

The impact of neuromuscular electric stimulation versus aerobic exercise in rehabilitation of patients with chronic heart failure

Manal K. Youssef

Department of Internal Medicine, Cairo University Hospitals, Giza, Egypt

Correspondence to Manal K. Youssef, PhD,
Department of Internal Medicine,
Cairo University Hospitals, Giza, Egypt
Tel: + 20 122 747 6409
e-mail: manal.kamel@hotmail.com

Received 1 March 2014

Accepted 18 March 2014

Journal of the Arab Society for Medical Research 2014, 9:40–47

Background/Aim

Heart failure can be defined as an abnormality of cardiac structure or function leading to failure of the heart to deliver oxygen at a rate commensurate with the requirements of the metabolizing tissues, despite normal filling pressures. Cardiac rehabilitation programs have become an integral part of the standard of care in modern cardiology. The current study was carried out to determine the effect of neuromuscular electric stimulation (NMES) versus aerobic exercise in cases of chronic heart failure.

Patients and methods

Overall, 30 patients with chronic heart failure were included in this study from Cairo University Hospitals. Their ages ranged from 40 to 60 years and they were divided randomly into two groups (A and B). Group A received aerobic training. Group B received lower limb NMES for 2 months. All participants were evaluated before the first session of treatment and at the end of treatment by physical evaluation that included minute ventilation, maximum ventilation, heart rate, systolic blood pressure, diastolic blood pressure, and the 6-min walk test.

Results

Analysis of results showed a significant increase in minute ventilation and maximum voluntary ventilation in both groups ($P \leq 0.001$) and no significant difference between both groups, 7.3 ± 0.6 and 7.4 ± 0.6 . There was a significant decrease in heart rate, systolic blood pressure, and diastolic blood pressure in group A ($P \leq 0.001$) and also a significant decrease in heart rate, systolic blood pressure, and diastolic blood pressure in group B ($P \leq 0.001$). There was a significant difference between group A and group B in the decrease in heart rate, 131.1 ± 9.9 and 134.5 ± 9.6 , respectively, systolic blood pressure, 121.3 ± 7.4 and 139.3 ± 24.9 , respectively, diastolic blood pressure, 80.3 ± 3.5 and 84.7 ± 3.1 , and 6 min walk, 33.9 ± 2.6 and 32.2 ± 8.1 .

Conclusion

NMES can be used instead of aerobic exercise in cardiac rehabilitation, especially in critically ill patients. It exerts an effect similar to that of aerobic exercise without cardiac load, especially in the beginning of rehabilitation.

Keywords:

aerobic exercise, cardiac rehabilitation, chronic heart failure, stimulation

J Arab Soc Med Res 9:40–47

© 2014 The Arab Society for Medical Research
1687-4293

Introduction

Cardiovascular diseases are the third leading cause of death after cancer and cerebrovascular disease according to the annual data issued by the Korean National Statistical Office in 2010, with a mortality rate of 46.9 per 100 000 members of the population per year. In those younger than fifty years of age, heart disease is the leading cause of death [1].

Heart failure (HF) is a leading cause of death in many countries. Mortality is as high as 80% in the 5-year period following the first decompensation event. Exercise intolerance and decreased quality of life have been found to be markers of poor prognosis in these patients, independent of left ventricular (LV) ejection fraction (LVEF) [2].

For the purposes of these guidelines, HF is defined, clinically, as a syndrome in which patients have typical

symptoms (e.g. breathlessness, ankle swelling, and fatigue) and signs (e.g. elevated jugular venous pressure, pulmonary crackles, and displaced apex beat) resulting from an abnormality in cardiac structure or function [3].

HF is a complex clinical syndrome that can result from any structural or functional cardiac disorder that impairs the ability of the ventricle to fill with or eject blood; the cardinal manifestations of HF are dyspnea and fatigue, which may limit exercise tolerance, and fluid retention, which may lead to pulmonary congestion and peripheral edema. Both abnormalities can impair the functional capacity and quality of life of affected individuals, but they do not necessarily dominate the clinical picture at the same time. Some patients have exercise intolerance, but little evidence of fluid retention, whereas others complain primarily of edema and report few symptoms of dyspnea or fatigue.

Because not all patients have volume overload at the time of initial or subsequent evaluation, the term 'heart failure' is preferred over the older term 'congestive heart failure' [4].

Cardiac rehabilitation programs include mainly exercise training sessions, but also educational interventions and psychological support, and allow both close follow-up and fine medication adjustments in these high-risk patients. Exercise training is recommended in most guidelines as a useful intervention for patients with stable chronic HF [5].

