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Effects of low frequency functional electrical stimulation with 15 and 50 Hz on muscle strength in heart failure patients

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Abstract

Purpose. To compare the acute effects of functional electrical stimulation (FES) with 15 and 50 Hertz (Hz) frequencies on muscle strength in patients with heart failure with healthy individuals.

Methods. Twenty-two 61.6 $\pm$ 1.0 y-old male volunteers were studied: 10 patients with heart failure (functional class II-III) and 12 healthy controls. The isometric muscle peak torque (IMPT) of the quadriceps femoral muscle was measured through a Biodex dynamometer in maximum voluntary contraction (MVC), and under FES of 50 Hz and 15 Hz, which was applied with a 0.4 ms pulse width, 10-s contraction time, 50- s resting time and maximum tolerable intensity.

Results. The IMPT differed in MVC, 50 Hz and 15 Hz FES both in patients (201.9 $\pm$ 14, 55.6 $\pm$ 13 and 42.1 $\pm$ 12 Newton-metre, respectively; $p < 0.001$) and in controls (179.3 $\pm$ 9, 62.4 $\pm$ 8 and 52.3 $\pm$ 7 Newton-metre, respectively; $p < 0.001$). There were no differences between the groups. In patients and controls, respectively, the 50 Hz FES corresponded to 27% *versus* 35% and the 15 Hz to 21% *versus* 29% of the IMPT generated at the MVC ($p < 0.001$).

Discussion. This result can be attributed to the fact that muscle strength is proportional to the stimulation frequency and to the number of recruited motor units. Thus, the higher the frequency, the greater the motor recruiting, producing increased muscle strength.

Conclusion. The IMPT generated by acute 50 Hz application of FES is higher than the one generated by 15 Hz, but it is lower than MVC in controls and patients with heart failure.

Keywords: *Functional, electrical stimulation, heart failure, muscle strength*

Introduction

The increase in heart failure prevalence has brought about high social and economic costs besides high morbid–mortality for patients with this disease [1]. Functional capacity limitation, commonly associated with reduced quality of life and poor prognosis, is a hallmark of the syndrome [2].

Muscle dysfunction is part of the heart failure syndrome [3], the strength of the skeletal muscle being reduced in these patients when compared with the healthy subjects [4]. It is well-known that the functional capacity limitation in heart failure is not solely a consequence of reduced myocardial contractility, but also a result of peripheral muscle changes that include decreased perfusion [5], reduced

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capillarity [6,7], fiber atrophy [8], transformation of slow-twitch type I to fast-twitch type II fibers [6,9] and changes in metabolic and nutritional status [10].

In patients with heart failure, reductions in the cross-sectional area of skeletal muscle fibers and in muscle strength are predictors of both exercise intolerance and patient's prognosis [7,11]. Physical training, inducing higher muscle strength, can be an integral part of the therapy in these patients [12]. However, some patients do not adapt themselves to conventional physical training, either because they give it up easily or because they have some kind of disability and cannot tolerate even low levels of physical efforts. Thus, functional electrical stimulation (FES) can represent a muscle training alternative for these patients because of its potential beneficial effects [13], such as the increase of maximum oxygen consumption [14], muscle mass (type I fibers), oxidative enzyme levels [15], endothelial function improvement [16] and better performance in functional tests [17,18].

Previous studies have shown that muscle strength and resistance will increase in the lower muscle limbs after a FES programme, both in healthy [19] and sick individuals [20,21]. The stimulation frequency needed to stimulate some types of fibers promoting muscle contraction was variable. In individuals with medullar lesions, frequencies between 10 and 20 Hertz (Hz) were shown to stimulate slow type I fibers, while frequencies between 30 and 60 Hz stimulated fast type II fibers [20]. In healthy individuals, frequencies between 7 and 25 Hz stimulate type I fibers and frequencies between 35 and 65 Hz stimulate type II fibers [19].

Besides, it is also known that type II fibers are those that produce a higher level of muscle strength, but generate a higher level of muscle fatigue [15]. We decided to analyse the effect of the 15 Hz and 50 Hz frequencies on muscle contractility because there are no studies on the acute effect of applying FES comparing these two frequencies and no study evaluated how much maximum strength is produced with these two stimulation frequencies in patients with heart failure, because these frequencies stimulate different types of muscle fibers. Thus, the aim of this study was to compare the acute effects of FES with frequencies of 15 and 50 Hz upon muscle strength in patients with heart failure and healthy individuals.

