Finger Blood Pressure During Leg Resistance Exercise

Authors

R. S. Gomides[1], R. M. R. Dias[2], D. R. Souza[1], L. A. R. Costa[1], K. C. Ortega[3], D. Mion Jr[3], T. Tinucci[1], C. L. de Moraes Forjaz[1]

Affiliations

[1] University of Sao Paulo, School of Physical Education and Sport, Sao Paulo, Brazil
[2] State University of Pernambuco, Faculty of Physical Education, Recife, Brazil
[3] University of Sao Paulo, General Hospital, Sao Paulo, Brazil

Key words
- finger photoplethysmography
- intra-arterial
- blood pressure measurement
- strength exercise

Abstract

Blood pressure (BP) assessment during resistance exercise can be useful to avoid high BP, reducing cardiovascular risk, especially in hypertensive individuals. However, non-invasive accurate technique for this purpose is not available. The aim of this study was to compare finger photoplethysmographic (FPP) and intra-arterial BP values and responses during resistance exercise. Eight non-medicated hypertensive subjects (5 males, 30–60 years) were evaluated during pre-exercise resting period and during three sets of the knee extension exercise performed at 80% of 1RM until fatigue. BP was measured simultaneously by FPP and intra-arterial methods. Data are mean ± SD. Systolic BP was significantly higher with FPP than with intra-arterial: at pre-exercise (157 ± 13 vs. 152 ± 10 mmHg; $p < 0.01$) and the mean (202 ± 29 vs. 198 ± 26 mmHg; $p < 0.01$), and the maximal (240 ± 26 vs. 234 ± 16 mmHg; $p < 0.05$) values achieved during exercise. The increase in systolic BP during resistance exercise was similar between FPP and intra-arterial (+73 ± 29 vs. +71 ± 18 mmHg; $p = 0.59$). Diastolic BP values and increases were lower with FPP. In conclusion, FPP provides similar values of BP increment during resistance exercise than intra-arterial method. However, it overestimates by 2.6 ± 6.1% the maximal systolic BP achieved during this mode of exercise and underestimates by 8.8 ± 5.8% the maximal diastolic BP.

Introduction

Resistance training is recommended as part of a comprehensive exercise program to improve physical fitness in healthy adult and elderly subjects, with and without chronic diseases [1, 6, 23]. Although hypertension is highly prevalent in elderly [5], the effects of resistance exercise on arterial blood pressure (BP) are paradoxical.

Although chronical resistance training might decrease BP [7], during exercise execution, there is an abrupt and huge increase in systolic and diastolic BPs [8, 15, 17–19], which can represent a risk for cardiovascular events, especially for aneurism rupture [11, 12]. MacDougall et al. [17] reported peak values of 320/250 mmHg for systolic/diastolic BPs during bilateral leg press exercise executed to fatigue in highly trained weight lifters. Therefore, the assessment of BP during resistance exercise can be useful to avoid high BP values, reducing cardiovascular risk, especially in hypertensive patients.

Classically, intra-arterial BP measurement technique, the gold standard to assess BP, has been employed to evaluate BP responses during resistance exercises [8, 15, 17–19]. However, because of its invasive characteristics, this technique is not feasible in clinical settings, limiting research and practical guidelines. As an alternative, the indirect auscultatory BP measurement technique was tested for this purpose, but it underestimated the intra-arterial BP levels by more than 13% [22].

The non-invasive BP measurement based on finger photoplethysmographic (FPP) technique is a valid method to assess BP at rest and during aerobic exercise [20]. However, to the best of our knowledge, up to now no previous study has compared FPP BP values with the ones obtained with intra-arterial measurement during resistance exercise. As in clinical settings cardiovascular risk is mainly attributed to a huge increase in BP, it is especially important to establish this comparison in subjects who achieve higher BP levels during this kind of exercise, which has been reported in hypertensive individuals [18].

Therefore, the aim of the present study was to compare FPP and intra-arterial BP values and

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Correspondence
Claudia Lucia de Moraes Forjaz, PhD
University of Sao Paulo
School of Physical Education and Sport
Av Prof. Mello Moraes 65 – Butanta
05508030 Sao Paulo
Brazil
Tel.: +55/113/091 3136
Fax: +55/113/813 5921
cforjaz@usp.br

responses during resistance exercise in hypertensive subjects. Based on previous studies with aerobic exercise, we hypothesize that FPP and intra-arterial BP measurements would detect similar BP increments during resistance exercise in hypertensive subjects.