Regular physical activity improves HDL-cholesterol, decreases visceral fat, and reduces glycemia as well as blood pressure. Another objective of cardiac rehabilitation is to control the modifiable risk factors. This involves not only smoking cessation and the optimization of medication for blood pressure, diabetes, and cholesterol control but also therapeutic education that emphasizes the importance of measures of therapeutic life changes. Regular physical activity has been shown to have many cardiovascular benefits including weight loss, blood pressure reduction, glycemic control, and improvements in lipid profile [6].

Moderate to intense aerobic physical activity and muscle strengthening have been proven to decrease the risk of chronic disease, premature death, and disability. This activity should be performed for at least 30 min five times a week or 20 min or three times a week if the activity is vigorous. To maintain physical independence, resistance training at least 2 days/week should be added to maintain or increase muscle strength using 25–40% loads involving all major muscle groups at a moderate to high level of effort. Flexibility should be maintained by stretching exercises at least twice a week [7].

A number of studies have documented wasting and a variety of histological and biochemical abnormalities of striated muscle in patients with the clinical syndrome of HF including a reduction in the proportion of fatigue-resistant type I fibers, reduced oxidative enzymes, reduced capillarity, and reduced single fiber myosin content. The clinical correlates of these changes are reduced muscle strength and endurance, with a reduced force per unit of cross-sectional area associated with reduced exercise capacity [8].

Chronic HF begins with a pump function injury. However, symptoms and disease progression also involve alteration of peripheral organs and neurohormonal activation. Both HF and peripheral organ injuries account for patients' exercise intolerance. In CHF populations with LV systolic dysfunction, neuromuscular electrical stimulation (NMES) appears

to produce the same benefits as conventional physical exercise training by increasing both exercise capacity and quality of life. NMES appears to be particularly useful in patients unable to perform conventional exercises [9].

NMEE is a form of exercise and mobilization that does not require active participation and can be applied to immobilized patients. NMEE has been shown to be beneficial in patients with CHF and chronic obstructive pulmonary disease as well as ICU and hospital inpatients [10].

The aim of this study is to compare the effect of aerobic exercise with NMES in cases of chronic HF.

Patients and methods

Patients

The current study was carried out on 30 patients from Cairo University Hospitals; their ages ranged from 40 to 60 years and all of them had CHF. Their BMI ranged between 25 and 29 kg/m².

Inclusion criteria

The inclusion criteria were symptomatic stability, NYHA class II–III, and optimized pharmacological treatment (unchanged 2 months before and throughout the study) [11].

Exclusion criteria

The exclusion criteria were as follows: uncontrolled arterial hypertension, history of major ventricular arrhythmias, acute coronary syndrome, percutaneous coronary intervention or brain event 3 months before the study, atrial flutter/fibrillation or other arrhythmia, previous coronary artery bypass graft surgery, implanted cardioverter-defibrillator and/or pacemaker or the presence of metal parts in the body, signs of osteoarticular dysfunction excluding participation in physical training, diabetes mellitus, chronic lung disease, and major anemia [12].

Materials

Electronic muscle stimulator: Q wave healthtronic three channels model (BM-1006), Cybermedical-USA, Respirometer cardiovit, CS-100, Schiller Tm-400 S, USA and Bicycle ergometer (Multi Glob DSL280S) USA.

Materials and methods

Complete history of all patients was assessed. Physical evaluation included assessment of minute ventilation, maximum ventilation [measured by Respirometer cardiovit, CS-100, Schiller Tm-400 S, USA and heart

rate (HR) by ECG], blood pressure and 6-min walk distance, and pulse readings (measured by pulseoximetry).

Assessment procedure

Six-minute walk test

A 20-m enclosed corridor within the cardiac care unit of the hospital was marked out for the test. Patients were allowed to rest for a period of 10 min in the sitting position before commencement of the exercise test.

Patients were instructed to walk from the starting point to the end at their own selected pace while attempting to cover as much ground as possible in 6 min. They were encouraged every 30 s or so in a standardized manner by saying: 'You are doing well' or 'Keep up the good work'. After 6 min, the distance covered was measured to the nearest meter.

Cardiopulmonary exercise test

An electronic bicycle ergometer (Multi Glob DSL280S) with a display screen and a programmable control unit was used. The bicycle ergometry test started with the patient sitting on the bicycle with an initial resistance of 20 W, which was increased by 10 W after 3 min. The 6-min ride is reported to be similar to the work of the 6-min walk. To overcome the inertia of the flywheel, the pedals were driven manually at 60 rpm at the start of the 6-min ride. Patients were asked to maintain the 60 revolutions/min throughout the test [13].