Methods

Participants

Ten patients with heart failure, aged 61.4 ± 1.8 (HF) and 12 healthy volunteers aged 61.8 ± 1.1 (C), paired by age, were evaluated. The study was previously approved by the Ethical Research Committee of the Institute of Cardiology of Rio Grande do Sul – University Foundation of Cardiology (no. 4035/07) and of the University of Passo Fundo (no. 210/2007), in agreement with the attributions defined in resolutions 196/96 and complementary ones of the National Council of Ethics in Health. After the protocol approval, a written informed consent was signed by all volunteers.

The inclusion criteria in the HF group were: to have a clinical diagnosis of class II or III heart failure according to the New York Heart Association (NYHA), ejection fraction less than 40% determined by echocardiography and no change in the medication therapy for at least 1 month before being included in the study. Subjects of the control group did not have any neurological or orthopaedic disease and had not practiced any regular physical activity for at least 6 months before being included in the study. The exclusion criteria were acute myocardial infarction 3 months before the inclusion in the study, presence of acute inflammatory diseases, peripheral vascular disease, neurologic disease, unstable angina, diabetes mellitus, chronic renal failure, musculoskeletal pathologies, an implanted cardiac pacemaker or being an active smoker.

Research design

The study was carried out in the Biomechanics Laboratory of the College of Physiotherapy and Physical Education of the University of Passo Fundo, Rio Grande do Sul State, Brazil.

The responsible evaluator remained masked in relation to the clinical diagnosis of the subjects. Patients with heart failure were selected at São Vicente de Paulo Hospital and at The Passo Fundo City Hospital, from December 2007 to February 2008, based on the results of the echocardiography exams and on the information of their medical records. Healthy subjects were selected by oral invitation in the same period, and were paired according to age, weight and height.

Patients underwent the FES application and were evaluated referring to the isometric muscle peak torque (IMPT) in three situations: maximum voluntary contraction (MVC), in the contraction provoked by the exclusive use of FES with 50 Hz frequency and in the contraction provoked by the exclusive use of FES with 15 Hz frequency. Systolic blood pressure and diastolic blood pressure were measured while resting (pre) and soon after (post) each situation [22], using the Missouri Blood Pressure Equipment – metal zipper/adult and the

BD stethoscope – Duosonic/adult, Juiz de Fora, Minas Gerais, Brazil.

The perimeter of the dominant thigh was measured every 5 cm from the upper patella border in the proximal direction.

Evaluation of the isometric muscle peak torque

Each participant was provided a 5-min warm-up (active stretching of the extensor and flexor musculature of the knee) prior to performing the test. The IMPT of the femoral quadriceps of the dominant limb was analysed by computerised dynamometry, Multi Joint System3 Pro equipment, Biodex trend mark, Shirley, New York.

The inclination of the chair of the equipment was 85° and the axis of rotation of the dynamometer was aligned to the lateral femoral epicondyle of the tested limb, and this was extended from 90 to 0° to ensure that the axis of the knee rotation was aligned to the axis of the dynamometer rotation. In order to limit the knee movement, preventing other parts of the body from being used as compensation, the test was performed with the subject sitting, with belts positioned on the main body, in the pelvic region, crossing at the iliac antero–superior spine, around the thigh of the lower contralateral limb and at the ankle of the dominant leg 2 cm above the medial malleolus. The 60° position of knee flexion was chosen because, according to the literature, it is at this angle that maximum strength is produced by the femoral quadriceps muscles [23]. The torque produced by the weight of the limb was recorded in the computer programme with the tested limb in the resting position and in movement to correct gravity, before the beginning of the evaluations. For each test, a prior calibration was performed [24,25].

