ORIGINAL REPORT

DO LOW-FREQUENCY ELECTRICAL MYOSTIMULATION AND AEROBIC TRAINING SIMILARLY IMPROVE PERFORMANCE IN CHRONIC HEART FAILURE PATIENTS WITH DIFFERENT EXERCISE CAPACITIES?

Gaëlle Deley, PhD\(^1\), Jean-Christophe Eicher, MD\(^2\), Bénédicte Verges, MD\(^3\), Jean-Éric Wolf, MD\(^2\) and Jean-Marie Casillas, MD\(^1\)

From the \(^1\)Laboratory INSERM ERM 207, University of Bourgogne, \(^2\)Department of Cardiology and \(^3\)Department of Rehabilitation Cardiology, Centre Hospitalo-Universitaire, Dijon, France

Objective: To confirm that electrical myostimulation is a good alternative to conventional aerobic training in patients with chronic heart failure and to compare the effects of both training programmes in patients with different exercise capacities.

Patients and methods: A total of 44 patients with stable chronic heart failure underwent 5 weeks of exercise training, with electrical myostimulation or conventional aerobic training programmes. At baseline and after the training period, patients performed a symptom-limited cardiopulmonary exercise test and a 6-min walk test.

Results: Oxygen uptake at the end of exercise (V\(_{\text{O}_2}\) peak) and at ventilatory threshold (V\(_{\text{O}_2}\) VT) increased after electrical myostimulation (p<0.001) and conventional aerobic training (p<0.001) training programmes. The slope of the relationship between V\(_{\text{O}_2}\) and workload was reduced after electrical myostimulation (p<0.05), but not after conventional aerobic training. Recovery was improved after both training programmes (p<0.05), and the distance walked in 6 min was increased (p<0.001). These improvements were not statistically different between electrical myostimulation and conventional aerobic training. Moreover, electrical myostimulation induced greater improvements in patients with low exercise capacity, whereas conventional aerobic training induced improved performance in patients with average exercise capacity.

Conclusion: Five weeks of electrical myostimulation and conventional aerobic training exercise training produced similar improvements in exercise capacity in patients with chronic heart failure. However, electrical myostimulation appears to be more effective in patients with low exercise capacity than in those with average exercise capacity.

Key words: chronic heart failure, low-frequency electrical myostimulation, conventional aerobic exercise training, exercise capacity.


INTRODUCTION

Originally regarded as a contraindication by the Scientific Council on Cardiac Rehabilitation, physical activity has become important in the management of patients with chronic heart failure (CHF) only during the last decade (1). Training programmes usually include aerobic activity alone or in combination with resistance exercise (2, 3) and their benefits are well established (4–7). However, other modes of rehabilitation, such as interval training and electromyostimulation (EMS), have been proposed for patients with CHF, regardless of severity (8–10). Two studies recently demonstrated that low-frequency EMS and conventional aerobic exercise training induce similar benefits in aerobic parameters, field tests parameters, and muscle strength in stable patients with CHF (10, 11). However, the number of patients in these studies was small (24 and 30 patients divided into 2 groups). The first aim of the present experiment was therefore to confirm these preliminary results with a comparison of the 2 methods with a larger patient population. Moreover, as suggested by Larsen & Dickstein (12), it is important to identify the CHF population that would benefit most from EMS. Thus, the secondary aim of this study was to compare the effects of EMS and conventional training in CHF patients with different exercise capacities. Therefore, a comparison was made of: (i) cardiorespiratory parameters during moderate to high workloads of exercise (i.e. oxygen uptake (V\(_{\text{O}_2}\)) at ventilatory threshold (VT) and at the end of exercise, slope of the V\(_{\text{O}_2}\)/workload relation and V\(_{\text{O}_2}\) during recovery); and (ii) submaximal field test parameters.