Training protocol

For patients of group A (aerobic training), the program consisted of a 10-min warm-up session and 40 min of intermittent aerobic training (5 min warm-up without workload, 30 min of training consisting of alternating periods of 1 min of work and 2 min without workload, and a 5 min cool-down period without workload). The final phase was 10 min of relaxation in the supine position. The exercise workload was adjusted individually and performed at the level of the anaerobic threshold determined by spirometry. The training sessions were performed three times a week at the same time, for a total period of 8 weeks. Exercise intensity was set as 60% of maximum HR. Maximal HR was calculated using the formula $(220 - \text{patient age})$.

Minute ventilation is the volume of expired air in l/min measured over a minimum of 1 min. Maximum voluntary ventilation is the maximum volume of air that can be moved on expiration while breathing as deeply and as rapidly as possible.

The mean arterial blood pressure is equal to the product of cardiac output (CO) and total peripheral resistance; thus, lowering of resting blood pressure must result from

a decrease in CO, total peripheral resistance, or both $\text{CO} = \text{HR} \times \text{SV}$. Thus, decreasing the HR leads to a decrease in CO and finally a decrease in the resting blood pressure.

The pulse rate or the count of arterial pulse per minute is equivalent to measuring the HR.

Stimulation protocol

Patients in group B underwent a 45-min NMES session of both lower extremities (vastus lateralis, vastus medialis, and peroneus longus). The NMES session was not performed until the patients were stable and had been adequately resuscitated. Wave frequency was modulated at 50 Hz, with a pulse duration of 40 ms. The stimulator was set to deliver 20 s of contraction and 4 s of relaxation. Adhesive surface electrodes 3 cm in diameter were used for electrostimulation. The current intensity was adjusted according to the sensitivity threshold of the patient [14].

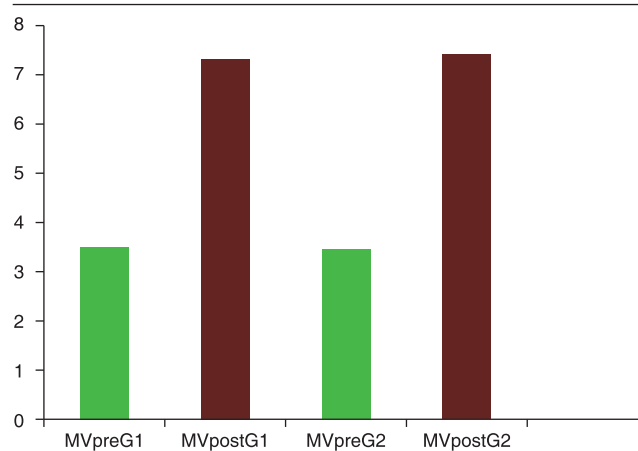
Statistical analysis

Data were presented as mean + SD. An unpaired *t*-test was used to compare the means before and after treatment of each group ($P < 0.001$), whereas the paired *t*-test was used to determine the difference between both groups; *P* less than 0.05 was considered significant. The data were analyzed using minitab 13.1 Pennsylvania, USA.

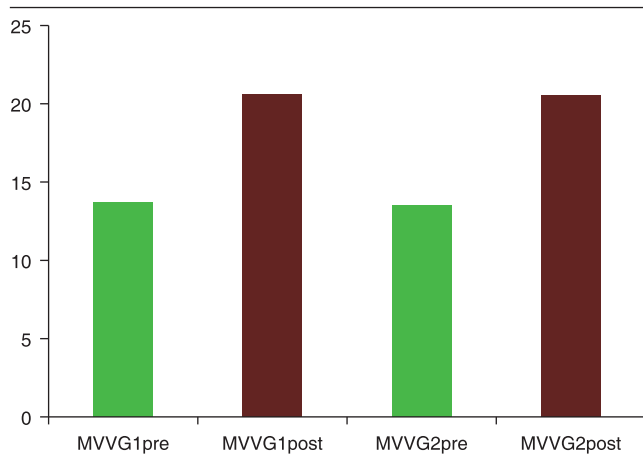
Results

The results of group A and group B are expressed as mean $\pm$ SD, mean difference. Paired *t* test and *P* value ≤ 0.001 was used to compare the means of pre and post treatment for each group while unpaired *t* test *P* value ≤ 0.05 was used for comparison between both groups using. Data are shown in figures (Figs. 1–6).