After positioning the individual appropriately, the amplitude of the maximum stimulus (intensity) that could be tolerated during FES application was determined. The subject position was individually adjusted before evaluation, taking into account the participants' capability to promote a complete knee extension movement and their sensation of comfort. This measure was taken with the patient sitting on the dynamometer chair, positioned as previously described. Auto-adhesive electrodes (Spes – 50 × 90 mm, Italy) were placed on the thigh approximately 5 cm below the inguinal fold, 5 cm above the upper patella border and in the vastus medial muscle, at the position of the medial femoral condyle. Before the electrodes were applied, the skin was properly cleaned by using cotton soaked in 70% alcohol in the coupling region.

Functional electrical stimulation

The FES was applied using equipment granted by the Orthopedics and Traumatology Institute of the Medical School of the University of São Paulo (Electrical Physiological Stimulator – LYNX – FMUSP, São Paulo, Brazil).

Each electrically stimulated contraction lasted 10 s (TON: 10 s), with 50 s resting intervals (TOFF: 50 s), which resulted in one contraction per minute. The stimulation time was 6 min, resulting in a total of six contractions at each FES application. Pulse width used was 0.4 milliseconds (ms), the current intensity (mA) was individually adjusted until the pain threshold of the evaluated patients. Between each FES application, patients remained in the same position as described above, and obeyed the following order: (1st) application of FES with 15 Hz frequency; (2nd) application of FES with 50 Hz frequency; during each contraction time (TON: 10 s) of the described applications, participants were advised to relax and let the stimulator perform the muscle contraction by itself; (3rd) MVC realisation in each contraction had a 10 s-duration followed by a 50 s intercalated resting period, totalising six contractions. During each contraction time, the participant received verbal feedback from the evaluator consisting of the researcher giving verbal commands encouraging the subject to push (knee extension) throughout the muscle contraction.

Maximum isometric muscle strength was defined as the peak of the highest torque (in Newton-metre [Nm]) by each application. This variable was used to determine if there were differences between applications and which of them was responsible for producing the highest torque peak.

The sample was calculated based on the α error rates of 5% and the β error of 80%, assuming a difference in the maximum strength of 25 Nm among the groups with a standard deviation of 20 Nm [11], resulting in a sample of 10 individuals for each group.

Statistical analysis

Distribution of variables was tested through tests of normality (Kolmogorov–Smirnov and Shapiro–Wilk). Continuous variables with symmetrical distribution were expressed as mean ± standard error. Student's *t*-test was used to compare two groups for the symmetrical data. For the variables measured more than two times, the analysis of variance repeated measures was used, followed by the Bonferroni test. For possible correlations between the studied variables, the pearson correlation coefficient was used. A $p < 0.05$ was considered statistically significant.

The SPSS version 15.0 software was used for the statistical analysis.

Results

Individuals of both groups presented similar anthropometric and hemodynamic characteristics (Table I). In the HF group, 60% of the patients presented functional NYHA class II and 40% functional NYHA class III. Their mean ejection fraction was 31.9 $\pm$ 1.9%. There was no change in the medication of patients during the evaluation period. Therefore, 68% of the patients with heart failure presented an ischaemic aetiology, and 32% a non-ischaemic one.

Figure 1 shows the data of the IMPT evaluation, which showed a difference between MVC, FES of 50 Hz and of 15 Hz both in the HF group ($p < 0.001$), and in the C group ($p < 0.001$). However, no difference was seen in the groups (MVC: $p = 0.204$, FES 50 Hz: $p = 0.665$ and FES 15 Hz: $p = 0.471$). The 50 Hz FES corresponded to 27% and the 15 Hz to 21% of the IMPT generated at the MVC, respectively ($p < 0.001$). The 50 Hz FES determined an IMPT 24% higher than that obtained with 15 Hz ($p = 0.026$) in the HF group. In the C group, the 50 Hz FES corresponded to 35% and 15 Hz to 29% of the IMPT generated at the MVC, respectively ($p < 0.001$). The 50 Hz FES determined an IMPT 16% higher than that obtained with 15 Hz FES ($p = 0.049$).

