monitor also has some limitations; however, previous studies have shown that the photoplethysmographic method is a valid alternative and in some cases, as in the present study, it is the only noninvasive approach available.[19,36]

In conclusion, peak values of heart rate, DBP, and SBP were achieved with 70% of 1RM. Both duration and intensity of the exercise have an impact on the blood pressure response. Above 30% of 1RM, the SBP response is different from a linear increase. The SBP decreases in approximately 20 seconds and starts to increase until the end of the set of the leg press exercise ('v-shape' response). For cardiac patients and when the leg press exercise is included in the rehabilitation programme, the length of the set should be shorter (20–30 s) to prevent the rise of cardiovascular parameters, especially arterial hypertension, during exercise. Further researches should investigate the 'v-shape' response in cardiac patients.

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References

1. ACSM. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009; 41: 687–708.
2. Vanhees L, Rauch B, Piepoli M, et al. Importance of characteristics and modalities of physical activity and exercise in the management of cardiovascular health in individuals with cardiovascular disease (Part III). *Eur J Prev Cardiol* 2012; 19: 1333–1356.
3. Cornelissen VA, Fagard RH, Coeckelberghs E, et al. Impact of resistance training on blood pressure and other cardiovascular risk factors: a meta-analysis of randomized, controlled trials. *Hypertension* 2011; 58: 950–958.
4. Vanhees L, De Sutter J, Gelada SN, et al. Importance of characteristics and modalities of physical activity and exercise in defining the benefits to cardiovascular health within the general population: recommendations from the EACPR (Part I). *Eur J Prev Cardiol* 2012; 19: 670–686.
5. Fleck SJ and Dean LS. Resistance-training experience and the pressor response during resistance exercise. *J Appl Physiol* 1987; 63: 116–120.
6. Lamotte M, Niset G and van de Borne P. The effect of different intensity modalities of resistance training on beat-to-beat blood pressure in cardiac patients. *Eur J Cardiovasc Prev Rehabil* 2005; 12: 12–17.
7. MacDougall JD, Tuxen D, Sale DG, et al. Arterial blood pressure response to heavy resistance exercise. *J Appl Physiol* 1985; 58: 785–790.
8. de Souza Nery S, Gomides RS, da Silva GV, et al. Intra-arterial blood pressure response in hypertensive subjects during low- and high-intensity resistance exercise. *Clinics (Sao Paulo)* 2010; 65: 271–277.
9. Palatini P, Mos L, Munari L, et al. Blood pressure changes during heavy-resistance exercise. *J Hypertens Suppl* 1989; 7: S72–S73.
10. MacDougall JD, McKelvie RS, Moroz DE, et al. Factors affecting blood pressure during heavy weight lifting and static contractions. *J Appl Physiol* 1992; 73: 1590–1597.
11. Hatzaras I, Tranquilli M, Coady M, et al. Weight lifting and aortic dissection: more evidence for a connection. *Cardiology* 2007; 107: 103–106.
12. Haykowsky MJ, Findlay JM and Ignaszewski AP. Aneurysmal subarachnoid hemorrhage associated with weight training: three case reports. *Clin J Sport Med* 1996; 6: 52–55.
13. Sale DG, Moroz DE, McKelvie RS, et al. Comparison of blood pressure response to isokinetic and weight-lifting exercise. *Eur J Appl Physiol Occup Physiol* 1993; 67: 115–120.
14. Asmussen E. Similarities and dissimilarities between static and dynamic exercise. *Circ Res* 1981; 48: I3–I10.

