

Neuromuscular electrostimulation in patients with heart failure: a systematic review with meta-analysis

Eletoestimulação neuromuscular em pacientes com insuficiência cardíaca: uma revisão sistemática com metanálise

Aline de Sousa Nassif , Fernanda Lobo de Jesus Brito , Gilmara Santa Rosa Santos ,
André Luiz Lisboa Cordeiro 

1. Centro Universitário Nobre, Feira de Santana, BA, Brazil

ABSTRACT

Introduction: Chronic Heart Failure (CHF) occurs when the heart is unable to meet the body's demands adequately, resulting in reduced blood flow. The patient experiences dyspnea, fatigue, and an inability to perform exercises that require greater effort. Neuromuscular electrostimulation (NMES) has been used as a treatment to increase muscle strength, functional capacity, and quality of life. **Objective:** To review the effectiveness of NMES on muscle strength, quality of life, and functional capacity in patients with heart failure. **Methods:** This is a systematic review using the PICO strategy, with searches conducted in the PUB-MED, SciELO, and LILACS databases using the descriptors: heart failure, transcutaneous electrical nerve stimulation, quality of life, muscle strength, and functional status, combined with the boolean operators 'AND' and 'OR'. **Results:** Eighteen studies were included after selection. NMES showed no statistically significant difference on the functional capacity outcome (difference between means 12.06 meters; 95% CI, -2.55 to +26.66), but there was a statistically significant difference in quality of life (difference between means 4.20 points; 95% CI, 2.79 to 5.62). The studies showed superiority in muscle strength for patients with CHF who were exposed to NMES. **Conclusion:** Neuromuscular electrostimulation can safely be implemented in patients with heart failure, positively impacting quality of life and muscle strength, but without affecting functional capacity.

Keywords: heart failure; transcutaneous electrical nerve stimulation; quality of life; muscle strength; functional status

RESUMO

Introdução: A insuficiência cardíaca crônica (ICC) ocorre quando o coração se torna incapaz de atender adequadamente às demandas do organismo, levando à redução do fluxo sanguíneo. O paciente apresenta dispneia, fadiga e incapacidade de realizar exercícios que exigem maior esforço. A eletroestimulação neuromuscular (EENM) tem sido utilizada como tratamento para aumentar a força muscular, a capacidade funcional e a qualidade de vida. **Objetivo:** Revisar a efetividade da eletroestimulação neuromuscular sobre força muscular, qualidade de vida e capacidade funcional em pacientes com insuficiência cardíaca. **Métodos:** Trata-se de uma revisão sistemática utilizando a estratégia PICO, com buscas realizadas nas bases de dados PUBMED, SciELO e LILACS, utilizando os descritores: insuficiência cardíaca, estimulação elétrica nervosa transcutânea, qualidade de vida, força muscular e estado funcional, combinados pelos operadores booleanos "AND" e "OR". **Resultados:** Dezoito estudos foram incluídos após o processo de seleção. A EENM não demonstrou diferença estatisticamente significativa no desfecho capacidade funcional (diferença entre médias de 12,06 metros; IC 95%, -2,55 a +26,66), porém houve diferença estatisticamente significativa para qualidade de vida (diferença entre médias de 4,20 pontos; IC 95%, 2,79 a 5,62). Os estudos demonstraram superioridade na força muscular em pacientes com ICC submetidos à EENM. **Conclusão:** A eletroestimulação neuromuscular pode ser implementada com segurança em pacientes com insuficiência cardíaca, impactando positivamente a qualidade de vida e a força muscular, porém sem efeito sobre a capacidade funcional.

Palavras-chave: insuficiência cardíaca; estimulação elétrica nervosa transcutânea; qualidade de vida; força muscular; estado funcional

Introduction

Heart failure (HF) is a clinical condition characterized by the heart's inability to pump blood efficiently, leading to symptoms such as fatigue, dyspnea, and fluid retention. According to McMurray et al. [1], the prevalence of HF has been increasing globally due to population aging and the improved survival of patients with cardiovascular diseases. Despite therapeutic advances, HF is still associated with high morbidity and mortality rates, necessitating the exploration of alternatives capable of improving patients' quality of life. Cardiovascular rehabilitation has established itself as an important approach, and neuromuscular electrical stimulation (NMES) has emerged as a promising intervention to optimize the muscular and functional performance of patients with HF [2].

