Original Article

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Heart rate responses during isometric exercises in patients undergoing a phase III cardiac rehabilitation program

Resposta da frequência cardíaca durante o exercício isométrico de pacientes submetidos à reabilitação cardíaca fase III

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Abstract

Background: The magnitude of cardiovascular responses is dependent on the static and dynamic components as well as the duration and intensity of the contraction performed. **Objective:** To evaluate the heart rate responses to different percentages of isometric contractions in 12 patients (63±11.6 years) with coronary artery disease and/or risk factors for coronary artery disease that were participating in a phase III cardiac rehabilitation program. **Methods:** Heart rate variation (ΔHR) was evaluated during maximum (MVC, five and ten seconds in duration) and submaximal (SMVC, 30 and 60% of MVC-5, until muscle exhaustion) voluntary contraction, using a handgrip dynamometer. Additionally, the representative index of cardiac vagal modulation (RMSSD index) was calculated at rest (pre-contraction), at the final 30 seconds of SMVC and during recovery (post-contraction). **Results:** ΔHR showed higher values in MVC-10 versus MVC-5 (17±5.5 vs 12±4.2 bpm, p<0.05) and the SMVC-60 vs SMVC-30 (19±5.8 vs 15±5.1 bpm, p<0.05). However, results for CVM-10 showed similar ΔHR compared to results for CVSM (p> 0.05). RICVM at rest decreased (p<0.05) during SMVC-30 (30% = 27.9±17.1 vs 12.9±8.5 ms) and SMVC-60 (60% =25.8±18.2 vs 9.96±4.2 ms), but returned to the baseline values when the contraction was interrupted. **Conclusions:** In patients with coronary artery disease and/or risk factors for coronary heart disease, low intensity isometric contraction, maintained over long periods of time, presents the same effect on the responses of HR, compared to a high intensity or maximal isometric contraction of briefly duration.

Key words: isometric contraction; heart rate; autonomic nervous system; cardiovascular diseases.

Resumo

Contextualização: A magnitude das respostas cardiovasculares depende dos componentes estático e dinâmico bem como da duração e intensidade da contração realizada. **Objetivo:** Avaliar as respostas da frequência cardíaca (FC) frente a diferentes percentuais de contração isométrica em 12 pacientes (63±11,6 anos; média±dp) com doença da artéria coronária e/ou fatores de risco para ela, participantes de um programa de reabilitação cardíaca fase III. **Métodos:** A variação da frequência cardíaca (ΔFC) foi avaliada durante as contrações voluntárias máximas (CVM; 5" e 10" de duração) e submáximas (CVSM; 30 e 60% da CVM-5, até exaustão muscular) de preensão palmar, utilizando-se um dinamômetro (*hand grip*). Adicionalmente, o RMSSD dos iR-R em ms (índice representante da modulação vagal cardíaca) foi calculado em repouso (pré-contração) nos últimos 30 segundos da CVSM e na recuperação (pós-contração). **Resultados:** A ΔFC apresentou maiores valores em CVM-10 vs CVM-5 (17±5,5 vs 12±4,2 bpm, p<0,05) e no CVSM-60 vs CVSM-30 (19±5,8 vs 15±5,1 bpm, p<0,05). No entanto, os resultados para CVM-10 mostraram ΔFC similar quando comparados aos resultados obtidos para CVSM (p>0,05). RMSSD de repouso reduziu-se (p<0,05) durante a CVSM-30 (30%=29,9±17,1 vs 12,9±8,5ms) e CVSM-60 (60%=25,8±18,2 vs 9,96±4,2 ms), mas retornou aos valores basais quando a contração foi interrompida. **Conclusões:** Em pacientes com doença da artéria coronária e/ou fatores de risco para ela, a contração isométrica de baixa intensidade mantida por longos períodos de tempo apresenta os mesmos efeitos sobre as respostas da FC, quando comparada à contração isométrica de alta ou máxima intensidade, porém de breve duração.

Palavras-chave: contração isométrica; frequência cardíaca; sistema nervoso autonômico; doenças cardiovasculares.

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Introduction

Every physical activity requires quick adjustments on cardiovascular system (CVS) to maintain circulatory homeostasis[1,2]. Heart rate (HR) regulation and the modulation of its oscillations are very dependent on the autonomic nervous system (ANS), through the stimulation or inhibition of its efferent, the parasympathetic nervous system (PNS), through the vagus nerve, and the sympathetic nervous system (SNS)[2].