Methods

Subjects

This study was performed in accordance with the ethical standards of the International Journal of Sports Medicine [10], and it was approved by the Ethical Committee of the General Hospital, Medical School, University of Sao Paulo.

After giving written consent, 8 subjects (5 males, aged 30–60 years) with essential hypertension stages 1 and 2 participated in this study. Hypertensive subjects were selected among those treated at the Hypertension Unit of the General Hospital.

Before study enrollment, all subjects underwent the routine screening protocol of the hypertension unit, which follows the international guidelines [5], and includes resting and exercise ECG, blood analysis, and urine tests. Subjects were excluded from the study if they showed any sign of cardiovascular disease, any other cardiovascular risk factor (except for smoking) and/or target organ damage. None of the subjects was engaged in any regular physical exercise program nor had any previous experience with resistance exercise. Subjects did not receive any anti-hypertensive medication during the study, and previous treatment was withdrawn at least 4 weeks before the experiments.

Auscultatory BP was measured three times during two visits to the laboratory, and the mean of these six measurements was used as the patient's BP level. The first and the fifth Korotkoff's sounds were employed, respectively, to determine systolic and diastolic BPs. Subjects were only included in the study if systolic/diastolic BP values were between 140/90 and 160/105 mmHg.

Measurements

Intra-arterial BP measurement

During the experiments, intra-arterial BP was measured in the radial artery of the non-dominant arm, as previously described [3]. Briefly, after subcutaneous administration of local anesthetic (2% lidocaine without vasoconstrictor), a 22-gauge catheter (BD-Angiocath; Becton Dickinson, Franklin Lakes, NJ, USA) was inserted into the radial artery, and it was maintained patent by a constant infusion of saline with heparin (15UI/ml). All procedures were performed inside the hospital and by a trained physician. The catheter was connected to a transducer kit (PX-260; Edwards Life Sciences, Irvine, CA, USA), which was positioned at the level of the fourth intercostal space. A signal amplifier was used (KS3800; Gould Instrument Systems, Valley View, OH, USA), and the signal was acquired on a computer, at a sampling frequency of 500 Hz, using a data acquisition system (WinDaq DI-720; Dataq Instruments Inc, Akron, OH, USA).

Photoplethysmographic BP measurement

Photoplethysmographic measurements were obtained simultaneously to intra-arterial BP with the Finometer (FMS, Amsterdam, Netherlands). This technique consists in adapting a pneumatic cuff to the phalange of the medial finger of the dominant hand. This 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 BP values [21], and permits the measurements of BP values beat-by-beat. The waveform generated by the equipment was acquired on a computer, at a sampling frequency of 500 Hz, using a data acquisition system (WinDaq DI-720; Dataq Instruments Inc, Akron, OH, USA).

Experiments

Prior to the experimental session, all subjects attended two familiarization sessions in order to learn the correct execution of the knee extension exercise. In each one of these sessions, they performed 10 repetitions of the exercise with the lowest load allowed by the knee extension machine (Physicus PHA 23; Sao Paulo, Brazil). In addition, one week before the experiment, they underwent a 1 repetition maximum (RM) test following Kraemer and Fry's protocol [14].

For the experiments, subjects were instructed to arrive at the laboratory between 3 and 5 pm. They were instructed to abstain from exercise for the last 24 h and from smoking for at least 3 h before the experimental session. They ingested a light meal at least 2 h before the experiment, and products containing caffeine and theophylline were not allowed in this meal.

After arriving at the laboratory, subjects' auscultatory BP was measured, and the experiment was only initiated if BP was below 160/105 mmHg, which is considered a secure BP level for beginning exercise [2]. Then, subjects rested in the supine position while the catheter was inserted into the non-dominant radial artery. Afterwards, they moved to the knee extension machine, and were fixed to it by a belt positioned at the waist level. The finometer cuff was adjusted to the middle finger of the dominant arm that was positioned on an armrest elevated to the level of the 4th intercostal space, and the nulling procedure was performed. The non-dominant arm with the radial intra-arterial BP measurement site was also positioned on an armrest elevated to the level of the 4th intercostal space, and the transducer was positioned at the same level for nulling procedure.

