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Hemodynamic response in one session of strength exercise with and without electrostimulation in heart failure patients: A randomized controlled trial

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Abstract

Background: *Studies have investigated the influence of neuromuscular electrostimulation on the exercise/muscle capacity of patients with heart failure (HF), but the hemodynamic overload has never been investigated. The aim of our study was to evaluate the heart rate (HR), systolic and diastolic blood pressures in one session of strength exercises with and without neuromuscular electrostimulation (quadriceps) in HF patients and in healthy subjects.*

Methods: *Ten (50% male) HF patients and healthy subjects performed three sets of eight repetitions with and without neuromuscular electrostimulation randomly, with one week between sessions. Throughout, electromyography was performed to guarantee the electrostimulation was effective. The hemodynamic variables were measured at rest, again immediately after the end of each set of exercises, and during the recovery period.*

Results: *Systolic and diastolic blood pressures did not change during each set of exercises among either the HF patients or the controls. Without electrostimulation: among the controls, the HR corresponding to the first (85 ± 13 bpm, $p = 0.002$), second (84 ± 10 bpm, $p < 0.001$), third (89 ± 17, $p < 0.001$) sets and recuperation (83 ± 16 bpm, $p = 0.012$) were different compared to the resting HR (77 bpm). Moreover, the recuperation was different to the third set (0.018). Among HF patients, the HR corresponding to the first (84 ± 9 bpm, $p = 0.041$) and third (84 ± 10 bpm, $p = 0.036$) sets were different compared to the resting HR (80 ± 7 bpm), but this increase of 4 bpm is clinically irrelevant to HF. With electrostimulation: among the controls, the HR corresponding to the third set (84 ± 9 bpm) was different compared to the resting HR (80 ± 7 bmp, $p = 0.016$). Among HF patients, there were no statistical differences between the sets. The procedure was well tolerated and no subjects reported muscle pain after 24 hours.*

Conclusions: *One session of strength exercises with and without neuromuscular electrostimulation does not promote a hemodynamic overload in HF patients.* (Cardiol J 2011; 18, 1: 39–46)

Key words: strength exercise, cardiac rehabilitation, electrostimulation, hemodynamic response

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Introduction

Although central hemodynamic abnormalities initiate and underlie the heart failure (HF) process, peripheral muscle disorders have played an important role in understanding the patient's symptoms [1–4]. Peripheral muscle disorders, such as atrophy, are considered by some investigators to be one of the most important components responsible for fatigue and exercise impairment [5–8].

Among this population, adherence to programs of exercise training is very poor and this situation could be partly due to hemodynamic factors or motor disabilities [9]. For these reasons, alternative methods to improve physical performance and, therefore, the quality of life of HF patients, are needed.

Neuromuscular electrostimulation is largely used to treat muscle atrophy secondary to disuse in healthy people and in patients with neuromuscular disorders [10]. Recently, some studies have investigated the benefits of neuromuscular electrostimulation for HF patients. Initial studies showed an increase in peak oxygen consumption [11], in the trained muscles' volume [12], improvements in physical performance and in tolerance to fatigue [13]. Furthermore, the effects of conventional exercise training in HF patients in a home-based program has been shown to be similar to the effects of an isolated neuromuscular electrostimulation [14].

Although some studies have investigated the influence of neuromuscular electrostimulation in peripheral muscles and in exercise capacity of patients with HF, there has been no study into exercise's hemodynamic response, considered an important functional marker of risk in this syndrome. Strength exercises have been considered dangerous due to the great hemodynamic overload, but, nowadays, they are recognized to be safe so long as certain precautions are followed. Electrostimulation could worsen this hemodynamic overload by increasing muscle fiber recruitment and vascular compression, and consequently increasing cardiac overload.

The aim of our study was to evaluate the hemodynamic response (heart rate — HR, systolic and diastolic blood pressure — SBP, DBP) in one session of strength exercises with and without neuromuscular electrostimulation in HF patients and in healthy subjects.

Methods

Study population

Ten (50% male, 50% female) sedentary HF patients (51 ± 5 years old) with an average left ventricular ejection fraction of 31 ± 5% (determined by echocardiography), and a control of ten healthy subjects (50% male, 50% female) were included in this study. The characteristics of the subjects and their medication profiles are shown in Table 1. All sedentary HF patients were in a clinically stable condition. The healthy subjects did not have any risk factors for cardiovascular diseases. Heart failure patients with atrial fibrillation, a pacemaker, non-cardiovascular functional limitations such as osteoarthritis and chronic obstructive pulmonary disease were excluded from the study (Fig. 1).