It is well documented that isometric contractions increase HR. It is characterized by a quick initial response, attributed to the inhibition of vagus modulation on sinus node (SN). This occurs in the first 10 seconds of exercise[2]. Depending on the intensity and duration of the isometric contraction performed, the HR increases gradually, especially due to the sympathetic modulation of the ANS[2-7].

Some studies have reported that the improvements on muscle strength and the resistance training are safe for low-risk patients[8-10]. However, it is important to note that this type of training mentioned includes both isotonic and isometric exercises, and the magnitude of cardiovascular responses depends on the static and dynamic components as well as the duration and intensity of the exercise[10].

Based on the fact that isometric contraction causes a high overload and increases sympathetic activity[7,11], the prescription of the isometric exercises alone must be avoided in programs of cardiovascular rehabilitation[9]. However, some current studies have reported that the isometric training with handgrip modifies some cardiovascular risk factors (that is, reduces blood pressure (BP), improves endothelial function and increases HR variability) in patients with arterial hypertension[12,13].

Therefore, studies considering the cardiovascular responses during isometric contractions in different intensities and durations are needed to generate evidences regarding the adequate prescription of this modality of exercise for patients enrolled in programs of cardiovascular rehabilitation.

The hypothesis of the this study is that the isometric contraction in 100% of the maximal voluntary contraction (MVC) (5" and 10") would lead to lower responses of the HR than the sub-maximal percentage of the MVC with longer duration.

The objective of the this study was to evaluate the responses of HR during three isometric contractions of different intensities in patients with coronary artery disease and/or risk factor for coronary artery disease.

Methods

Twelve men (63±11.6 years) with coronary artery disease and/or risk factors for coronary artery disease (Table 1) participated in this study. All this patients were enrolled, for at least six months, in a phase III cardiovascular rehabilitation program. This rehabilitation program (60'/session, 3 sessions/week) was predominantly aerobic, including exercises in treadmill and cycloergometer, at an intensity of 70 to 75% of the HR observed during the clinical ergometric test. Patient were submitted to clinical exams (general examination, conventional electrocardiogram (ECG), physical exams (maximal ergometric test and/or limited by symptom, performed by a cardiologist) and laboratory tests (total cholesterol and fractions, triglycerides, fasting blood glucose, complete blood count, type 1 urine and urea).

Smokers and patients with musculo skeletal diseases were excluded. All patients were informed about the experimental proceedings and, after agreeing with it, they signed the informed consent, which had been approved by the Ethics Committee of Research in Humans from the Universidade Federal de São Carlos (UFSCar), São Carlos (SP), Brazil (protocol 071/2005). All participants were evaluated at the same time of the day considering the influence of circadian cicle.

The data collection was performed in an acclimatized room. The temperature and relative humidity were maintained at 22-23°C and 50-60%, respectively. The tests were performed in non-consecutive days, separated by a five-day interval. Patients were previously familiarized with the proceedings and equipments to be used in the study. They were oriented to avoid caffeine, alcohol and physical exercise and to maintain the usual medication in the day before and in the experiment day. Before the starting of the test, the participants were asked about the occurrence of a regular sleep at night. They were also examined to certificate that the basal conditions were within the normality limits (BP≤130/85mmHg; HR: 60-80bpm)[14].

During the experiments, the HR and the intervals between two waves R of the ECG (R-R interval) were collected at each heart beat from the CM5 derivation by a cardiac monitor of one channel (TC–500, ECAFIX, São Paulo, SP, Brazil) coupled to an analogue-digital converter Lab – PC + (National Instruments, Co, Austin, TX, USA), which is an interface between the cardiac monitor and the computer. Then, the analogical sign of the ECG was converted in binary values to a computer input at a sampling rate of 500Hz which, through a specific software[15], allowed the data processing and analysis to be performed later.

Prior to the measure of the HR subjects remained at rest (20') to obtain its stabilization. Then, HR and R-R interval were obtained during the rest pre-contraction (60"); the isometric contractions (5" and 10" to the maximal and until muscle exhaustion to sub-maximal) and recovery post-contraction (120") were performed with the patient seated. Furthermore, blood pressure (BP) was measured with a mercury sphygmomanometer before and immediately after muscle contraction.