METHODS

Participants

Table I presents the baseline characteristics of the 44 patients enrolled in this study. They had stable CHF due to dilated or ischaemic cardiomyopathy, an ejection fraction < 40% as measured by echocardiography and were in New York Heart Association (NYHA) classification II–IV. All patients were symptomatically stable and their medical treatment (angiotensin-converting enzyme (ACE) inhibitors, diuretics, beta-blockers) was stable throughout the study. Exclusion criteria were obstructive valvular heart disease and pulmonary disease, acute coronary syndrome or myocardial infarction during the preceding 3 months and...
Exercise training

Following baseline assessment, all patients were blind randomized to receive either a conventional (CONV) or low-frequency EMS ambulatory training. Both training programmes consisted of 1-h sessions, 5 days a week over 5 weeks. According to the recommendations of the European Society of Cardiology (17), patients undergoing conventional training had to perform aerobic exercise (treadmill, bicycle) with a global warm-up and cool-down. Exercise intensity was determined on an individual basis, so that the patient’s target heart rate corresponded to the heart rate at VT (obtained during the initial cardiopulmonary exercise test). During training, exercise intensity was also checked individually by the determination of perceived exertion rating using the Borg scale with a target range between 13 and 15 (10, 18).

The EMS programme was the same as used in our previous study (10). It consisted of a stimulation of both quadriceps and calf muscles using 2 portative dual-channel stimulators (Elpha 2000, Dannmeter, Odense, Denmark). Each delivered a low-frequency 10-Hertz biphasic current, with pulse duration of 200 microsec. The stimulus was alternatively on for 12 sec and off for 8 sec. The stimulation intensity for each muscle was increased throughout the training programme according to the patient’s tolerance, in order to be always at the maximum tolerated value (8). If the patient reached the maximum intensity deliverable by the stimulator, the training remained at this level.

Statistical analysis

All data are expressed as mean (standard deviation (SD)). The anthropometric and clinical values were compared between the 2 groups using a Student’s t-test. A two-way analysis of variance (ANOVA) with repeated-measures (group × time) was used to assess each parameter. After this primary analysis, each group was divided into 2 subgroups in order to distinguish the effects of the 2 training modalities according to exercise capacity. The cut-off value of 11 ml/min/kg for VO₂ at VT (19, 20) was used to determine subgroups, termed “average” and “low”. A three-way analysis of variance was then used to assess each parameter.

When the p-value from ANOVA was significant, a post hoc Newmann-Keuls test was used. Significance was set at p<0.05.

RESULTS

Participants

Prior to rehabilitation, there were no significant differences between the 2 groups for any parameter. A total of 70 patients were screened, 46 were randomly assigned to the 2 groups, and 44 completed the training programme with no significant injury or muscle pain reported in either group (2 patients were excluded from the study due to their lack of compliance during the first 2 weeks of exercise training). Fourteen patients in the “EMS group” reached the maximum intensity deliverable by the stimulator (11 in the “average exercise capacity group” and 3 in the “low exercise capacity group”).

Changes after rehabilitation

Electromyostimulation vs conventional exercise training. Table II presents the values measured during the symptom-limited exercise test and the 6-MWT, before and after both training modalities.
Myostimulation in chronic heart failure

Table II. Baseline (PRE) and post-training (POST) data (mean (SD)) registered during the tests

<table>
<thead>
<tr>
<th></th>
<th>EMS</th>
<th>CONV</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>PRE</td>
<td>POST</td>
</tr>
<tr>
<td>Peak heart rate, beat/min</td>
<td>136.7 (26.2)</td>
<td>137.7 (26.3)</td>
</tr>
<tr>
<td>Peak VO₂, ml/kg/min</td>
<td>16.4 (3.1)</td>
<td>18.4 (3.6)</td>
</tr>
<tr>
<td>VO₂ at VT, ml/kg/min</td>
<td>11.0 (2.1)</td>
<td>12.7 (2.7)</td>
</tr>
<tr>
<td>VO₂/WL, ml O₂/W/min</td>
<td>9.7 (4.0)</td>
<td>7.9 (2.3)</td>
</tr>
<tr>
<td>T₁/₂, sec</td>
<td>114.0 (38.0)</td>
<td>97.9 (29.9)</td>
</tr>
<tr>
<td>Distance 6-MWT, m</td>
<td>428.0 (60.4)</td>
<td>487.1 (57.7)</td>
</tr>
</tbody>
</table>