NMES uses electrical stimuli to induce muscle contraction and improve muscle strength and endurance in individuals with neuromuscular dysfunction. In patients with HF, peripheral muscle function is often compromised due to chronic physical deconditioning, resulting in reduced functional capacity [3]. According to Barlow et al. [4], NMES has shown potential in the rehabilitation of skeletal muscle—particularly in the lower limbs, which are most affected by HF. This therapeutic modality is capable of stimulating both slow- and fast-twitch muscle fibers, thereby promoting improved muscle trophism and reducing the risk of atrophy [5].

Recent studies demonstrate that NMES can improve muscle strength, exercise tolerance and quality of life in patients with heart failure [6,7]. The combination of NMES with cardiovascular rehabilitation programs has been shown to be effective in optimizing outcomes related to the functionality and global physical health of these patients [7]. However, there are still disagreements regarding the most appropriate stimulation protocol, including frequency, intensity and duration of treatment. Among these parameters, therapeutic individualization seems to be an essential factor to maximize the benefits of the intervention [8].

Based on current evidence, it is expected that the findings will provide support for the integration of NMES into the clinical practice of cardiovascular rehabilitation, offering more effective therapeutic alternatives for this population [9,10]. Given this scenario, the present systematic review aims to evaluate the effectiveness of neuromuscular electrical stimulation on muscle strength, quality of life and functional capacity in patients with heart failure.

Methods

Study type and registration

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [11]. The article was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under number CRD42025637595.

Eligibility criteria

This systematic review used the PICOS strategy [12]. The study population was made up of patients with heart failure undergoing neuromuscular electrical stimulation. The control group consisted of patients who did not undergo electrical stimulation. The outcomes evaluated were related to muscle strength, quality of life and functional capacity. Randomized clinical trials were included, without restrictions on language or year of publication.

Information sources

An electronic search was carried out in the databases Web of Science, Latin American and Caribbean Literature in Health Sciences (LILACS), PubMed, Cochrane Central Register of Controlled Trials (CENTRAL) and OVID. Additionally, the reference lists of previous systematic reviews and clinical trials eligible for this review were examined. The search for articles was completed in November 2024.

Search

The search was based on the previously described PICOS strategy and the boolean operators AND and OR. The search strategy used in PubMed is presented in Chart 1.

Chart 1 - Search strategy

("Heart Failure"[Mesh] OR "heart failure"[tiab] OR "cardiac failure"[tiab] OR "congestive heart failure"[tiab]) AND ("Electric Stimulation Therapy"[Mesh] OR "neuromuscular electrical stimulation"[tiab] OR "NMES"[tiab] OR "electromyostimulation"[tiab] OR "muscle electrical stimulation"[tiab]) AND ("Muscle Strength"[Mesh] OR "muscle strength"[tiab] OR "muscle force"[tiab] OR "Quality of Life"[Mesh] OR "quality of life"[tiab] OR "Exercise Tolerance"[Mesh] OR "functional capacity"[tiab] OR "exercise capacity"[tiab]) AND ("Randomized Controlled Trial"[Publication Type] OR "randomized"[tiab] OR "randomised"[tiab])

Study selection

This systematic review included randomized controlled trials involving patients with heart failure. To be eligible, clinical studies had to allocate patients with heart failure to treatment with neuromuscular electrical stimulation. Studies involving participants of both sexes were also included.

Neuromuscular electrical stimulation (NMES) consists of the application of low or medium frequency electrical current through electrodes positioned on the skin, with the aim of stimulating a specific muscle. Studies involving other types of interventions combined with NMES were excluded.

Data collection process

The extraction of selected articles went through the following stages: screening of titles (first stage), analysis of abstracts (second stage) and reading of full texts (third stage). Subsequently, an exploratory reading of the selected studies was carried out, followed by a selective and analytical reading. The data extracted from

the articles were synthesized according to authors, periodical, year of publication, title and conclusions, aiming to gather relevant information for the research.