15. McArdle WD and Foglia GF. Energy cost and cardiorespiratory stress of isometric and weight training exercise. *J Sports Med Phys Fitness* 1969; 9: 23–30.
16. Phillips AA, Burr J, Cote AT, et al. Comparing the Finapres and Caretaker systems for measuring pulse transit time before and after exercise. *Int J Sports Med* 2012; 33: 130–136.
17. Fitzgibbon LK, Coverdale NS, Phillips AA, et al. The association between baroreflex sensitivity and blood pressure in children. *Appl Physiol Nutr Metab* 2012; 37: 301–307.
18. Hodgson Y and Choate J. Continuous and noninvasive recording of cardiovascular parameters with the Finapres finger cuff enhances undergraduate student understanding of physiology. *Adv Physiol Educ* 2012; 36: 20–26.
19. Imholz BP, Settels JJ, van der Meiracker AH, et al. Non-invasive continuous finger blood pressure measurement during orthostatic stress compared to intra-arterial pressure. *Cardiovasc Res* 1990; 24: 214–221.
20. Kraemer WJ and Fry AC. *Strength testing: development and evaluation of methodology*. Champaign, IL: Human Kinetics, 1995, pp.115–138.
21. Parati G, Casadei R, Groppelli A, et al. Comparison of finger and intra-arterial blood pressure monitoring at rest and during laboratory testing. *Hypertension* 1989; 13: 647–655.
22. Lentini AC, McKelvie RS, McCartney N, et al. Left ventricular response in healthy young men during heavy-intensity weight-lifting exercise. *J Appl Physiol* 1993; 75: 2703–2710.
23. Hanson P and Nagle F. Isometric exercise: cardiovascular responses in normal and cardiac populations. *Cardiol Clin* 1987; 5: 157–170.
24. Mitchell JH, Payne FC, Saltin B, et al. The role of muscle mass in the cardiovascular response to static contractions. *J Physiol* 1980; 309: 45–54.
25. Seals DR, Chase PB and Taylor JA. Autonomic mediation of the pressor responses to isometric exercise in humans. *J Appl Physiol* 1988; 64: 2190–2196.
26. Sejersted OM, Hargens AR, Kardel KR, et al. Intramuscular fluid pressure during isometric contraction of human skeletal muscle. *J Appl Physiol* 1984; 56: 287–295.
27. Narloch JA and Brandstater ME. Influence of breathing technique on arterial blood pressure during heavy weight lifting. *Arch Phys Med Rehabil* 1995; 76: 457–462.
28. Shepherd JT, Blomqvist CG, Lind AR, et al. Static (isometric) exercise. *Retrospection and introspection*. Circ Res 1981; 48: I179–I188.
29. Baum K, Ruther T and Essfeld D. Reduction of blood pressure response during strength training through intermittent muscle relaxations. *Int J Sports Med* 2003; 24: 441–445.
30. Smolander J, Aminoff T, Korhonen I, et al. Heart rate and blood pressure responses to isometric exercise in young and older men. *Eur J Appl Physiol Occup Physiol* 1998; 77: 439–744.
31. de Sousa NMF, Magosso RF, Pereira GB, et al. The measurement of lactate threshold in resistance exercise: a comparison of methods. *Clin Physiol Funct Imaging* 2011; 31: 376–381.
32. Williams MA, Haskell WL, Ades PA, et al. Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation* 2007; 116: 572–584.
33. de Sousa NM, Magosso RF, Pereira GB, et al. Acute cardiorespiratory and metabolic responses during resistance exercise in the lactate threshold intensity. *Int J Sports Med* 2012; 33: 108–113.
34. Lamotte M, Fleury F, Pirard M, et al. Acute cardiovascular response to resistance training during cardiac rehabilitation: effect of repetition speed and rest periods. *Eur J Cardiovasc Prev Rehabil* 2010; 17: 329–336.
35. Vermeer SE, Rinkel GJ and Algra A. Circadian fluctuations in onset of subarachnoid hemorrhage. New data on aneurysmal and perimesencephalic hemorrhage and a systematic review. *Stroke* 1997; 28: 805–808.
36. Chin KY and Panerai RB. Comparative study of Finapres devices. *Blood Press Monit* 2012; 17: 171–178.