The intensity tolerated during the FES application with 15 Hz frequency was approximately 10% higher than that tolerated during the 50 Hz application in both groups ($p = 0.015$ for HF group and $p = 0.011$ for C group). However, there was no difference in this variable between HF and C groups (FES 50 Hz: $p = 0.946$ and FES 15 Hz: $p = 0.789$) (Figure 2). There was no correlation between the IMPT generated by 15 Hz and 50 Hz FES application and the respective intensities (mA) tolerated by the subjects in both groups (IMPT and FES (mA) 15 Hz: $r = 0.40$ $p = 0.07$; IMPT and FES (mA) 50 Hz: $r = 0.28$ $p = 0.20$).

Systolic and diastolic blood pressures were not different before and after performing MVC and FES application with 15 and 50 Hz in both groups studied.

There was a positive correlation between IMPT and weight ($r = 0.76$, $p = 0.01$), IMPT and body mass index ($r = 0.80$, $p = 0.005$) and IMPT and upper patellar perimeter of 5 cm ($r = 0.68$, $p = 0.03$) and 10 cm ($r = 0.74$, $p = 0.01$) in the HF group (Table II). There was no correlation between IMPT and systolic or diastolic blood pressure in this group. The same correlations were non-significant when performed for the subjects in the C group.

Discussion

In this study comparing the acute effects of different electro stimulation frequencies in patients with heart failure, the main findings were the demonstration that IMPT generated by FES application with 50 Hz frequency is greater than the one produced by 15 Hz FES and that both are inferior to the IMPT produced by MVC. Similar results were obtained in control subjects.

In this work, we chose to study the frequencies of 15 Hz and 50 Hz in patients with heart failure, because studies in other populations showed that low frequencies (up to 25 Hz) stimulate mainly the oxidative type I fibers and that frequencies above 30 Hz stimulate predominantly the glycolytic type II fibers [19,26]. Besides, it is also known that type II fibers are those that produce a higher level of muscle

Table I. Baseline data of the studied subjects.

	HF group ($n = 10$)	C group ($n = 12$)	p-value
Age (years)*	61.4 $\pm$ 1.8	61.8 $\pm$ 1.1	0.84
Length (m)*	1.7 $\pm$ 0.0	1.7 $\pm$ 0.0	0.94
Weight (kg)*	90.4 $\pm$ 4.0	84.6 $\pm$ 4.1	0.32
BMI (kg/m^2)*	29.9 $\pm$ 0.9	28.1 $\pm$ 1.1	0.22
SBP MVC (mmHg)*	127.4 $\pm$ 10.1	136.7 $\pm$ 8.0	0.48
DBP MVC (mmHg)*	79.2 $\pm$ 3.9	84.2 $\pm$ 4.0	0.39
SBP FES 50 Hz (mmHg)*	129.8 $\pm$ 7.9	136.7 $\pm$ 7.8	0.54
DBP FES 50 Hz (mmHg)*	77.7 $\pm$ 3.9	84.2 $\pm$ 4.0	0.26
SBP FES 15 Hz (mmHg)*	135.8 $\pm$ 9.3	142.5 $\pm$ 6.5	0.56
DBP FES 15 Hz (mmHg)*	80.8 $\pm$ 3.9	85.8 $\pm$ 4.4	0.40

Values are presented as mean $\pm$ standard error.
HF, heart failure; C, control; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; MVC, maximum voluntary contraction; FES, functional electrical stimulation.
*Student's t-test.

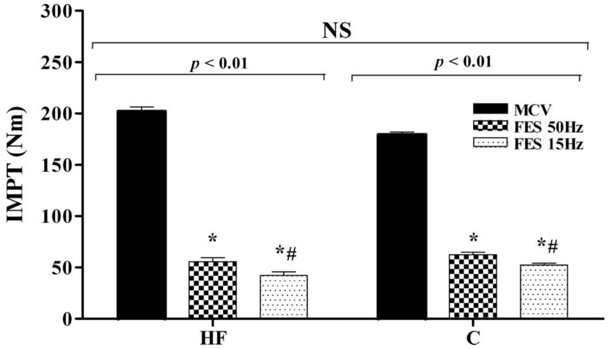

Figure 1. Isometric muscle peak torque (IMPT) in the HF group and C group. MVC, maximum voluntary contraction; FES 50 Hz, functional electrical stimulation with 50 Hz frequency; FES 15 Hz, functional electrical stimulation with 15 Hz frequency. Analysis of variance followed by the Bonferroni test. NS, non-significant; $^{*}p < 0.01$ MCV *vs.* FES 50 Hz and FES 15 Hz; $^{\#}p < 0.05$ FES 50 Hz *vs.* FES 15 Hz.