This protocol was approved by the Ethical Committee of our institution. All patients provided informed consent prior to participation.

Study design

This clinical trial was designed to evaluate the hemodynamic responses (HR, SBP, DBP) during a session of strength exercise training with and without neuromuscular electrostimulation of the quadriceps. All HF patients and healthy subjects performed the exercise protocol with and without neuromuscular electrostimulation randomly, with one week between sessions at the same time of day (between 1:00 and 3:00 pm). Throughout, electromyography was performed to guarantee the electrostimulation was effective. The HR (Polar, Electro Oy, Kempele, Finland), SBP and DBP (Geratherm desktop, Geratherm Medical, Germany) were measured at rest, again immediately after each exercise set, and during recovery (one minute after the last exercise). In all, subjects performed three sets of eight repetitions. The patients were asked to grade their muscle pain (on a scale of 0 to 5) immediately after the procedure and again after 24 hours. Evaluating muscle pain after 24 hours was done over the telephone.

Exercise protocol

All subjects performed three sets of eight repetitions of an eccentric muscle contraction. Each repetition was performed with the individuals in a standing position, with the dominant leg on a step ahead of the non-dominant. A fleximeter was coupled at the proximal region of the tibia. From this position, a knee flexion of the dominant leg was performed in association with a neuromuscular electrostimulation until obtaining the angle of 30° (lasting 5 s), which was sustained for a further 10 s. After these 15 s of muscle contraction, the starting position was resumed (Fig. 2). The gap between each repetition was 15 s, and between each set 2 min.

Electromyography

The electromyograph (Phenix USB 2 V4.01 R8) was used with two channels interfaced with a com-

Table 1. Patient characteristics.

	Heart failure	Controls	p
Etiology: non ischemic	10 (100%)	–	–
NYHA functional class			
I	5 (50%)	–	–
II	3 (30%)	–	–
III	2 (20%)	–	–
Peak VO_2 [mLO_2/kg/min]	17 ± 5	26 ± 6	0.009
Sex: male/female	5 (50%)/5 (50%)	5 (50%)/5 (50%)	0.98/0.98
Age (years)	51 ± 5	32 ± 11	0.002
Left ventricular ejection fraction (%)	31 ± 5	–	–
Weight [kg]	82 ± 16	62 ± 17	0.095
Height [cm]	167 ± 10	169 ± 13	0.72
Perimeter of the quadriceps	54 ± 6	48 ± 7	0.07
Current medications [mg/day]			
Diuretics (%)	60%	–	–
Enalapril	80, 20 ± 13	–	–
Losartan	20, 75 ± 27	–	–
Carvedilol	100, 40 ± 24	–	–
Spironolactone	50, 25 ± 0	–	–
Digoxin	40, 0.25 ± 0	–	–