A pre-exercise resting period was recorded for 3 min, and then, subjects performed, without warming up, three sets of the knee extension exercise at 80% of 1RM until fatigue, with a 90-s rest interval between the sets. Fatigue was employed as the finishing point in order to assure the highest increase in BP [17], and it was identified when subjects were unable to perform a complete repetition of the movement.

Data analysis

Intra-arterial and FPP BP waves were registered simultaneously by WinDaq software. Although there was a time delay between waveforms of both methods, corresponding waveforms were compared. For comparisons between methods, the absolute values of BP obtained in each beat by both methods were compared for the pre-exercise (last minute of pre-exercise period), as well as for the exercise conditions. In addition, the maximal values achieved during exercise in each set were compared, and the differences between pre-exercise and maximal BPs (BP response to exercise) were analyzed.

Statistical analysis

Normality was checked by Shapiro-Wilks and visual inspection, while Levene's test confirmed the homoscedasticity of the data (SPSS for Windows 13.0;. Lead Technologies Inc., Chicago, IL, USA). Intraclass correlation coefficients between methods for each variable were calculated, and paired Student's t-test was employed for comparing the mean values of both methods (Statistica for Windows 5.0; Statsoft Inc., Tulsa, OK, USA). The correlations between the difference in BP between methods and the intra-arterial values were analyzed with Pearson correlation coefficient. The absolute changes in systolic and diastolic BP during exercise were analyzed by the concordance correlation coefficient [16]. Bland and Altman's plots were used to determine the bias and the limits of agreement between FPP and Intra-arterial methods [4]. For all analyses, $P<0.05$ was set as significant. Data are presented in mean ± SD.

Results

The characteristics of the subjects included in the study as well as the workload and the number of repetitions performed in each exercise set are presented in ▶ **Table 1**.

An example of simultaneous FPP and intra-arterial BP signals recorded during the execution of knee extension exercise is presented in ▶ **Fig. 1**.

Mean values of BP measured at rest and during exercise, as well as the maximal BP value achieved during exercise, assessed with FPP and intra-arterial methods, are presented in ▶ **Table 2**.

Table 1 Subjects and exercise characteristics.

	Mean ± SD	Range
N	8 (5 males)	
age, yrs	45 ± 7	33–55
antropometric parameters		
weight, kg	79.9 ± 12.6	59.0–95.7
height, m	1.68 ± 0.11	1.50–1.87
BMI, kg/m²	28.1 ± 1.5	26.2–29.8
cardiovascular parameters		
resting heart rate, beat/min	73 ± 7	64.7–82.0
maximal heart rate, beat/min	121 ± 19	97–155
exercise parameters		
workload, kg	51 ± 12	35–70
set 1, number of repetitions	11 ± 3	6–16
set 2, number of repetitions	9 ± 2	7–11
set 3, number of repetitions	8 ± 2	5–10

Six hundred and thirty-five measurements were taken during the pre-exercise period, 854 measurements were taken during exercise, and 24 maximal BP values were obtained during exercise sets. At rest, coefficient of variation for systolic and diastolic BP measured by FPP were, respectively, 4.0 ± 0.7 and 4.4 ± 0.8 %, while these coefficients during exercise were 12.3 ± 0.2 and 15.0 ± 0.2 %. For intra-arterial BP, the coefficients of variation for systolic and diastolic BP at rest were, respectively, 3.9 ± 0.6 and 4.6 ± 1.1 %, and during exercise they were 11.3 ± 0.2 and 14.7 ± 0.3 %. Significant intraclass correlation coefficients between methods were observed for systolic and diastolic BP at rest, during exercise and for maximal BP values. However, systolic BP values were significantly higher, while diastolic BP levels were significantly lower when measured with FPP than with intra-arterial method at all conditions.

BP absolute increases produced during resistance exercise assessed with FPP and intra-arterial methods are also presented in ▶ **Table 2**.

The absolute increase in systolic BP during resistance exercise was similar between FPP and intra-arterial methods. On the other hand, diastolic BP increase during resistance exercise was significantly lower when measured with FPP than with intra-arterial method.

Concordance correlation coefficient between FPP and intra-arterial systolic and diastolic BP increases during resistance exercise are shown in ▶ **Fig. 2**. There were expressive concordance correlation coefficients between FPP and intra-arterial SBP and DBP increases during this exercise.