The isometric contractions were performed using an analogue hand grip dynamometer (Jamar® - Sammons Preston, INC Bolingbrook, IL, USA) with the patient sitting in a chair with back support and adjustable arm support, so that the flexion forearm angle was maintained at 90°.

On the first day of the study, the participants performed two sets of three MVC, which were randomly sustained for 5 (MVC-5) and 10 (MVC-10) seconds. On the second day, patients were instructed to maintain a 30% (SMVC-30) and 60% (SMVC-60) contraction of the MVC-5, in a randomized order by draw, until muscle exhaustion. On both test days, patients rested for a three minutes period or until the return of HR to the basal levels. In addition, they were instructed to maintain normal breathing and to avoid the Valsalva maneuver during exercise.

The cardiovascular responses to isometric contraction were evaluated by the difference between HR peak (highest value observed before the end of contraction) and HR rest (pre-contraction). The duration of voluntary sub-maximal contraction (SMVC) was not predetermined that is, the subjects maintained the muscle contraction until exhaustion. The RMSSD index (square root of the sum of the square of the differences between the R-R interval in ms in the record divided by the number of R-R interval in ms at a given time minus one) was also calculated during the SMVC-30 being the period of analysis was chosen based in the individual time to exhaustion observed for the SMVC-60. Moreover the autonomic modulation of HR was assessed at rest (pre-contraction), in the 30 seconds preceding the end of the contraction and in the first seconds of the recovery period.

For data analysis, the SMVC at 30% (30% of MVC, considering 5”) was divided in SMVC-30%A=value calculated based in time to exhaustion at 60% SMVC and SMVC-30%B= value calculated based in time to exhaustion at SMCV at 30% of SMCV.

Statistical analysis

Data are presented as mean ± SD. The differences of HR and RICVM among all contractions were compared through one-way analysis of variance for repeated measures (one-way ANOVA). Blood pressure values pre and post contraction were compared by Student’s *t* test. The level of significance was set at $p<0.05$.

Table 1. Patients’ characteristics.

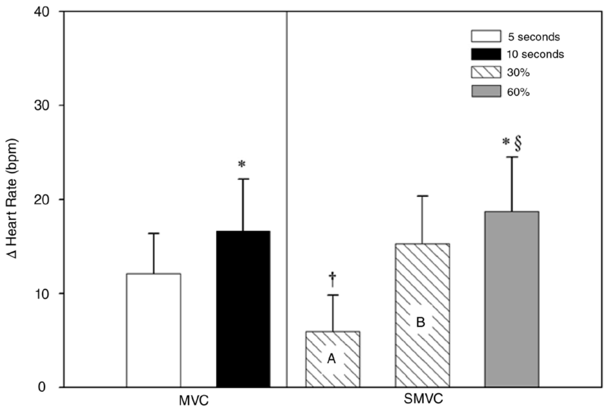
Characteristics	n=12
Age (years)	63±11.6
Weight (kg)	82.2±14.6
Height (m)	1.70±0.1
BMI (Kg/m^2)	25.4±9.9
Clinical diagnosis	
Arterial hypertension	7 (58%)
CAD	1 (8%)
CAD + CABG	4 (33%)
Myocardial infarction	2 (17%)
Dyslipidemia	6 (50%)
Medications	
β-blockers	3 (25%)
Diuretics	8 (66%)
Diuretics	4 (33%)
Calcium channel blockers	1 (8%)
Hipolipidemic	6 (50%)
Hipolipidemic	6 (50%)
Antiarrythmic	1 (8%)

BMI= body mass index; CAD= coronary artery disease; CABG= coronary artery bypass graft.

Table 2. Isometric contractions.