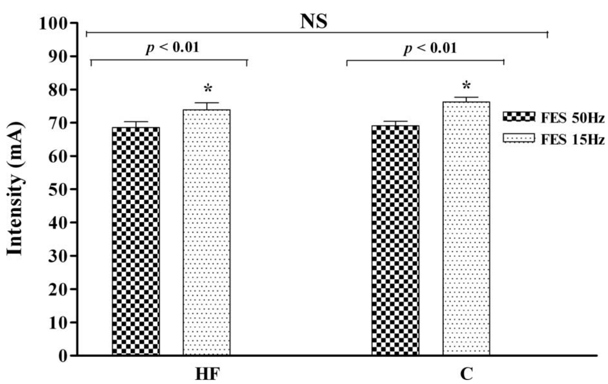

Figure 2. Supported intensities in the studied groups, HF group and C group. FES 50 Hz, functional electrical stimulation with 50 Hz frequency; FES 15 Hz, functional electrical stimulation with 15 Hz frequency. Analysis of variance followed by the Bonferroni test. NS, non-significant; $^{*}p < 0.01$ *vs.* FES 15 Hz.

Table II. Correlations between maximum voluntary contraction and anthropometric variables in the HF group.

Variables	*r*	*p*-value
MVC × Weight (kg)	0.7643	0.010*
MVC × BMI (kg/m^2)	0.8084	0.005*
MVC × perimeter 5 (cm)	0.6835	0.029*
MVC × perimeter 10 (cm)	0.7422	0.014*
MVC × perimeter 15 (cm)	0.5943	0.070
MVC × abdominal circumference	0.6053	0.064

r = Pearson Correlation.
$^{*}p<0.05$.
HF, heart failure; MVC, maximum voluntary contraction; BMI, body mass index.

strength, but generate a higher level of muscle fatigue [15]. We decided to analyse the effect of these two stimulation frequencies on muscle contractility since there are no studies on the acute effect of applying FES comparing these two frequencies in patients with heart failure.

A 50 Hz FES determines a greater IMPT than a 15 Hz FES. This result is attributable to the fact that muscle strength is proportional to the stimulation frequency and to the number of recruited motor units. Thus, the higher the frequency, the greater the motor recruiting, producing increased muscle strength [27]. In a study carried out in individuals with chronic obstructive pulmonary disease it was observed that after a 6-week training using a 50 Hz FES frequency, there was an increase in type II fiber and a decrease in type I fibers [28]. It is important to mention that type II fibers are classified as fast contraction fibers and have a lower excitability threshold [15], being activated by the use of electrical stimulation [29], offering a more efficient gain in muscle strength [15]. Patients with heart failure present an increase in type II fibers and a decrease in type I fibers [7], and this may have contributed to the results found in the present study.

It is possible that FES effects upon motor units selected depend on the electro stimulation frequency [30]. With a frequency of less than 20 Hz the work is directed toward type I fibers [15], which present very effective muscle contractions, being executed at a low metabolic cost, decreasing muscle fatigue [31]. With electro stimulation between 35 and 70 Hz it is possible to work on the fast fibers – type II [31]. This offers the possibility to work strength gain using selective muscle stimulation [32] that may be advantageous when the objective is to work specific muscle fibers, like the aerobic ones, which are decreased in patients with heart failure [7,18].

Quittan et al. [33] evaluated the effect of FES on muscle strength and resistance in seven patients with heart failure (class II and III) using 50 Hz frequency for 8 weeks, demonstrating an increase in both muscle strength and resistance of the lower limbs of treated individuals [33]. These results were confirmed in a subsequent study [32] that also analysed a heart failure control group receiving electro stimulation that did not produce muscle contraction. In this study, the authors have also observed a 15% increase of the transverse region of the thigh in the FES group, and 15% in the control group. These adaptations may improve the patients with heart failure' quality of life. The use of FES with a 15 Hz frequency, 4 h/day, 20 to 30% of the maximum force/10 weeks was evaluated by other authors [15], also in patients with heart failure, showing an increased muscle mass of the lower limbs, mainly type I fibers (20%), with reduction of type II fibers (−20%). There was also an improvement in the maximum oxygen consumption ($V0_2$ max) (+21%) and in the 6-min walking test performance (31%), which was different from the control group that received electro stimulation but without producing muscle contraction, presenting a decrease in type I fibers (−5%) and $V0_2$ max (−11%), demonstrating that besides preventing muscle atrophy, FES improves physical performance in patients with heart failure.