The correlations between the difference between methods and the intra-arterial BP value are presented in ▶ **Fig. 3**. There was a positive and significant correlation between intra-arterial maximal systolic BP value, and the difference observed between methods in measuring this value (panel **a**). A positive and significant correlation was also observed between systolic BP increase measured with intra-arterial method and the difference between methods in estimating this increase (panel **b**).

For better comparison between methods, Bland and Altman's analysis is presented in ▶ **Fig. 4**. The average bias in the absolute increase of systolic BP during resistance exercise was +2 mmHg, and the limits of agreement were −28 and +32 mmHg. The aver-

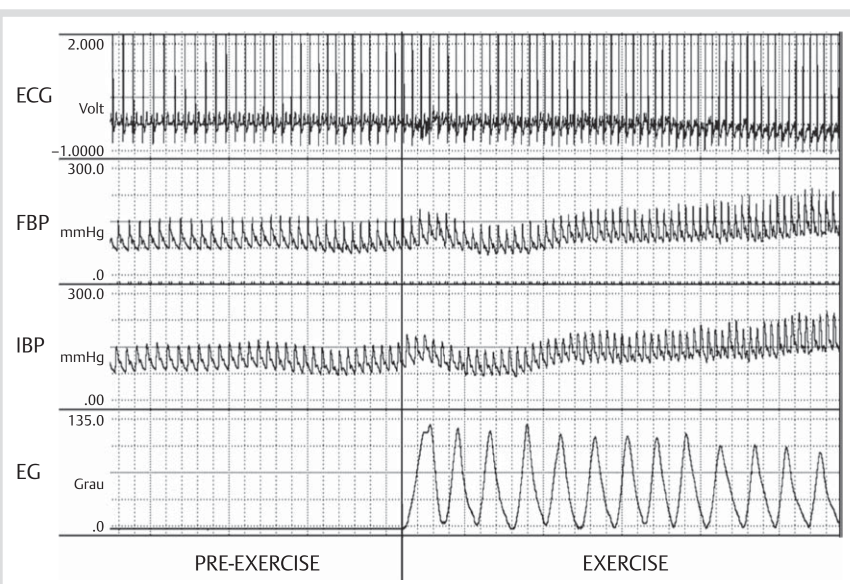

Fig. 1 Example of the signals obtained before and during one set of knee-extension resistance exercise performed to fatigue at 80 % of 1RM. ECG = electrocardiogram wave; FBP = finger photoplethysmography blood pressure; IBP = Intra-arterial blood pressure; EG = Exercise goniometry.

Table 2 Comparison between finger photoplethysmography (FPP) and intra-arterial systolic and diastolic blood pressures (BP) at different conditions.

	Intra-arterial		FPP		P	ICC	P
	Mean ± SD	Range	Mean ± SD	Range			
pre-exercise mean values (n = 635 measurements)							
systolic BP, mmHg	152 ± 10	132–182	157 ± 13	126–201	< 0.01	0.81	< 0.01
diastolic BP, mmHg	89 ± 7	72–117	84 ± 8	69–112	< 0.01	0.77	< 0.01
exercise mean values (n = 854 measurements)							
systolic BP, mmHg	198 ± 26	122–249	202 ± 29	128–284	< 0.01	0.89	< 0.01
diastolic BP, mmHg	127 ± 22	77–219	117 ± 24	64–211	< 0.01	0.77	< 0.01
exercise maximal values (n = 24 measurements)							
systolic BP, mmHg	234 ± 16	191–249	240 ± 26	173–284	< 0.05	0.87	< 0.01
diastolic BP, mmHg	167 ± 24	134–219	153 ± 28	99–211	< 0.01	0.98	< 0.01
difference between maximal and last minute pre-exercise values (n = 24 measurements)							
Δsystolic BP, mmHg	+ 71 ± 18	29–101	+ 73 ± 29	20–124	0.59	0.90	< 0.01
Δdiastolic BP, mmHg	+ 79 ± 25	46–132	+ 71 ± 27	22–122	< 0.01	0.99	< 0.01