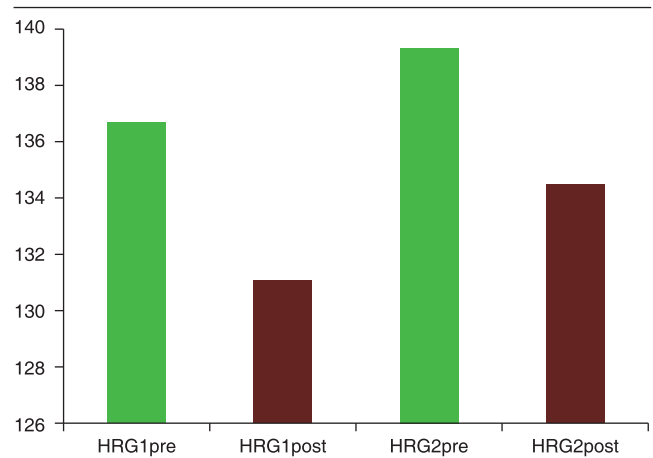
Figure 1



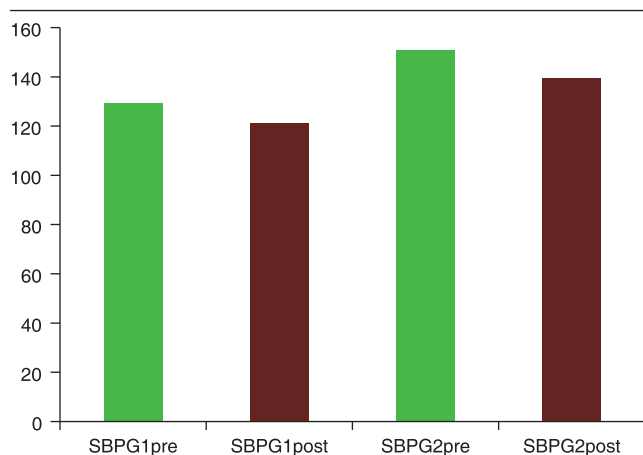
Minute ventilation of both groups before and after treatment.

Figure 2

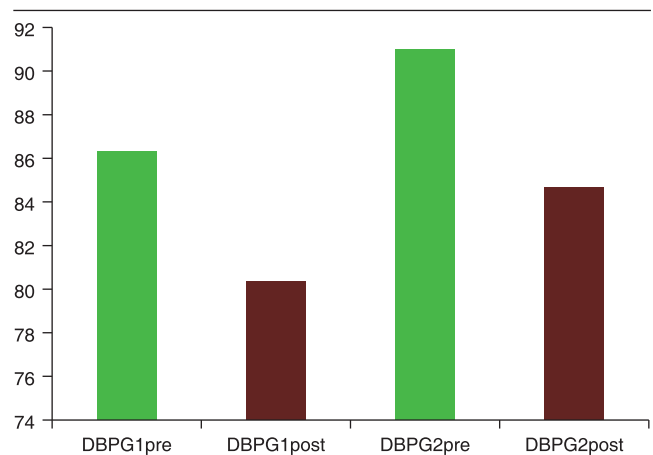
Maximum voluntary ventilation of both groups before and after treatment.

Figure 3

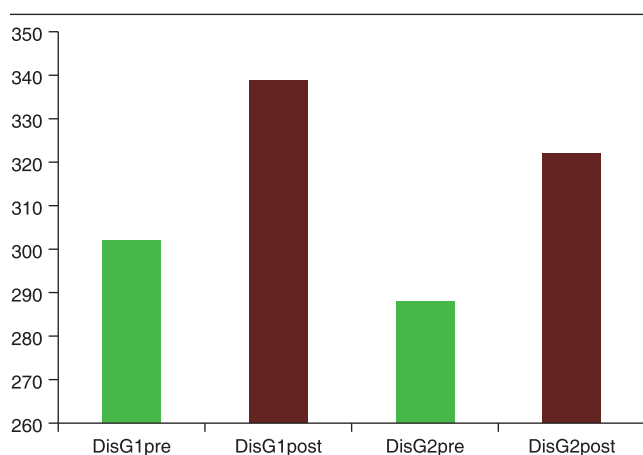
Heart rate of both groups before and after treatment.

Figure 4

Systolic blood pressure of both groups before and after treatment.

Figure 5

Diastolic blood pressure of both groups before and after treatment.

Figure 6

Six-minute walk of both groups before and after treatment.

The results of group A showed that there was a significant increase in minute ventilation from 3.5 to

7.3, an increase in maximum voluntary ventilation from 13.7 to 20.6, a decrease in HR from 136.7 to 131.1, a decrease in systolic blood pressure (SBP) from 151.0 to 121.3, a decrease in diastolic blood pressure (DBP) from 86.3 to 80.3, and an increase in 6 min walk from 300.2 to 330.9 (Table 1).

Results of group B showed that there were significant increases in minute ventilation from 3.5 to 7.4, an increase in maximum voluntary ventilation from 13.5 to 20.5, a decrease in HR from 139.3 to 134.5, a decrease in SBP from 151.0 to 139.3, a decrease in DBP from 91.0 to 84.7, and an increase in 6 min walk from 288 to 322 (Table 2).