The difference between the IMPT generated by 15 and 50 Hz frequency application and the one produced by MVC as observed in this study was the same observed in healthy subjects that undergone 20, 50 and 100 Hz FES frequencies. The MVC torque percentages were 63%, 84% and 88%, respectively [30]. The results indicate that a fast increase in muscle torque occurs even with small frequency changes and that, after a recruiting plateau is reached, torque variations are minimal, even if the frequency remains high [30]. Other studies that compared electrical stimulation with MVC in healthy subjects have demonstrated that the contraction obtained by isolated electro stimulation use applied to the quadriceps musculature does not exceed the maximum voluntary isometric contraction in the same individuals. The percentage values of these torques vary from 20%, 25% [34] to 90% of the MVC [35], and may vary due to the stimulation frequency. According to Kramer et al. [36], individuals who underwent electrical stimulation obtained a muscle contraction around 53% when compared to the maximum performed contraction, and those who performed an isometric contraction of the same muscle group obtained a contraction of approximately 93% when compared to the maximum contraction. Another study did not show any significant differences regarding muscle strength gain, which was 22–18%, respectively [37], when compared with the FES efficacy versus isometric exercise in the strengthening of the femoral quadriceps for a 5-week training period.

The intensity of the current tolerated by the subjects with FES application was similar between groups and there was no correlation between this variable and the generated IMPT, which was also observed by other authors [37]. It is possible that certain individuals are more apt than others to receive effective electrical stimulation, probably because of anatomical differences and factors related to tissue impedance [34]. Such factors, like the differences in body fat, may contribute to the lack of correlation between the intensity and the muscle torque, since fat acts as an insulating material, increasing impedance to an electrical current passage through the tissues.

A positive correlation observed between IMPT generated in MVC with anthropometric variables such as weight, body mass index (BMI) and upper patellar perimeter of 5 to 10 cm in patients with heart failure has also been demonstrated, although no correlation could be found with haemodynamic variables. Similar results were observed by Opasich et al. [3] in patients with heart failure: muscle strength was not related to the clinical severity indexes, metabolic status, neural-hormones or systolic or diastolic cardiac dysfunction, but rather to weight, age, muscle strength and NYHA functional class. Other authors [4], using an isokinetic dynamometer to evaluate the skeletal muscle strength of the femoral quadriceps and the brachial biceps in patients with heart failure, obstructive chronic pulmonary disease and healthy individuals observed that the free fat mass of the patients was smaller than that in control healthy subjects, being correlated with the force of the quadriceps and biceps in the three studied groups, concluding that the free fat mass is a strong indicator of muscle peripheral strength. Another study also demonstrated a positive correlation between the cross-sectional area and the isometric muscle strength of the leg extensor muscles in patients with heart failure [32].

There are some limitations related to this study. First, the methodology used was limited because there were no biological parameters included in the design of the study able to clarify some mechanisms concerning the role of FES in generating IMPT. In addition, the number of patients studied was low (22 patients), so caution should be applied when considering the results. Further investigations should yield more detailed data, including information about possible interactions between central and peripheral cardiovascular mechanisms during muscle stimulation. Clinical trials in larger groups of patients will be needed before fully utilising FES in cardiovascular rehabilitation.

Conclusions

This study showed that the IMPT generated by the acute application of 50 Hz FES is greater in relation to a 15 Hz FES, but inferior in relation to MVC in patients with heart failure. The FES is capable of producing uniform muscle contractions and may be an adequate technique for the treatment of patients unable to perform voluntary contractions, also allowing the selective recruitment of muscle fibers, thus optimising the treatment of these patients.

Declaration of interest

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