**p-value, PRE vs POST (Newman-Keuls post hoc): *p<0.05, †p<0.01.**

EMS: patients under low-frequency electrical myostimulation rehabilitation programme; CONV: patients under conventional rehabilitation programme; peak VO₂: oxygen uptake at the end of the symptom-limited cardiopulmonary exercise test; VO₂ at VT: oxygen uptake at ventilatory threshold; VO₂/WL: slope of the oxygen uptake/workload relation above the ventilatory threshold; T₁/₂: time to recover half of peak VO₂; distance 6-MWT: distance in the 6-minute walk test; SD: standard deviation.

Peak oxygen uptake was increased by 12.2% after EMS (p<0.001) and by 16.8% after CONV (p<0.001). VO₂ at VT was increased by 15.4% after EMS (p<0.001) and by 17.4% after CONV (p<0.001). These increases were not significantly different between EMS and CONV protocols.

The slope of the VO₂/WL relationship was decreased after EMS (–18.5%, p<0.05). This parameter was not significantly modified by CONV (–3.4%, p=0.9).

T₁/₂ of VO₂ was decreased after both training protocols (–14.1% after EMS and –19.7% after CONV, p<0.05). The training modality had no influence on this parameter.

Both training protocols induced significant improvements in the distance walked in 6 min (+13.8% in EMS and +16.5% in CONV, p<0.001). These increases were not significantly different between EMS and CONV protocols.

**Effects of exercise training in the subgroups.** As mentioned above, patients from each group were subdivided according to VO₂ at VT. Patients with VO₂ at VT < 11 ml/min/kg were allocated to the low exercise capacity group and those with VO₂ at VT > 11 ml/min/kg to the average exercise capacity group. Table III presents the number of patients in each subgroup and their baseline values measured for the symptom-limited exercise test and the 6-MWT. Fig. 1 presents the values of the PRE to POST ratios calculated for the different parameters measured during the symptom-limited exercise test (VO₂ peak, VO₂ at VT, slope VO₂/WL and T₁/₂) and for the distance in the 6-MWT.

After EMS (Fig. 1a), these ratios demonstrate that peak VO₂ (p<0.01), VO₂ at VT and 6-MWT distance were significantly increased both in average and low exercise capacity patients (p<0.05). However, VO₂/WL and T₁/₂ decreased significantly only in the low exercise capacity patients (p<0.05).

After conventional training (Fig. 1b), all patients demonstrated significant increases in peak VO₂, VO₂ at VT and 6-MWT distance (p<0.05), whereas only average exercise capacity patients demonstrated a significant improvement in T₁/₂. The slope VO₂/WL was not significantly modified by conventional training in either subgroup.

Comparison of the percentage increase in average vs low exercise capacity patients suggests greater improvements in all parameters in low exercise capacity patients compared with average exercise capacity patients after EMS; whereas after CONV VO₂ peak, slope VO₂/WL and T₁/₂ showed a greater improvement in average exercise capacity patients. However, there was no significant difference.

**DISCUSSION**

Programmes of physical activity, either aerobic and/or strength exercises, are used as supplemental treatment for patients with CHF (5). However, these interventions are usually only

Table III. Baseline data (mean (SD)) registered in the 4 subgroups

<table>
<thead>
<tr>
<th></th>
<th>EMS Average n = 10</th>
<th>Low n = 12</th>
<th>p-value</th>
<th>CONV Average n = 11</th>
<th>Low n = 11</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak VO₂, ml/kg/min</td>
<td>18.2 (2.3)</td>
<td>15.4 (3.1)</td>
<td>††</td>
<td>18.1 (2.6)</td>
<td>15.1 (2.8)</td>
<td>††</td>
</tr>
<tr>
<td>VO₂ at VT, ml/kg/min</td>
<td>12.6 (1.9)</td>
<td>9.5 (0.9)</td>
<td>††</td>
<td>12.4 (1.4)</td>
<td>9.8 (1.2)</td>
<td>*</td>
</tr>
<tr>
<td>VO₂/WL, ml O₂/W/min</td>
<td>10.7 (2.6)</td>
<td>9.1 (3.0)</td>
<td>††</td>
<td>9.5 (1.8)</td>
<td>8.8 (1.8)</td>
<td>–</td>
</tr>
<tr>
<td>T₁/₂ sec</td>
<td>92.4 (23.2)</td>
<td>128.8 (36.8)</td>
<td>††</td>
<td>112.1 (35.4)</td>
<td>120.4 (22.9)</td>
<td>–</td>
</tr>
<tr>
<td>Distance 6-MWT, m</td>
<td>441.1 (38.8)</td>
<td>421.7 (45.0)</td>
<td>–</td>
<td>460.0 (47.1)</td>
<td>425.8 (49.7)</td>
<td>–</td>
</tr>
</tbody>
</table>