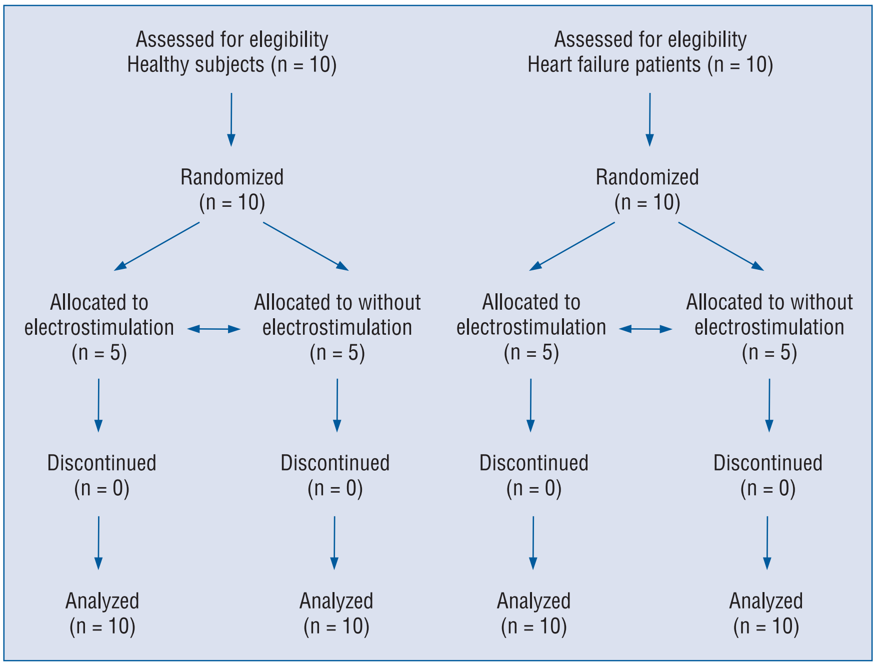

Figure 1. Flow of participants through the trial.

puter that showed and recorded the electromyographic sign. Two adhesive surface electrodes (3 cm in diameter) were used to capture the electrical activity of the vastus medialis oblique (VMO) and two adhesive surface electrodes (5 cm in diameter) to capture the electrical activity of the vastus lat-

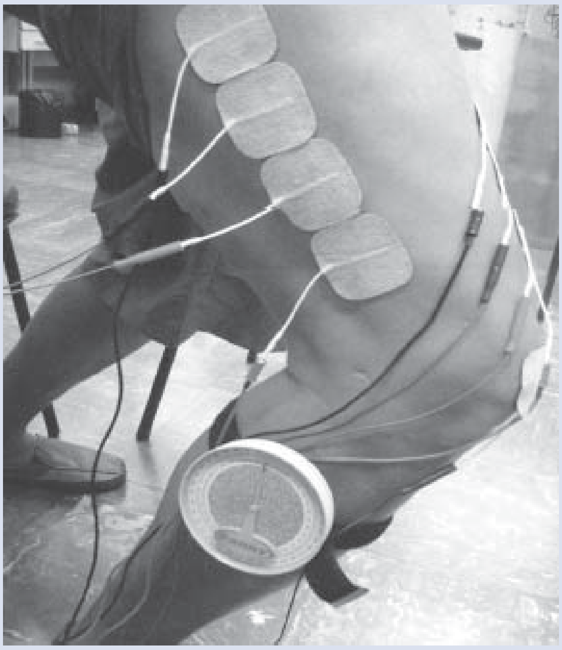

Figure 2. Exercise protocol: 30° of knee flexion in closed kinetic chain, electromyography and neuromuscular electrostimulation.

eralis (VL). We followed the recommendations of the 'Surface EMG for the Non-Invasive Assessment of Muscles — SENIAM' [15].

The quadriceps circumference was measured with a tape of 1.5 m while the patients were seated with full contraction extension of the knee. We used a spot 10 cm from the edge of the patella as a reference point to capture electrical activity.

Neuromuscular electrostimulation

Neuromuscular electrostimulation was applied by an electrostimulator (Biosistemas, Modelo Endophasys NMS 0501) during all the muscle contraction, with alternating, biphasic and symmetric currents with rectangular pulses. The carrier wave frequency was 2,500 Hz, modulated at 50 Hz, pulse duration of 400 us, with the active cycle of work of 20%. The time of ascent and descent of the current was 3 s and contraction and relaxation was 9 s.

Adhesive surface electrodes 3 cm in diameter were used for the VMO and 5 × 5 cm for the VL. The VMO and VL were chosen because they are the main dynamic stabilizers of the knee joint. Moreover, they are the first ones to show signs of atrophy and the most difficult to rehabilitate after a period of disuse. The vastus intermedius was not studied because it is a deeper muscle, and the rectus femoris because it is a bi-articular muscle.

We followed the electrostimulation parameters used successfully by previous authors [16–19].

Statistical analysis

Descriptive analyses are presented as mean, standard deviation. The muscle microvolt, HR, SBP and DBP were normally distributed. To compare the muscle microvolt response between the exercises performed with and without neuromuscular electrostimulation in each group, we used the paired *T* test. To compare HR, SBP and DBP between the resting, three sets of eight repetitions, and recuperationm between HF patients and controls, we used the two-way ANOVA with post-hoc Turkey test.

Data was analyzed using the Statistical Package for Social Sciences for Windows, 11.5 (SPSS Inc, Chicago, Illinois, USA). Statistical significance was defined as $p < 0.05$.