Comparison of data of both groups showed no significant difference between both groups in minute ventilation, 7.3 ± 0.6 and 7.4 ± 0.6 , respectively ($P \leq 0.05$) and maximum voluntary ventilation, 20.6 ± 2.3 and 20.5 ± 2.6 (P Comparison of data of both

groups showed no significant difference between both groups in minute ventilation, 7.3 ± 0.6 and 7.4 ± 0.6 , respectively ($P \leq 0.05$) and maximum voluntary

Table 1 Measurements before and after treatment for group A (aerobic training)

Item	Mean $\pm$ SD		MD	t value	P value
	Pretreatment	Post-treatment			
Minute ventilation (l/min)	3.5 ± 0.3	7.3 ± 0.6	3.8	-27.18	0.00**
Maximum ventilation (l/min)	13.7 ± 1.1	20.6 ± 2.3	6.9	-9.43	0.00**
Heart rate (beats/min)	136.7 ± 11.5	131.1 ± 9.9	5.6	4.72	0.00**
Systolic blood pressure (mmHg)	129.3 ± 7.3	121.3 ± 7.4	8.0	12.22	0.00**
Diastolic blood pressure (mmHg)	86.3 ± 5.2	80.3 ± 3.5	6.0	5.39	0.00**
Six-minute walk distance (m)	30.2 ± 9.4	33.9 ± 2.6	3.7	-1.39	0.00**

MD, mean difference; *Significant difference at $P < 0.05$; **Highly significant difference at $P < 0.001$.

Table 2 Measurements before and after treatment for group B (NMES)

Item	Mean $\pm$ SD		MD	t value	P value
	Pretreatment	Post-treatment			
Minute ventilation (l/min)	3.4 ± 0.4	7.4 ± 0.6	3.1	-30.35	0.00**
Maximum ventilation (l/min)	13.5 ± 1.6	20.5 ± 2.6	7.0	-13.32	0.00**
Heart rate (beats/min)	139.3 ± 11.4	134.5 ± 9.6	4.9	4.57	0.00**
Systolic blood pressure (mmHg)	151.0 ± 25.0	139.3 ± 24.9	11.7	3.54	0.00**
Diastolic blood pressure (mmHg)	91.0 ± 5.1	84.7 ± 3.1	6.3	6.14	0.00**
Six-minute walk distance(m)	28.8 ± 5.2	32.2 ± 8.1	3.4	-1.17	0.00**

MD, mean difference; NMES, neuromuscular electric stimulation; *Significant difference at $P < 0.05$; **Highly significant difference at $P < 0.001$.

Table 3 Measurements pre and post treatment for both groups

Item	Group A	Group B	T value	P value
	Mean $\pm$ SD	Mean $\pm$ SD		
Minute ventilation (L/min)	7.3 ± 0.6	7.4 ± 0.6	0.45	0.661
Maximum ventilation (L/min)	20.6 ± 2.3	20.5 ± 2.6	0.09	0.928
Heart rate (beats/min)	131.1 ± 9.9	134.5 ± 9.6	0.92	0.374*
Systolic blood pressure (mm Hg)	121.3 ± 7.4	139.3 ± 24.9	3.34	0.005*
Diastolic blood pressure (mm Hg)	80.3 ± 3.5	84.7 ± 3.1	3.67	0.003*
6-minute walk distance (meter)	33.9 ± 2.6	32.2 ± 8.1	0.73	0.478*

SD, standard deviation; MD, mean difference;

*Significant difference at $P < 0.05$.

ventilation, 20.6 ± 2.3 and 20.5 ± 2.6 ($P \leq 0.05$), but there was a significant difference in HR, 131.1 ± 9.9 and 134.5 ± 9.6 , respectively ($P \leq 0.05$). There was a significant difference in SBP, 121.3 ± 7.4 and 139.3 ± 24.9 , respectively ($P \leq 0.05$). There was a significant difference in DBP, 80.3 ± 3.5 and 84.70 ± 0.5 , but there was a significant difference in HR, 131.1 ± 9.9 and 134.5 ± 9.6 , respectively ($P \leq 0.05$). There was a significant difference in SBP, 121.3 ± 7.4 and 139.3 ± 24.9 , respectively ($P \leq 0.05$). There was a significant difference in DBP, 80.3 ± 3.5 and 84.7

Discussion

The present study showed that there was a significant increase in minute ventilation and maximum ventilation in both groups (aerobic exercise group and NMES group). These were consistent with the findings reported by Thomas and colleagues. Dyspnea is recognized as a leading symptom in patients with CHF that often contributes toward limitations in activities of daily living. Importantly, a critical link has been established between increased ventilation and worsening prognosis [15].