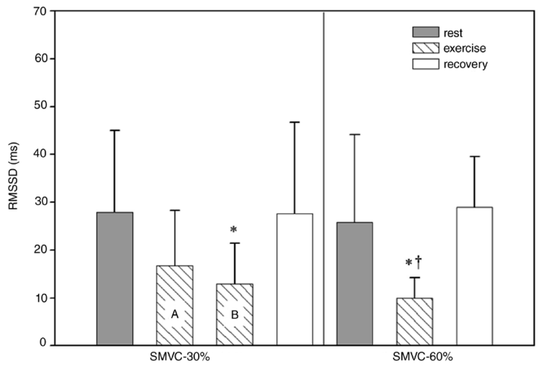
	MVC		SMVC		
	5	10	30%A	30%B	60%
Time (sec)	5	10	69±13.8	198±58.0	69±13.8
Intensity (%)	100	100	30	30	60
HR_{rest} (bpm)	61±9.1	60±9.7	61±8.7	61±9.0	61±8.7
HR_{peak} (bpm)	73±10.2	77±12.7	67±10.6*	76±11.1	79±12.4†
ΔHR (bpm)	12±4.2	17±5.5†	6±3.9*	15±5.1	19±5.8†§
RICVM (ms)					
Rest	-	-	27.9±17.1	27.9±17.1	25.8±18.2
Exercise	-	-	16.8±11.5	12.9±8.5^{+}	9.96±4.2$^{+\ddagger}$
Recovery	-	-	27.6±19.1	27.6±19.1	28.9±10.6
Strength (Kgf)	37.9±7.1	35.4±5.3	12.7±2.3	12.7±2.3	23.2±4.1
SBP (mmHg)					
Rest	120.4±6.3	120.4±6.3	120.0±12.9	120.0±12.9	120.0±12.9
Recovery	129.2±11.3^{+}	128.3±12.9^{+}	-	127.9±12.3^{+}	129.2±10.6^{+}
DBP (mmHg)					
Rest	80.4±4.8	80.4±4.8	79.6±9.3	79.6±9.3	79.6±9.3
Recovery	85.0±6.8^{+}	86.7±7.2^{+}	-	80.8±9.3	82.1±10.0

Values shown as mean±SD. HR=heart rate; SBP=systolic blood pressure; DBP=dyastolic blood pressure; MVC=maximal voluntary contraction; SMVC=submaximal voluntary contraction; 30=intensity at 30% of MVC (5”); A=value calculated based on time to exhaustion of SMVC at 60%; B= value calculated based on time to exhaustion of SMVC at 30%; 60=intensity at 60% of MVC (5”); *$p<0.05$ *vs.* all the contractions studied; $^{\dagger}p<0.05$ *vs.* MVC-5; $^{\S}p<0.05$ *vs.* SMVC-30%B; $^{+}p<0.05$ *vs.* rest and recovery conditions (when applied); $^{\ddagger}p<0.05$ *vs.* SMVC-30%A.



A=value calculated based on time to exhaustion of SMVC at 60%; B= value calculated based on time to exhaustion of SMVC at 30%; $^*p<0.05$ *vs.* MVC-5 $^\dagger p<0.05$ *vs.* all the contractions studied; $^\S p<0.05$ *vs.* SMVC-30%B.

Figure 1. Variation of heart rate during maximal (MVC) and sub-maximal (SMVC) voluntary contractions.



A=value calculated based on time to exhaustion of SMVC at 60%; B= value calculated based on time to exhaustion of SMVC at 30%; $^*p<0.05$ *vs.* rest and recovery conditions; $^\dagger p<0.05$ *vs.* SMVC-30%A.

Figure 2. Autonomic modulation of heart rate through the RMSSD index of the R-R intervals in ms, assessed at rest, during sub-maximal voluntary contractions (SMVC) and recovery.

Results

Table 1 presents the patients' characteristics, the clinical diagnosis and the medications in use. No differences were found for resting HR for all contractions analyzed (Table 2). For the HR peak, the SMVC-30%A, determined based on time to exhaustion of SMVC-60, showed the lowest value compared to the other contractions ($p<0.05$) (Table 2). Moreover, the MVC-5 had HR peak significantly lower than the SMVC-60 ($p<0.05$) (Table 2).

Considering the ΔHR, the SMVC-30%A produced the lowest cardiovascular response ($p<0.05$) in comparison with to the remaining contractions, while the SMVC-60 presented the highest ΔHR among the contractions measured (except for MVC-10). For the SMVC-30%B, in which ΔHR was calculated considering muscle exhaustion; it was observed a ΔHR similar to the MVC-5 and MVC-10 (Table 2 and Figure 1).