Results

We found a significant difference in the muscle microvolt (VMO and VL) measured by electromyography between the exercise sets with and without neuromuscular electrostimulation to all groups (VMO = 307 ± 223 us without electrostimulation *vs* 1797 ± 235 us with electrostimulation in the HF group; and VL = 268 ± 144 us without electrostimulation *vs* 1797 ± 236 us with electrostimulation in the HF group, $p < 0.001$; VMO = 410 ± ± 213 us without electrostimulation *vs* 1959 ± 57 us with electrostimulation in the healthy group; and VL = = 270 ± 123 us without electrostimulation *vs* 1921 ± 113 us with electrostimulation in the healthy group, $p < 0.001$). No changes were found in the muscle microvolt during each set of exercises among HF patients or among controls, even when the sets of exercise were performed with neuromuscular electrostimulation. This data confirms the efficiency of our neuromuscular electrostimulation's protocol. The SBP and DBP did not change during each set of exercises among HF patients or among controls (Figs. 3, 4).

Heart rate in the group without neuromuscular electrostimulation: in the HF group, we found a difference between the resting HR and the first set's HR ($p = 0.041$) and between the resting HR and the third set's HR ($p = 0.036$). In the control group, we found a difference between the resting HR and the first set ($p = 0.002$), between the resting HR and the second set ($p < 0.0001$), between the resting HR and the third set ($p < 0.0001$), and between

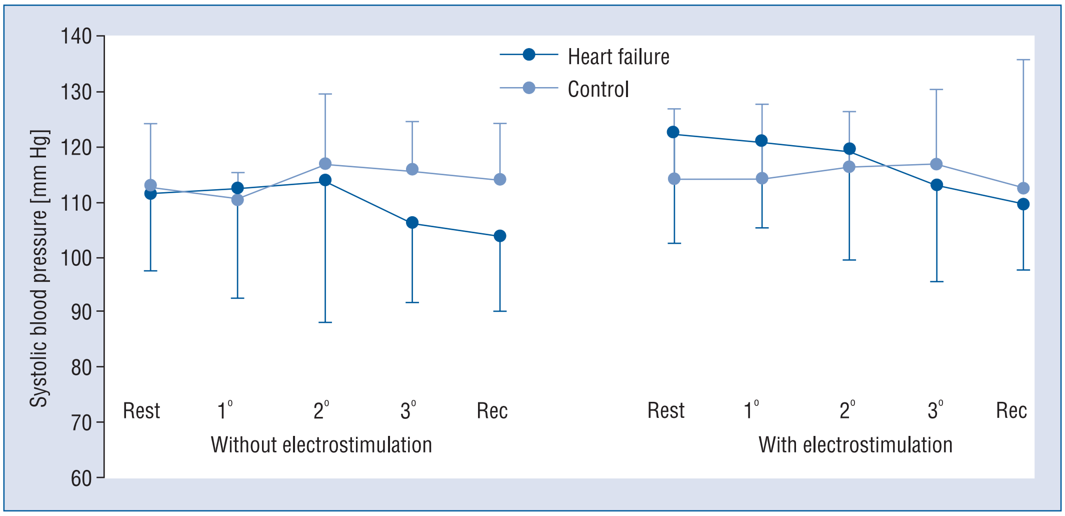

Figure 3. Hemodynamic response — systolic blood pressure; Rest — resting systolic blood pressure; Rec — resting systolic blood pressure at one minute of recuperation. No differences were found between the exercise sets among either the heart failure patients or the controls.