The present study found a highly significantly increase in minute ventilation and maximum voluntary ventilation in both groups and these were consistent with the findings reported by Andrew. The VO_2 level depends on the stroke volume, which increases the O_2 delivery to the exercising muscles, and the capability to consume O_2 by skeletal muscles. NMES is a useful tool to improve the cardiopulmonary responses in individuals with CHF and consequently provides both central (cardiorespiratory system) and peripheral adaptations (muscle changes). NMES reduces the peripheral limitations to exercise because of the recruitment of a large lower muscle mass and reactivates the leg muscle pump. The higher the venous return, the higher the cardiac preload and CO through the Frank-Starling mechanism [16].

Also, Andrew and his colleagues [17] reported that home-based unsupervised cycling at 60–80% of previously determined maximal HR for 20 min, 5 days/week for 8 weeks, led to an improvement in exercise capacity, reduction in norepinephrine (noradrenalin) spillover, and improvement in the abnormal sympathovagal balance.

Programs of physical activity, either aerobic and/or strength exercises, are used as a supplemental treatment for patients with CHF. However, these interventions are usually only proposed for patients with moderate symptoms [18]. The present study found an increase in the exercise capacity measured as a 6 min walk in the aerobic exercise group ($P \leq 0.001$).

NMES has been used widely as a complement to voluntary exercise in athletes and in patients who cannot perform conventional forms of voluntary exercise because of various pathologies such as HF, chronic obstructive pulmonary disease, or cancer [19]. The present study found an increase in the exercise capacity measured as 6 min walk in the NMES group ($P \leq 0.001$).

NMES can induce changes in muscle function without any form of ventilator stress. NMES can be performed easily in the ICU and applied to the lower limb muscles of patients lying in bed [20].

The results of the present study showed that the aerobic exercise group treated by aerobic training showed a significant increase in minutes ventilation, maximum ventilation, and 6 min walk ($P \leq 0.001$) and these were consistent with the findings reported by Jorge and colleagues. It has been shown that skeletal muscle abnormalities limit the aerobic capacity during the exercise, which results in accumulation of metabolites in the muscles, leading to sensitization of muscle receptors called metaboreceptors. The activation of metaboreceptors induces a reflex response, which results in hyperventilation, exacerbating the dyspnea sensation. Moreover, it promotes peripheral vasoconstriction with a reduction in blood flow, which contributes toward the reduction of tolerance to exercise on CHF [21].

NMES is used widely to activate muscle in a rehabilitation setting for the recovery and maintenance of muscle performance. The relationship between HF, muscle impairment, and low exercise capacity is well known in cardiology. Thus, NMES has been proposed as a promising adjuvant therapy to potentialize the effects of exercise training in patients engaged in cardiovascular rehabilitation programs [22].

The present study found a significant difference between pretreatment and post-treatment values of HR, SBP, and DBP ($P \leq 0.001$) in the NMES group and this was consistent with the findings reported by Bruna and colleagues. It has already been shown that the use of NMES in patients with CHF improves functional capacity, muscle strength, and inflammatory markers. The possible mechanisms involved could be increases in the number of muscle fibers, enzyme activity, and energy expenditure (i.e. being limitations), and would justify the improvement observed in the variables studied. Other factors that would support the occurrence of an increase in muscle fibers were the observed increases in strength and increase in perimeter values of the lower limbs. There was a significant decrease in the values of DBP, mean blood pressure (MBP), and, in particular, of SBP, which showed a

decrease of 8 mmHg, shifting its value of pressure for a condition considered to be ideal [23].

In addition, lifelong exercise training seems to limit age-related cardiac stiffening, resulting in a more compliant LV in older age and possibly reducing the risk of HF with preserved EF [24]. Physical activity has been shown to have beneficial effects on glucose metabolism, skeletal muscle function, ventilator muscle strength, bone stability, locomotor coordination, psychological well-being, and other organ functions [25].

Transport of gases between the muscle and the environment is mediated by the integrated function of multiple organ systems, any of which could become limiting to exercise if sufficiently impaired. The dependence of gas transport on large excursions in output of the heart and lungs makes disease of these organs a particularly common cause of exercise intolerance. Aerobic exercise prescriptions ideally entail 30 min of moderate to vigorous intensity exercise several days per week. Effectiveness of training is greatest if the intensity is high, but not so high as to be unsustainable, precluding adherence. Consistent with this, cardiac rehabilitation exercise typically targets HR or work rates that are 50–80% of the measured peak [26].

In the present study, aerobic exercise at 60% of maximum led to a significant decrease in HR, SBP, and DBP ($P \leq 0.001$) and this was consistent with the findings Juan and his colleagues [27] reported that. Through a 12-week lifestyle modification program using the resources of cardiac rehabilitation, a trend toward improvement in SBP and DBP, triglycerides, high-density lipoprotein cholesterol, glucose levels, and waist circumference was found. Heart rate recovers more rapidly after exercise after a concentrated, intensive program of exercise training in patients with CHF. Most of the improvement in heart rate recovery was associated with a widening of the difference between resting and peak exercise HR [28].