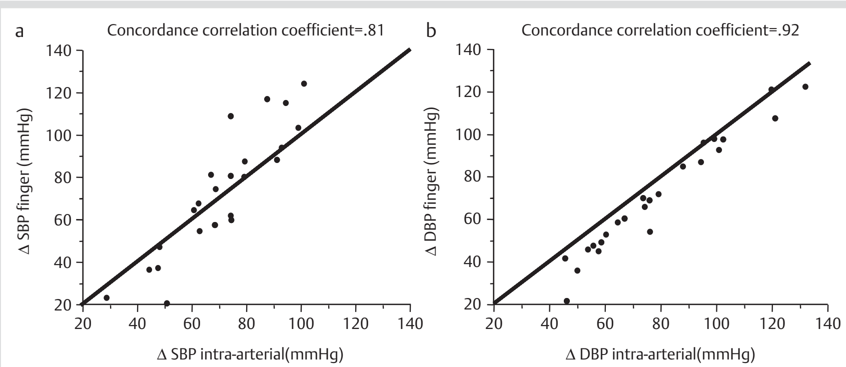

Fig. 2 Correlation between systolic (ΔSBP) and diastolic (ΔDBP) blood pressure increases measured during knee-extension resistance exercise with finger photoplethysmography (FPP) and intra-arterial (IA) methods.

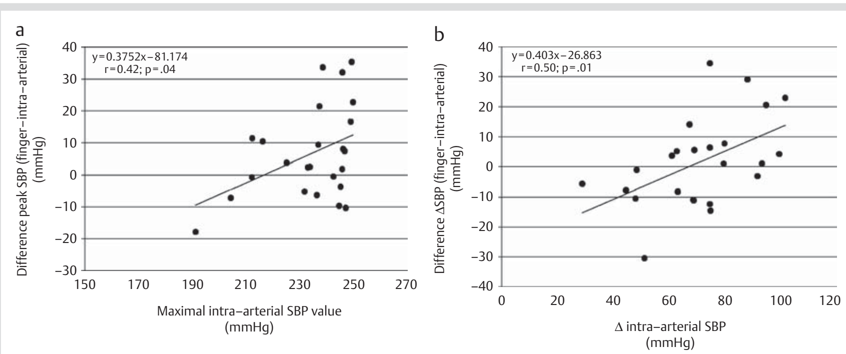

Fig. 3 Correlations between the differences in values measured with finger photoplethysmography (FPP) and intra-arterial (IA) methods and the intra-arterial values. Panel **a**. Analysis for maximal systolic blood pressure achieved during exercise (SBP). Panel **b**. Analysis for systolic blood pressure increase during exercise (ΔSBP).

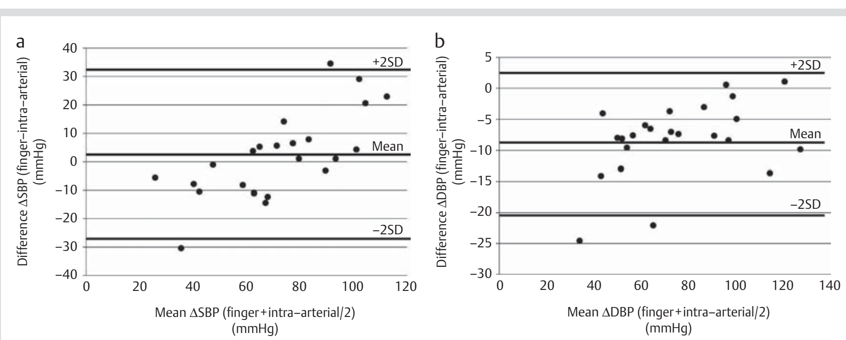

Fig. 4 Bland and Altman's plots between the absolute increases in systolic (SBP) and diastolic (DBP) blood pressures measured with finger photoplethysmography and intra-arterial methods during resistance exercise.

age bias in the absolute increase of diastolic BP during resistance exercise was −8 mmHg, and the limits of agreement were – 20 and + 4 mmHg.

Discussion

The main findings of the present study were that: (a) FPP and intra-arterial absolute BP values measured at rest and during resistance exercise were slightly different; (b) the absolute increase in systolic BP produced during resistance exercise was similar when obtained with FPP and intra-arterial methods.

The assessment of BP during resistance exercise remains a challenge for researches. While the intra-arterial method that provides accurate BP values is highly invasive, limiting its use in clinical settings, the non-invasive indirect auscultatory BP measurement underestimates systolic BP during resistance exercise [22]. Although FPP has already been used to assess BP during this mode of exercise, no previous study has compared it with intra-arterial technique in this condition.