At rest, there were no statistical differences for the RMSSD index of the SMVC-30 and SMVC-60. As expected, the RMSSD index reduced during isometric contraction, reaching statistical significance ($p<0.05$), except for SMVC-30%A. Moreover, when this index was calculated considering time to exhaustion of SMVC-60, a lower value of RMSSD index was observed for CVSM-60 when compared to SMVC-30%A ($p<0.05$). In the recovery period after contraction, the values of RMSSD index were similar for both intensities tested ($p>0.05$) (Table 2 and Figure 2).The values of systolic blood pressure (SBP) and diastolic blood pressure (DBP), measured in the first seconds of the recovery period were higher in comparison to the resting values ($p<0.05$), except the SMVC, which presented similar values of DBP ($p>0.05$) between the rest and recovery periods (Table 2).

Discussion

This study investigated the response of the HR during isometric contractions, with different intensities and durations, in patients with cardiovascular disease and/or risk factors for cardiovascular disease. The magnitude of cardiovascular responses, evaluated through ΔHR and index RMSSD of R-R interval in ms, showed to be dependent of the intensity and duration of the isometric contractions. Thus, for an isometric contraction of low intensity, maintained for long period of time, there were observed effects on HR responses similar to those of a high or maximal intensity contraction, maintained for a short period of time.

Cardiovascular system has an important role on homeostasis maintenance. During physical exercise, hemodynamic adjustments occur to allow the appropriate distribution of blood to supply the demands of muscles in activity. Moreover, the magnitude of these adjustments seems to depend on the exercise's characteristics[2,16].

The isometric exercise promotes a significant increase on HR, BP and peripheral vascular resistance[11] being the mechanisms responsible for these responses are central and peripheral[1,11,16,17]. The central mechanism activates neuronal pathways from central nervous system to modify the activities of sympathetic and parasympathetic systems, consequently determining some cardiovascular responses[1]. In addition, evidences from electromyography records show that the activation of more motor units of muscle fibers recruited during a contraction is related to the neural mechanism of central command, which determines immediate changes in the level of efferent activity from SNS and PNS, acting on heart, and of SNS, acting on blood vessels[17,18].

Moreover, the reflex neural mechanism, related to mechanical and metabolic activities from the muscle in contraction, also determines the level of autonomic activity on cardiovascular system. Neural impulses related to the mechanical activity are transmitted initially by muscle receptors through afferent fibers from groups III and IV and reach areas of cardiovascular control almost simultaneously to the neural impulses from central command[4,19,20]. The neural impulses related to muscle metabolic activity are transmitted primarily by afferent muscle fibers from group IV and reach the area of vascular control with a delay of some seconds[17,21,22]. The afferent muscle receptors from groups III and IV are divided in ergoreceptors (group III), which are activated by muscle contraction, and nociceptors (group IV), activated by stimuli responsible for muscle pain sensation[20,23].

Thus, the reduction on oxygen supply of active muscles, which is caused by a mechanical obstruction of blood vessels during isometric contraction of high intensity, causes an increase on metabolites on the muscle and, consequently, stimulates pressor reflex of exercise[19].

The elevation of HR occurs suddenly in the beggining of the isometric exercise, being its magnitude seems to be directly related to the levels of muscle tension[2,24]. This initial elevation of HR that occurs within the first seconds of contraction (5" to 30") is also associated to the intensity of the exercise and is attributed to the withdrawal of vagal modulation on sinus node. However, if the exercise is maintained until exhaustion, HR will increase gradually due to the increased sympathetic modulation acting on heart[2,7,21]. In this study, it was possible to observe that the fast increase of HR, evaluated through ΔHR, for the same tension (MVC), is dependent on the period in which the contraction is maintained. Therefore, our results are in agreement with the authors mentioned above, since MVC maintained for 5 seconds may not have been long enough to generate maximal vagal withdrawal.

Iellamo et al.[7] evaluated the autonomic control of HR in young subjects through the analysis of rate domain during 4 minutes of isometric contraction of knee extension (30% of MVC). The authors observed a reduction on vagal modulation and an increase on cardiac sympathetic modulation, which suggests the participation of the sympathetic component on HR regulation during low intensity and long duration exercises. Although Stewart et al.[25] had shown a reduction on vagal modulation during hand grip exercises (35% MVC) in young subjects, they were not able to reproduce the same results of Iellamo et al.[7]. However, the authors observed a reduction on sympathetic modulation in the first minute of exercise and its return for pre-exercise basal levels. Since Stewart et al.[25] used only periods of 1 minute to analyze HR variability, it is possible that sympathetic modulation has been underestimated, which could explain partially the divergence between the results found on the two studies discussed above.