The methodological quality of the studies was assessed by three independent reviewers. When disagreements arose, the article was read in full for reassessment. If disagreement remained, a fourth reviewer evaluated the study and made the final decision.

Data items

Two authors independently extracted data from the published reports using a standard data extraction method, considering the following aspects:

1. Study population characteristics, such as mean age, sex, number of patients, and diagnosis;
2. Intervention details, including sample size, type of neuromuscular electrical stimulation, presence of supervision, intensity, frequency, and duration of each session;
3. Follow-up;
4. Loss to follow-up;
5. Outcome measures;
6. Reported results.

Quality of each study

The methodological quality of the studies was assessed using the PEDro scale [13], an instrument widely used to analyze the methodological quality of randomized clinical trials in health research. The scale is composed of 11 criteria that evaluate aspects related to the methodological design and risk of bias, including eligibility criteria, random allocation, allocation concealment, initial comparability between groups, blinding of participants, therapists and evaluators, adequate follow-up, analysis by intention to treat, comparisons between groups and presentation of specific and variability measures. Each item receives a score of presence (1) or absence (0), with a maximum score of 10 points, since the first item, referring to the eligibility criteria, is not counted in the final score. The methodological assessment was carried out independently by the reviewers, allowing the analysis of the methodological robustness and internal quality of the studies included in this systematic review

Synthesis of results

The presence of heterogeneity was evaluated using the X² test and the I² statistic. This statistic illustrates the percentage of variability in effect estimates from heterogeneity rather than sampling error.

Statistical assessment

The difference between group means and their respective 95% confidence intervals were calculated and used to quantify the effect of continuous outcomes. In meta-analyses in which studies used the same assessment scales, results were presen-

ted as mean difference (MD) and 95% confidence intervals. In cases where different scales were used, the effects were calculated using the standardized mean difference (SMD) and respective 95% confidence intervals. The effect size of the interventions was defined as small if $DM < 10\%$ of the scale or $DMP < 0.4$, moderate if $DM = 10\%$ to 20% of the scale or $DMP = 0.41$ to 0.7 , or large if $DM > 20\%$ of the scale or $DMP > 0.7$.

Results

Study selection and characteristics

According to the data presented in the study selection flowchart (Figure 1), the database search identified a total of 1,980 articles, 43 of which were duplicates. Initially, 1,870 studies were excluded after screening titles and abstracts. Subsequently, after reading the full texts, 49 articles were excluded because they combined neuromuscular electrical stimulation (NMES) with other interventions. Thus, 18 studies met the eligibility criteria and were included in this systematic review.