**p-value, Average exercise capacity vs Low exercise capacity (Newman-Keuls post hoc): *p<0.05, †p<0.01.**

EMS: chronic heart failure patients under low-frequency electrical myostimulation rehabilitation programme; CONV: chronic heart failure patients under conventional rehabilitation programme; peak VO₂: oxygen uptake at the end of the symptom-limited cardiopulmonary exercise test; VO₂ at VT: oxygen uptake at the ventilatory threshold; VO₂/WL: slope of the oxygen uptake/workload relation above the ventilatory threshold; T₁/₂: time to recover half of peak VO₂; distance 6-MWT: distance in the 6-minute walk test.
Our results demonstrate increases of peak $\text{VO}_2$ by 12.2% and 16.8% after EMS and CONV, respectively (Table II). These results, in accordance with those of previous studies (8, 9, 22), are of great interest, as peak $\text{VO}_2$ is considered a main predictor of death (23). However, peak $\text{VO}_2$ needs to be considered with other indices. VT is an interesting and objective parameter that can be derived from submaximal exercise. Although controversy exists concerning the mechanisms determining VT, adaptations at the peripheral level must be involved (24, 25). Thus, the 15.4% and 17.4% increases of $\dot{\text{VO}}_2$ at the VT after EMS and conventional training are very interesting since both enhance the subjects’ capacity to perform sustained submaximal activities (25).

In the present experiment, we were particularly interested in the effects of both training protocols on the slope of the $\text{VO}_2$/workload relationship and its relation to the $T_{1/2}$ value. Indeed, it has been suggested that the lower the $\text{VO}_2$/workload slope value and the longer the $T_{1/2}$ value, the more severe is the CHF (26–30). The inverse correlation between exercise $\dot{\text{VO}}_2$/workload and $T_{1/2}$ value implies that CHF patients with a low $\dot{\text{VO}}_2$/workload during exercise were not efficient, but rather were accumulating a large oxygen debt that was repaid after the completion of exercise. Our results reveal a significant decrease in the $\dot{\text{VO}}_2$/workload slope after EMS and of $T_{1/2}$ after both protocols (Table II). These results are similar to those found in our previous study (10) and suggest that after only 5 weeks, EMS induces intramuscular changes improving $\dot{\text{VO}}_2$ kinetics (22). Indeed, if a decreased $\dot{\text{VO}}_2$/workload slope, per se, could be considered as an aggravation of the pathology (29), when accompanied by a faster recovery, it suggests that muscles are able to work harder with less oxygen and without accumulating debt that results in a longer recovery from exercise. This more efficient kinetics of oxygen uptake during exercise could be explained by EMS training-induced modification of the myotype (i.e. an increase in the relative distribution of type I myosin heavy chain isoforms and a decrease in type IIX myosin heavy chain isoforms (22)) since the motor recruitment pattern and percentage distribution of type IIX fibres are thought to be the main determinants of $\dot{\text{VO}}_2$ kinetics above the VT (14). For a given workload, type I fibres are more efficient than type IIX fibres in terms of oxygen requirement (14, 31).

Walk tests have recently been demonstrated to directly evaluate physical performance related to activities of daily living (32, 33). The present study found increased performance in the 6-MWT comparable to previous studies (8, 10), suggesting improved functional capacity. This result is very interesting, since it may relate to better autonomy, physical independence and increased quality of life for trained patients (34).