The results of this study showed significant intraclass correlation coefficients between FPP and intra-arterial methods for systolic and diastolic BP in all conditions, suggesting that both methods detect BP in the same direction and with the same relative magnitude. Nevertheless, this analysis does not detect the bias between the methods. In fact, the present study showed that FPP overestimated systolic BP by 2.9 ± 6.1 % at rest. These differences have already been described previously, and were probably caused by the differences in the site of BP measurement. It is known that pressure pulsations are progressively distorted on their way towards the periphery. Finger BP waveforms are more undulatory than brachial artery BP waveforms because of reflections of the systolic pulse wave in the artery system of the arm. The reflected and forward BP waves might be added to each other, increasing SBP values [9,13]. This effect is greater when BP measurements are taken in distal segments of the body, which explain the higher SBP value observed in the finger.

To eliminate this difference, some equipment, such as Finometer (FMS, Amsterdam, Netherlands), have mathematical tools for reconstructing brachial BP from finger BP measurements [9]. However, other devices, such as Finapres (Ohmeda, Wisconsin, USA), do not have these tools [13]. Thus, in the present study, we assessed finger BP without reconstruction to evaluate BP measurement without mathematical corrections, which amplifies the applicability of the results for more equipment and research groups. Nevertheless, the reconstruction process might correct the difference observed between methods in the present study, which should be tested in the future during resistance exercise.

The present study is the first to describe that differences in resting absolute BP values measured with FPP and intra-arterial methods are maintained during resistance exercise. Maximal systolic BP levels achieved during resistance exercise were overestimated in approximately 2.6 ± 6.1 % with FPP. Moreover, there was a positive correlation between the difference in systolic BP between methods and intra-arterial BP values, which shows that this overestimation was greater when intra-arterial BP levels were higher. Thus, finger BP is not an accurate method for assessing BP absolute values during resistance exercise, and might produce some bias when used for this purpose in research.

In clinical practice, the measurement of BP during resistance exercise is recommended for assuring the safety of exercise, especially in hypertensive subjects. This measurement might help to avoid an excessive BP increase by allowing the interruption of exercise when BP is too high [23]. As FPP provides BP values greater than the intra-arterial method, although not accurate, it might be used for this purpose, which was not the case with the indirect auscultatory BP measurement method that underestimates BP in this condition [22].

Although FPP was not accurate enough to measure the absolute maximal BP values achieved during resistance exercise, the present results showed that it was accurate enough to evaluate BP increment during this mode of exercise. In fact, FPP was sufficiently sensitive to detect the rapid changes in systolic BP that occurred during resistance exercise, supporting its use in clinical research setting. Many scientific questions in this field are related to the effects of different exercise protocols on BP responses during exercise or to the determinants of this BP increase. Since intra-arterial method has limited application, the results of this study provide an insight into the use of FPP to analyze these issues. However, it is important to consider that the positive correlation observed between the differences between methods and intra-arterial BP increases suggests that the accuracy of FPP decreases when BP response to exercise is too low or too high (values obtained in the present study varied from + 29 to + 101 mmHg). Nevertheless, this study did not analyze other magnitudes of increments that should be evaluated in the future.

The diastolic BP assessed by FPP was underestimated at rest, during resistance exercise, and for the maximal value, showing that this method is not accurate for analyzing this variable. These results are in agreement with a previous study [9,13], and were probably caused by the different sites of BP measurement between methods. Moreover, the increase in diastolic BP during resistance exercise was also underestimated by FPP, suggesting that the changes in diastolic BP might not be assessed with this technique. As resistance exercise presents an accentuated isometric component, the increase in vascular constriction might decrease the sensitivity of the device to detect the changes in this diastolic BP.

This study presents some limitations that should be considered in the interpretation of the results. First, only one resistance exercise was tested. This exercise involved only a lower body segment, and allows a constant position of the finger. Exercise involving upper body segments might make finger measurement more difficult, producing different results. Only one exercise intensity was employed, and thus, results cannot be extrapolated for other intensities. Finally, this study included hypertensive subjects not treated with anti-hypertensive medication. Since BP responses during resistance exercise in medicated patients are attenuated, it is possible that responses in these patients are lower than the range of response observed in the present study.

Conclusion

In conclusion, the results of the present study indicates that FPP provides similar values of BP increment during resistance exercise compared to intra-arterial measurement. However, it overestimates the maximal systolic BP and underestimates maximal diastolic BP levels achieved during this mode of exercise.

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