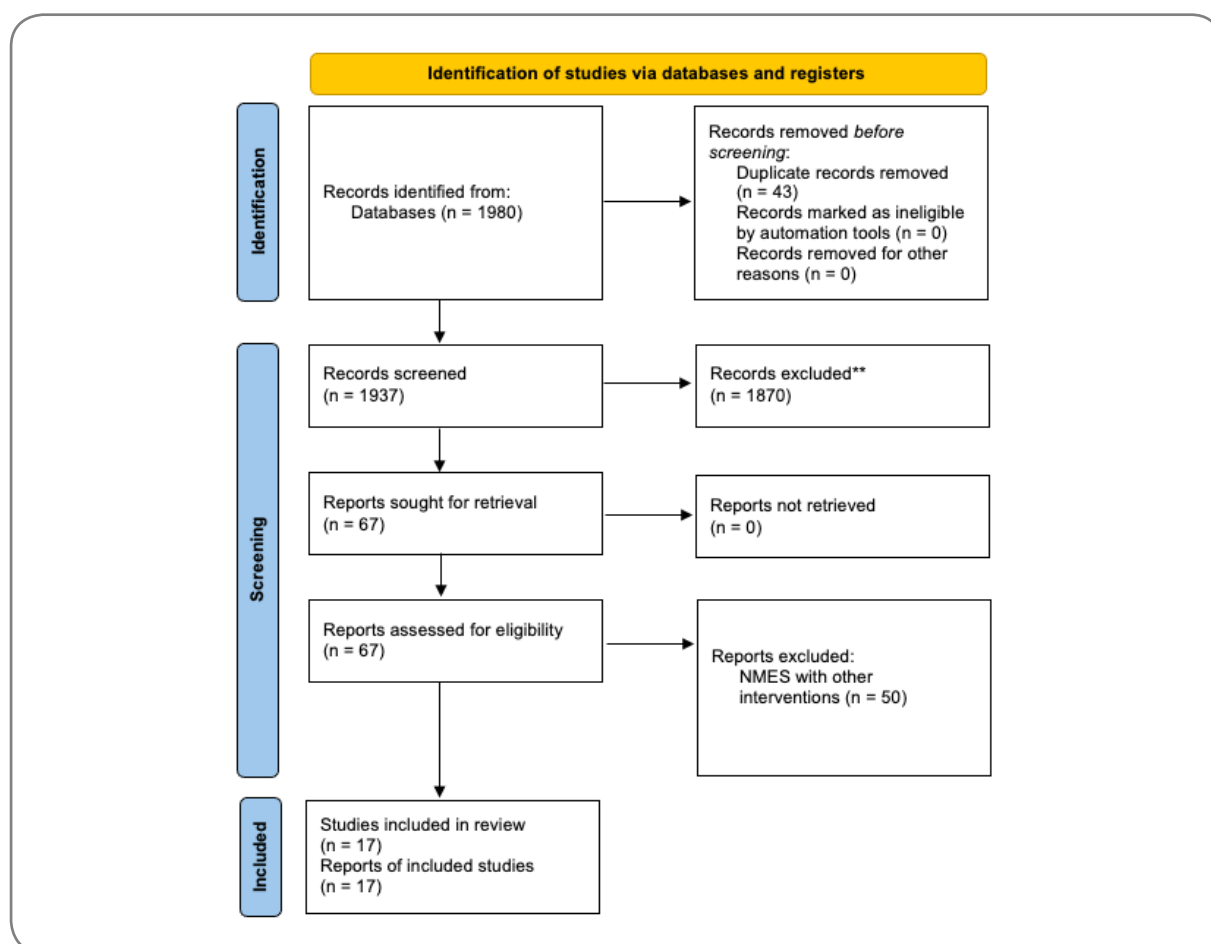


Figure 1 – Flowchart for study selection

Methodological quality results

According to the PEDro scale, six studies were rated as having low methodological quality, eleven as moderate, and two as high. The criteria evaluated by the PEDro scale, and the scores obtained by each study are presented in detail in Table I.

Table I - Classification of articles on the PEDro Scale

	1	2	3	4	5	6	7	8	9	10	11	Total
Dobšák <i>et al.</i> [14]		X		X						X	X	4
Deley <i>et al.</i> [15]		X		X				X		X	X	5
Deley <i>et al.</i> [16]		X		X						X	X	4
Eicher <i>et al.</i> [17]		X									X	2
Harris <i>et al.</i> [18]		X		X				X		X	X	5
Karavidas <i>et al.</i> [19]		X		X			X	X		X	X	6
Araújo <i>et al.</i> [20]		X	X	X			X	X		X	X	7
Banerjee <i>et al.</i> [21]		X								X	X	3
Karavidas <i>et al.</i> [22]		X		X			X			X	X	5
Karavidas <i>et al.</i> [23]		X		X			X	X		X	X	6
Nuhr <i>et al.</i> [24]		X	X	X				X		X	X	6
Quittan <i>et al.</i> [25]		X		X			X			X	X	5
Groehs <i>et al.</i> [26]		X		X			X	X			X	5
Sacilotto <i>et al.</i> [27]		X		X				X	X	X	X	6
Kucio <i>et al.</i> [28]		X	X	X				X		X	X	6
Forestieri <i>et al.</i> [29]		x	x	x			x			x	x	6
Kadoglou <i>et al.</i> [30]		x		x						x	x	4
Ennis <i>et al.</i> [31]		x	x	x	x		x		x	x	x	8

PEDro Scale Items: 1) Eligibility criteria were specified (*- This item is not used to calculate the PEDro score); 2) Subjects were randomly allocated to groups; 3) Allocation of subjects was concealed; 4) Groups were initially similar with regard to important prognostic indicators; 5) All subjects were blinded to the study; 6) All therapists who administered the therapy were blinded; 7) All assessors who measured at least one key outcome were blinded; 8) Measurements of at least one key outcome were obtained from more than 85% of subjects originally allocated to groups; 9) All subjects for whom outcome measurements were presented received the treatment or control condition as allocated, or if this was not the case, the data were analyzed for at least one outcome using intention-to-treat analysis; 10) Results of between-group statistical comparisons were reported for at least one key outcome; 11) The study presents both measures of precision and measures of variability for at least one key outcome. Methodological Quality Classification: a. High methodological quality; b. Moderate methodological quality; c. Low methodological quality.