Conventionally, the skeletal muscle pump (i.e. the lumped functions including local and central circulatory effects) is deemed to be vital in coordinating the local and systemic blood flow responses by enhancing venous return, central venous pressure, end-diastolic volume of the heart and thus SV, and Q during exercise [29].

Patients with CHF are often limited in their activities by symptoms of dyspnea and fatigue. Accordingly, exercise intolerance is a hallmark of symptomatic CHF. Because of the pathophysiological sequelae of CHF, initial studies attempted to link exercise capacity

with measures of ventricular function (i.e. LVEF, LV dimensions, and cardiac index) [30].

The present study showed an increase in the 6 min walk in the aerobic exercise group from 30.2 ± 9.4 to 33.9 ± 2.6 and in the NMES group from 28.8 ± 5.2 to 32.2 ± 8.1 and there was a significant difference between both groups.

NMES can be applied as a complementary intervention to voluntary exercise training. NMES involves the application of an electric current through electrodes placed on the skin over the targeted muscles, thereby depolarizing motor endplates by the motor nerve and in turn inducing skeletal muscle contractions. NMES is composed of stimulation rest cycles situated in muscle motor points. In contrast to voluntary muscle actions, NMES activates the muscle to a greater extent under identical technical conditions. The muscle reaches higher values in blood flow and oxygen consumption during NMES compared with voluntary contraction [31]. Comparison of the results of both groups indicated no significant difference in minute ventilation and maximum voluntary ventilation, but there was a significant difference in HR, SBP, and DBP and 6 min walk.

Conclusion

Unloaded electrical muscular stimulation (EMS)-induced cardiovascular exercise could provide an attractive alternative to customary forms of cardiovascular exercise that involve repetitive joint loading (such as running). It could also be used to induce a cardiovascular exercise response in patients who experience barriers to participation in voluntary weight-bearing exercise.

Acknowledgements

Conflicts of interest

None declared.