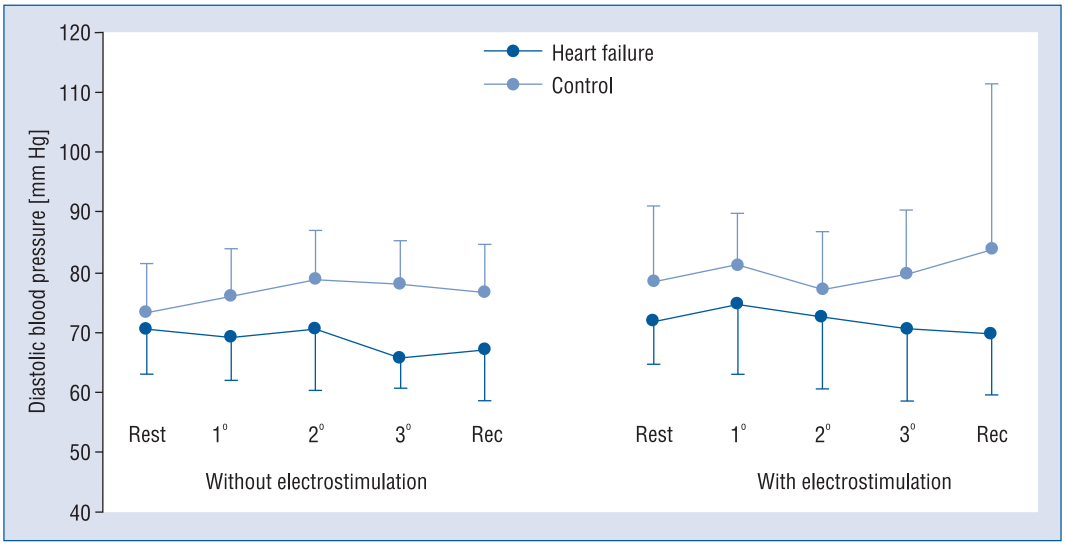

Figure 4. Hemodynamic response — diastolic blood pressure; Rest — resting diastolic blood pressure; Rec — resting diastolic blood pressure at one minute of recuperation. No differences were found between the exercise sets among either the heart failure patients or the controls.

the resting HR and the recuperation ($p = 0.012$). The recuperation's HR was also different to the third set of exercises ($p = 0.018$).

Heart rate in the group with neuromuscular electrostimulation: in the HF group, we did not find differences in the HR through the exercise sets; there was no significant HR increase. In the control group, the resting HR was different only in relation to the third set ($p = 0.016$) (Fig. 5).

No patient complained of muscle pain immediately after the protocol or after 24 hours.

Discussion

The main finding of our study was that one session of strength exercises does not increase the HR, SBP and DBP does not show a clinically significant increase in HF patients with and without neuromuscular electrostimulation. Moreover, none of the studied subjects complained of muscle pain immediately after the protocol or after 24 hours of follow-up.

The increased total peripheral resistance, reduction of blood supply and impaired peripheral

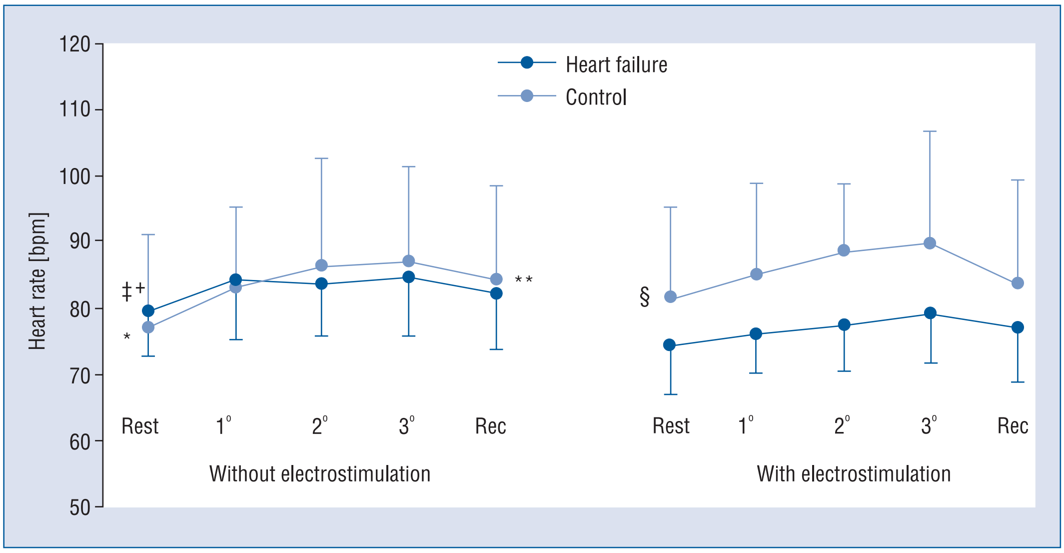

Figure 5. Hemodynamic response — heart rate; Rest — resting heart rate; Rec — resting heart rate at one minute of recuperation; without electrostimulation: *Among the controls, the heart rate corresponding to the first (85 ± 13 bpm, p = 0.002), second (84 ± 10 bpm, p < 0.001), third (89 ± 17, p < 0.001) sets and recuperation (83 ± 16 bpm, p = 0.012) were different compared to the resting heart rate (77 ± 14 bpm). **Recuperation was different to the third set (0.018). Among the heart failure patients, the heart rate corresponding to the first ‡ (84 ± 9 bpm, p = 0.041) and third + (84 ± 10 bpm, p = 0.036) sets were different compared to the resting heart rate (80 ± 7 bpm); with electrostimulation: § among the controls, the heart rate corresponding to the third set (84 ± 9 bpm) was different compared to the resting heart rate (80 ± 7 bmp, p = 0.016). In heart failure patients, there were no statistical differences.