Participants

A total of 292 patients received the intervention in the studies included in this review. The participants' ages ranged between 18 and 66 years old, with a predominance of males, representing 195 individuals (66%) of the total sample. Other demographic and clinical data are presented in Table II.

Table III presents the main parameters used for the application of neuromuscular electrical stimulation (NMES) in the studied population

Table II – Summary of the characteristics of the articles analyzed

Author / Country Year	Sample	Participants	Control	Intervention	Mensure	Results
Deley et al. 2008 [15]	EUA	44	Patients with stable chronic heart failure	Conventional aerobic training programmes.	5 weeks of exercise training with electrical myostimulation (EMS)	Functional capacity Both training protocols induced significant improvements in the distance walked in 6 min (+ 13.8% in EMS and + 16.5% in control, $p < 0.001$).
Dobšák et al. [14]	Czech Republic.	30	Patients with stable chronic heart failure, NYHA class II-III	8 weeks of exercise bicycle training	8 weeks of home-based low-frequency electrical stimulation (LFES)	Functional capacity and quality of life Distance walked in 6 minutes (LFES group: from 398 ± 105 m to 435 ± 112 m, $P < 0.05$; bicycle group: from 425 ± 118 m to 483 ± 120 m, $P < 0.03$)
Deley et al. 2005 [16]	France	24	Patients with stable CHF	Conventional aerobic training programmes.	EMS consisted of stimulating both quadriceps and calf muscles using two portative dual-channel stimulators	Functional capacity and muscle strength Both training protocols have induced significant improvements in the distance covered in 6 min (+ 11.9%, $P < 0.01$ in EMS and + 15.3%, $P < 0.001$ in conventional exercise. The strength measured on the knee extensors increased by 9.9 and 10.6% for the left lower limb after EMS and conventional exercise, respectively ($P < 0.05$) and by 9.5 and 12% for the right lower limb ($P < 0.05$).
Eicher et al. [17]	França	24	Patients with stable CHF	Classical bicycle training program	Electrical stimulation of inferior limb muscles	Functional capacity Distance walked in 6 minutes improved significantly in both groups. It improved more in the EMS group (+ 72m) than in the bicycle group (+ 29m)
Harris et al. [18]	UK	46	Stable NYHA Class II/III heart failure	6-week training programme using either a bicycle ergometer	Electrical stimulation of the quadriceps and gastrocnemius muscles.	Functional capacity, quality of life and muscle strength Significant increases were seen in 6-min walk (44.6 m, 95% confidence interval (CI) 29.3–60.9 m) and similar significant increases were seen following training for 6-min walk (40.6 m, 95% CI 28.2–53.0 m), Maximum leg strength (5.32 kg, 95% CI 3.18–7.45 kg) and maximum leg strength (5.35 kg, 95% CI 1.53–9.17 kg) Quality of life scores improved following training when the bicycle and stimulator groups were considered together, but not when considered separately (–0.43, 95% CI –8.13 to –0.56).
Karavidas et al. 2013 [19]	Greece	30	Patients with chronic HFpEF,	Placebo training program	6-week FES training program	Functional capacity and quality of life A significant improvement in 6-minute walked distance ($F = 21.61$, $P = .001$), Kansas City Cardiomyopathy Questionnaire summary ($F = 8.68$, $P = .006$), Minnesota Living with Heart Failure Questionnaire ($F = 6.43$, $P = .017$)