References

- So YL, Sang H, Bo RK, Jun HC, Seog JL, Eun YH. The effects of neuromuscular electrical stimulation on cardiopulmonary function in healthy adults. *Ann Rehabil Med* 2012; 36:849–856.
- Guirado GN, Roscani MG, Polegato BF, Matsubara LS, Bazan SG, Matsubara BB. Diastolic function is associated with quality of life and exercise capacity in stable heart failure patients with reduced ejection fraction. *Braz J Med Biol Res* 2013; 46:803–808.
- John JV, Stamatias A, Stefan DA, Angelo A, Michael B, Kenneth D, *et al.* Guidelines for the diagnosis and treatment of acute and chronic heart failure. *Eur Heart J* 2012; 33:1787–1847.
- Sharon AH, William TA, Marshall HC, Arthur MF, Gary SF, Theodore GG, *et al.* Diagnosis and management of heart failure in adults: a report of the American College of Cardiology Foundation/American Heart Association Task Force on practice guidelines developed in collaboration with the international society for heart and lung transplantation. *J Am Coll Cardiol* 2009; 53:e1–e90.
- Jean YT, Philippe M, Ahmed BD, Hélène W, Nathalie R, Anne G, *et al.* Benefits of exercise training in chronic heart failure. *Arch Cardiovasc Dis* 2009; 102:721–730.
- Warner MM. Cardiac rehabilitation past, present and future: an overview. *Cardiovasc Diagn Ther* 2012; 2:38–49.
- Roberto CC, Isabel M, Alguacil D, Joaquin JA, Juan CM. Cardiac rehabilitation programs and health-related quality of life. State of the art. *Rev Esp Cardiol* 2012; 65:72–79.
- Nicholas SH, Mark JD, Sophie AJ, Elisabeth BS, Raphael P, Ali V, *et al.* Central and peripheral quadriceps fatigue in congestive heart failure. *Int J Cardiol* 2013; 167:2594–2599.
- Hugo SB, Erenaldo SJ, Cristiano G, Alves C, Alessandro M, Francisco JF, *et al.* Neuromuscular electrical stimulation in a patient with chronic heart failure due to chagas disease: a case report. *Clinics* 2011; 66:927–928.
- Eleftherios K, Vasiliki G, Dimitrios Z, Elli ST, Kleovoulos A, Ioannis V, *et al.* Electrical muscle stimulation: an effective form of exercise and early mobilization to preserve muscle strength in critically ill patients. *Crit Care Res Pract* 2012; 43:52–59.
- Petr D, Marie N, Bohumil F, Jarmila S, Pavla B, Lenka S, *et al.* Electrical stimulation of skeletal muscles an alternative to aerobic exercise training in patients with chronic heart failure?. *Int Heart J* 2006; 47:441–453.
- Artur K, Kalina KJ, Bogumiła B, Aleksandra K, Mieczysław P, Piotr K, *et al.* Physical training in patients with chronic heart failure of ischemic origin: effect on exercise capacity and left ventricular remodeling. *Eur J Cardiovasc Prev Rehabil* 2007; 14:85–91.
- Rufus A, Samuel AA, Michael OB, Anthony OA, Rasaaq AA, Patience OA, *et al.* Assessment of exercise capacity in African patients with chronic heart failure using six minutes walk test. *Int J Gen Med* 2010; 3:109–113.
- Vasiliki G, Elli T, Eleftherios K, Theodore P, Vasiliki M, Dimitrios Z, *et al.* Short-term systemic effect of electrical muscle stimulation in critically ill patients. *Chest* 2009; 136:1249–1256.
- Thomas PO, Michael JJ, Niki MD, John HE, Timothy BC, Bruce DJ Effects of respiratory muscle work on blood flow distribution during exercise in heart failure. *J Physiol* 2010; 588:2487–2501.
- Carvalho DCL, Cassia MZ, Sereni JM, Cliquet A. Metabolic and cardiorespiratory responses of tetraplegic subjects during treadmill walking using neuromuscular electrical stimulation and partial body weight support. *Spinal Cord* 2005; 43:400–405.
- Andrew LC. Exercise and heart failure: assessment and treatment. *Heart* 2006; 92:699–703.
- Gaëlle D, Jean CE, Bénédicte V, Jean EW, Jean MC. Do low-frequency electrical myo stimulation and aerobic training similarly improve performance in chronic heart failure patients with different exercise capacities? *J Rehabil Med* 2008; 40:219–224.
- Julien G, Lorenza B, Elena B, Giuseppe D, Nicola AM, Danilo M, *et al.* Neuromuscular electrical stimulation training induces atypical adaptations of the human skeletal muscle phenotype: a functional and proteomic analysis. *J Appl Physiol* 2011; 110:433–450.
- Ambrosino N, Vaghegini EV, Clini E. Rehabilitation, weaning and physical therapy strategies in chronic critically ill patients. *Eur Respir J* 2012; 39:487–492.
- Jorge PR, Gaspar RC, Carine CC. The contributions of inspiratory muscles function to exercise limitation in heart failure: pathophysiological mechanisms. *Rev Bras Fisioter* 2012; 16:261–267.
- Carlos JA, Fernanda SG, Hugo SB, Noélia GS, Sérgio VM. Effects of neuromuscular electro stimulation in patients with heart failure admitted to ward. *J Cardiothorac Surg* 2012; 7:124–128.
- Bruna E, Graciele S, Thiago D, Karina RC, Rodrigo DM. Functional electrical stimulation training on functional capacity and blood pressure variability in a centenarian woman: case study. *Rev Bras Fisioter* 2011; 15:338–341.
- Jarett DB, Ambarish P, Ang G, David L, Ramin F, Colby A, *et al.* Physical fitness and risk for heart failure and coronary artery disease. *Circ Heart Fail* 2013; 6:627–634.
- Stephan G, Gerhard S, Volker A. Cardiovascular effects of exercise training molecular mechanisms. *Circulation* 2010; 122:1221–1238.
- Ross A, Kathy ES. Cardiopulmonary exercise testing in the clinical evaluation of patients with heart and lung disease. *Circulation* 2011; 123:668–680.
- Juan PR, Virend KS, Amy LH, Randal JT, Ray WS, Ondrej S, *et al.* Effect of a lifestyle therapy program using cardiac rehabilitation resources on metabolic syndrome components. *J Cardiopulm Rehabil Prev* 2013; 33:360–370.

- 28 Jonathan M, David H, Ulrike O, Karin B, Wilhard K, Leon H, *et al.* Effects of exercise training on heart rate recovery in patients with chronic heart failure. *Am Heart J* 2007; 153:1056–1063.
- 29 Jose GA, Stefan PM, Tina DJ, Leena A, Horace B, Rasmus D, *et al.* Haemodynamic responses to exercise, ATP infusion and thigh compression in humans: insight into the role of muscle mechanisms on cardiovascular function. *J Physiol* 2008; 586:2405–2417.
- 30 Eddy F. Critical illness neuromyopathy and the role of physical therapy and rehabilitation in critically ill patients. *Respir Care* 2012; 7:933–944.
- 31 Maurice JH, Caroline MS, Rose MA, Paul PJ, Scott SW, Emiel FM, *et al.* Effects of neuromuscular electrical stimulation of muscles of ambulation in patients with chronic heart failure or COPD: a systematic review of the english-language literature. *Chest* 2013; 136:44–61.