In this study, patients were unable to maintain, at SMVC, the time required to perform the analysis of ΔHR in the rate domain (30%=3 minutes and 60%=1 minute, approximately) since it requires, at least, 4-5 minutes of data recording and, also, with the ECG signal remaining stable[26]. In this context, the autonomic control of HR was assessed only through the RMSSD index of R-R interval in ms (time domain), which represents the fast oscillatory component, that is, the vagal modulation responsible by the variation between the cardiac cycles. Since the RMSSD index reduced during isometric contraction for both sub-maximal intensities studied, our results agree partially with those of Iellamo et al.[7] and Stewart et al.[25]. However, nothing can be asserted on the sympathetic modulation during isometric contraction from these results.

The literature has reported that the magnitude of HR response during isometric exercise is related to muscle mass, duration and tension developed during contraction[17,27]. In this study, we sought to study the effect of different intensities and times of contraction on HR response. Thus, the protocol used tested only one muscle group (palmar flexors) at a specific angle, that is, at the same muscle length since the wrist was in a neutral position. Under these conditions, HR has shown to be influenced by duration and intensity of isometric contraction, since maximal efforts of short duration produced similar responses to sustained sub-maximal efforts. Furthermore, the effect of time was shown when the ΔHR was compared at the same intensity (SMVC-30% A versus SMVC-30% B) but with a different duration (69" versus 198").

In this study, patients had adequate cardiovascular responses to isometric exercise and none had signs or symptoms that required exercise interruption. It is noteworthy that, prior to the start of the experiment, all patients underwent a clinical ergometric test and, besides this, they already participated of an aerobic physical training for at least six months, so they presented adequate aerobic capacity and, also, were using specific medication. Thus, the prescription of isometric exercises seems to be promising and safe for low risk patients. Low risk patients are those with good functional capacity, controlled hypertension, with no evidence of myocardial ischemia at rest or induced by effort, without severe left ventricular dysfunction or complex ventricular arrhythmia, which are common characteristics of the patients from the this study, whom are enrolled in programs of cardiac rehabilitation (phase III). For this, they shall be correctly examined and guided during the performance of this type of exercise.

The responses of the BP are also directly related to the duration of isometric contraction. However, the assessment of BP during MVC could not be performed due to the limitation in contraction duration and the absence of a non-invasive equipment for checking the BP during exercise continuously; with regards to the SMVC, the variability of the duration of contraction of the subjects did not allow a standardized data collection, reason for why they are not presented in this manuscript. Considering this, we decided to assess BP responses immediately after the interruption of the contractions (MVC and SMVC), and the values of SBP showed to be higher in relation to rest values. For future studies, it would be interesting to examine BP during isometric contractions that could lead to additional contributions.

Overall, in patients with cardiovascular diseases and/or risk factors for cardiovascular diseases, HR response and its autonomic control seem to be dependent on the intensity and duration of isometric contractions. In addition, all patients had adequate HR responses during exercise, suggesting its prescription in cardiovascular rehabilitation for low risk patients, since they have characteristics similar of those from this study, and the exercises are carefully selected and guided.

It is also noteworthy that some participants (n=3) were using drugs that directly affect the responses of HR (e.g. beta blockers). As beta blockers are often used in the treatment of patients with stable coronary artery disease, hypertension and congestive heart failure[28,29] mainly due to its positive effect on their prognosis, in clinical practice is very common to find patients in Phase III of the cardiovascular rehabilitation using beta blockers in combination to other drugs. Therefore, the results of this study should be interpreted with caution and should not be transferred to all types of people and / or patients.

In conclusion, in the patients studied, the results showed that isometric contraction of low intensity sustained for long periods of time has the same effects on HR responses than an isometric contraction of high or maximal intensity with short duration.

Considering that the response of PA is directly related to the isometric exercise, its evaluation would bring relevant and complementary data to this study. For future studies it would be interesting: a) to assess BP continuously during isometric contraction, with a non invasive method; b) to evaluate the chronic effects of isometric training in low risk patients and c) to work with a control group.

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