vascular dilatation in response to vasodilator stimuli, due to the sympathoadrenergic hyperactivity [20], results in atrophy of skeletal muscle and decreased oxidative activity [21]. Physical training can have a positive effect on these disorders by maintaining skeletal muscle structure and reversing muscle metabolic abnormalities [22].

Using neuromuscular electrostimulation on skeletal muscles has become clinically established in inactivity-related weakening as a method of inducing muscle contractile activity, increasing muscle strength, dealing with muscle fiber hypertrophy, and increasing muscle cross-sectional diameter [10]. Recently, neuromuscular electrostimulation, originally suggested as an alternative method of exercise training, has been the subject of some published studies involving patients with HF [12––14]. Despite this, a basic question (about the hemodynamic response to an exercise session using neuromuscular electrostimulation) has never been answered. It is well known that cardiovascular risk control during exercise training is crucial for safety reasons [4].

In the past, most professionals involved in cardiovascular rehabilitation have been hesitant to prescribe strength exercise training to patients with cardiac diseases because they thought that the acute blood pressure elevations and hemodynamic overload could increase the risk of cardiovascular complications [5]. It is well accepted in the literature that the response of blood pressure to resistance exercise depends on the magnitude of the isometric component, the number of repetitions, the load intensity (a percentage of maximum voluntary contraction) and the amount of muscle mass involved [5]. One study that measured the intra-arterial blood pressure during leg-press resistance training in cardiac patients showed that a resistance exercise carried out at an intensity 40–60% of maximum voluntary contraction and with fewer (10–15) repetitions provides only a moderate rise in blood pressure when compared to the increases seen during moderate endurance training [23]. In this way, the danger of cardiac overload caused by moderate strength exercises seems to be reduced. Interestingly, in our study, we did not find a significant hemodynamic overload in a high strength exercise session. In our opinion, the position of the patient could have played an important role. Probably, if the patients were not in a standing position (impairing venous return) during the protocol, we could have found a great hemodynamic overload.

However, new studies are required to confirm our hypothesis.

In studies involving the use of neuromuscular electrostimulation, a wide variety of protocols is used, and there seems to be no consensus on the parameters (duration and frequency) used for the biphasic pulses. A duration of pulses between 0.1 and 0.5 us and a modulation frequency between 10 and 100 Hz are widely accepted by the scientific community and well tolerated by patients. The modulation of the pulse duration from 300 to 400 us seems to be more suitable for large muscle groups [24]. Furthermore, studies have shown that frequencies > 50 Hz seem to be more efficient in terms of gaining muscle strength [25, 26], whereas frequencies < 50 Hz seem to be more efficient in terms of oxidative capacity gain [27]. For this reason, we used wave frequency of 2,500 Hz, modulated at 50 Hz and a pulse duration of 400 us in our protocol.

The decision to perform the movement in a closed kinetic chain was due to significant dynamic stabilization of the knee joint by a powerful co-contraction and a great strength development of agonist and antagonist muscles of the thigh [28]. Also, in general, the knee extensor muscles (which include the VMO and VL) show a greater electrical activity when compared to the flexor muscles at an angle of 30° of knee flexion. For this reason, we used this angle in our protocol (Fig. 2) [29].

Limitations of the study

The average age of the healthy group was different to that of the HF group. Blood pressure was measured by a non-invasive method, although this is the most commonly used clinical method.

Conclusions

One session of strength exercises with and without neuromuscular electrostimulation does not promote a hemodynamic overload in HF patients or in healthy subjects. It seems that our strength exercise's protocol associated with electrostimulation is safe, and could be used in HF patients, but further studies are required for a definitive answer.

Acknowledgements

The authors do not report any conflict of interest regarding this work.

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