As suggested by Larsen & Dickstein (12), low-frequency EMS is a very attractive intervention, but it is necessary to identify the population most likely to benefit from it. The second aim of the present experiment was therefore to investigate the effects of both training modalities in patients differently deconditioned. The value of $\dot{\text{VO}}_2$ at VT, and more precisely, the critical value of 11 ml/min/kg (19, 20), has been identified previously as able accurately to separate patients by fitness. Indeed, we thought that it was the most objective and accurate parameter to evaluate the patients’ exercise capacities and to separate patients with average and low exercise capacities.

The results of this study show that the greatest improvements in all parameters after EMS occurred in patients with low exercise capacity. These results are not surprising regarding the
development of heart failure: the disease and the subsequent inactivity lead to deconditioning characterized by alterations at the peripheral level, such as skeletal muscle atrophy, changes of fibre-composition, reduced capillary density and reduced cytochrome oxidase activity (35, 36). Thus, a method mainly improving peripheral factors, such as EMS, seems to be of great interest and particularly effective to improve exercise capacities in low exercise capacity patients. Regarding patients with average exercise capacity, the results may be explained by an insufficient intensity of stimulation. Indeed, some patients reached the maximum intensity deliverable by the stimulator after only a few weeks and therefore trained during several weeks at a submaximal intensity. It is well known that EMS-induced benefits are related to the stimulation intensity and that at least 4 weeks at the maximal tolerable intensity are necessary to induce significant modifications of the myotopyology (increased transcription of myosin heavy chain-I and decreased transcription of myosin heavy chain-Ix) and the enzyme activity (increased oxidative potential) (37).

Our results also show that after conventional training, improvements in most parameters (VO2 peak, slope VO2/workload and Tp) were greater in patients with average exercise capacity. These results may also be due to the training intensity: in most patients from the low group, the exercise capacity at baseline did not allow training work rates in excess of approximately 40 W. As the patients were already accustomed to these intensities from activities of daily living, training at this level would probably have had only slight effects (e.g. 21). This could also explain the increased value of the slope VO2/workload obtained after conventional training in patients with low exercise capacity (whereas this parameter was decreased in patients with average exercise capacity). Indeed, as suggested above, the motor recruitment pattern and percentage distribution of type IIX fibres are thought to be the main determinants of VO2 kinetics above the VT (14). For a given workload, type I fibres are more efficient compared with type IIX fibres in terms of oxygen requirement (14, 31). While aerobic training performed at or above the VT induces an increase in skeletal muscles oxidative capacity (a shift from type II to type I fibres and an increase in total volume density of mitochondria, a lower training intensity is not sufficient to induce these modifications (38, 39).

Study limitations

One could argue that the results of this study are not new, since several groups have already reported similar findings (9–11). However, as mentioned above, there is a need for repetition of studies investigating the effects of this method in order to assemble a body of evidence regarding its effectiveness. The parameter chosen to separate average and low exercise capacity patients, i.e. VO2 at VT, may also be questionable. However, in regards of the literature, authors were of the opinion that this parameter is more accurate than peak VO2 (40), NYHA class or left ventricular ejection fraction (41, 42).

Conclusions about the effects of EMS and conventional training in the subgroups are based on comparisons of percentage increases for each parameter. A greater number of patients are needed to highlight statistical differences.

In conclusion, 5 weeks of low-frequency EMS or conventional aerobic exercise training induce similar beneficial effects on aerobic variables (assessed across the moderate to high workloads and during recovery), and on field test parameters in stable patients with CHF. These results therefore confirm that EMS is not only a good alternative to conventional rehabilitation, eliciting improvements of peripheral factors, but also an interesting new method, opening the door of rehabilitation to the most severely affected patients. However, due to the small number of patients in each subgroup (and thus the low statistical power of this study), caution should be applied when considering the results. An extension of this work would be to assess the effects of EMS in a larger population of patients with severe heart failure.

REFERENCES

1. Dickstein K, Aarsland T. Which patients with heart failure are likely to benefit from participation in an exercise training program? Heart Failure Rev 1999; 3: 283–286.