Table II – Continuation

Author / Year	Country	Sample	Participants	Control	Intervention	Mensure	Results
Araújo et al. [20]	Brazil	30	Patients hospitalized in the ward for the treatment of heart failure at a tertiary cardiology hospital.	Did not receive NMES	Underwent conventional rehabilitation and NMES for 60 minutes (20 Hz wave frequency, 20 μ s pulse duration), twice a day, on consecutive days until hospital discharge	Functional capacity	Distance covered in meters on the 6MWT by patients undergoing NMES before: 372.9 ± 62.4 and after: 500 ± 68 , $p < 0.001$. The control group patients had before: 379.7 ± 43.5 and after: 372.9 ± 46.9
Banerjee et al. [21]	UK	18	Stable CHF from left ventricular systolic dysfunction with New York Heart Association Class II-III symptoms	8-week control period during which they maintained their habitual activity level	8-week EMS training program	Functional capacity and muscle strength	6MWT and quads strength compared with both baseline values and the control response
Karavidas et al. 2008 [22]	Greece	30	Patients with stable CHF	Placebo	6-week FES training program	Functional capacity and quality of life	A significant improvement in KCCQ functional ($F = 76.666$, $p < 0.001$), KCCQ overall ($F = 41.508$, $p < 0.001$) was observed in the FES group compared to placebo. Patients in the FES group had also a significant increase in 6MWT ($F = 19.413$, $p < 0.001$) compared to placebo.
Karavidas et al. 2006 [23]	Greece	24	Patients with a left ventricular ejection fraction of less than 40% and New York Heart Association class II-III symptom	Received current input up to the sensory threshold without muscle contractions.	6-week training programme of FES	Functional capacity and quality of life	A significant improvement on the 6-min walk test ($7.5 \pm 3.3\%$) and Minnesota Living Score ($18.2 \pm 8.6\%$) was observed only in the FES-treated group.
Nuhr et al. [24]	Austria	32	Patients with a diagnosis of chronic heart failure	NMES up to the sensory threshold without muscle contractions	NMES that generated muscle contractions; (Pulse width of 0.5 ms and frequency of 15 Hz)	Functional capacity and quality of life	The quality of life score decreased in the intervention group (53 ± 20 , $P < 0.001$), while the control group remained unchanged (66 ± 22 , ns). In the 6-minute walk test (6MWT), a significant difference was observed: Intervention group (227 ± 138 m vs 299 ± 137 m). Control group (237 ± 132 m vs 243 ± 145 m)

Table II – Continuation

Author / Country Year	Sample	Participants	Control	Intervention	Mensure	Results
Quittan et al. [25]	Austria 42	Patients with stable disease progression listed for transplantation	NMES up to the sensory threshold without muscle contractions.	The patients received daily NMES sessions, twice a day, for 8 weeks, with a frequency of 50 Hz and a duty cycle (on/off regime)	Muscle strenght and quality of life	Muscle strength increased by an average of 22.7 for the knee extensor muscles and 35.4 for the knee flexor muscles. The Control Group remained unchanged or decreased by -8.4 in extensor strength. Cross-sectional area increased by 15.5 in the Stimulation Group and 1.7 in the Control Group. Activities of daily living and quality of life improved in the Stimulation Group, but not in the Control Group.
Groehs et al. [26]	Brazil 30	Patients hospitalized with decompensated heart failure.	Electrical stimulation with an intensity < 20 mA	Functional electrical stimulation consisted of stimulating the lower limbs with a frequency of 10 Hz, pulse width of 150 ms, and intensity of 70 mA for 60 minutes/day over 8 to 10 consecutive days	Functional capacity, muscle strength, and quality of life	Both the FES group and the control group showed an increase in the results of the walking test ($p < 0.001$ and $p = 0.001$, respectively). However, the distance covered was greater in the FES group than in the control group ($p < 0.001$). Knee extensor muscle strength increased in the FES group ($p < 0.001$), but not in the control group. Comparisons between the groups revealed that the quality of life score was higher in the FES group than in the control group ($p < 0.001$).
Sacilotto et al. [27]	Brazil 28	Patients with severe heart failure	The application of the current did not induce muscle contraction.	The stimulation was applied, inducing visible muscle contraction, twice a week for a period of 7 days per week, 50 minutes (pulse frequency of 50 Hz, rise/fall time of 2/2 seconds, and contraction/relaxation time of 3/9 seconds, respectively).	Quality of life and functional capacity	The distance covered in the 6-minute walk test (6MWT) increased immediately after the completion of the NMES protocol when compared to the distance covered before the NMES treatment: 324 ± 117 m vs 445 ± 100 m, $p = 0.02$. The placebo group showed no differences in the 6MWT values before and after the treatment. In the NMES group, there was a significant reduction in the scores obtained through the Quality of Life Questionnaire (QQV), indicating an improvement in quality of life (64 ± 22 vs 45 ± 17 , $p < 0.01$)
Kucio et al. [28]	Poland 72	Patients with stable CHF	Received solely pharmacological and exercise treatment	Administered NMES	Quality of life and functional capacity	Three weeks of rehabilitation induced significant increases ($p < 0.05$) in the distance covered in the 6-minute walk test and improved quality of life in all groups, but between group differences were not significant ($p > 0.05$).

Table II – Continuation

Author / Country Year	Sample	Participants	Control	Intervention	Mensure	Results
Forestieri et al. [29]	Brazil 70	Patients hospitalized with advanced decompensated heart failure	They did not receive NMES, only standard care	A biphasic current of 40 Hz, pulse duration of 400 μ s, 'on-time' mode of 10 seconds and 'off-time' of 20 seconds, with a maximum amplitude of 60 mA, was increased according to the patient's tolerance until a muscle contraction was observed. The treatment lasted for 2 weeks, twice a day, for 60 minutes.	Functional capacity	Regarding functional capacity, the groups were homogeneous at baseline, and a significant improvement in the distance covered in the 6-minute walk test was observed in both groups post-protocol compared to baseline values ($p < 0.05$). However, the EMS group showed a significantly greater increase compared to the control group after the protocol application ($p < 0.001$), relative to baseline ($p < 0.001$)
Kadoglou et al. [30]	Greece 120	With stable recent (without decompensation) CHF (NYHA class II/III and left ventricular ejection fraction $<40\%$)	Lower intensity stimulation (5 Hz), not leading to visible or palpable contractions.	Visible muscle contractions by arranging the delivery of a direct electrical current at 25 Hz for 5 seconds followed by a 5-second rest by each stimulator.	Functional capacity	6MWT was significantly improved in the FES group (treatment effect on 6MWT change 41.8, 95% CI 34.6–48.9)
Ennis et al. [31]	UK 60	Randomised feasibility trial into the effects of low-frequency electrical stimulation in advanced heart failure patients.	Very low level of stimulation (LF-EMS) (frequency: 99Hz, pulse width: 150 μ s, maximum current amplitude: 7.3 mA)	Rhythmical contractions in the leg muscle groups	Functional capacity, muscle strength and Quality of life	Non-significant improvements after LF-EMS (8week time point) and sham groups were observed in 6 min walk distance (6MWD) with a mean increase from baseline of 24m ($p=0.13$) in the LF-EMS group No significant differences between groups in the change from baseline for muscle strength. There was a non-significant improvement in quality of life in both groups.

EMS = electrical myostimulation; LFES = low-frequency electrical stimulation; NYHA = New York Heart Association; CHF = Chronic Heart Failure; HFpEF = Heart Failure preserved ejection fraction; FES = Functional Electrical Stimulation; 6MWT = 6 minute walk test; KCCQ - Kansas City Cardiomyopathy Questionnaire

Table III - Characteristics of the NMES intervention in the studies included in the review

Author	Intensity	Current	Frequency	Muscles	Pulse Width	Time m/day	Frequency d/wk	Duration wks
Deley et al. 2008 [15]	Maximum tolerated	Biphasic	10 Hz	QDC/CM	0.2 ms	60	5	5
Dobšák et al. [14]	↑ to maximum of 60 mA	Biphasic	10 Hz	QDC/CM	200 ms	60	7	8
Deley et al. 2005 [16]	Maximum tolerated	Biphasic	10 Hz	QDC/CM	0.2 ms	60	5	5
Eicher et al. [17]	NA	NA	10 Hz	QDC/GM	200 ms	30	7	3.5
Harris et al. [18]	Visible muscle contraction	NA	25 Hz	QDC/GM	NA	30	6	6
Karavidas et al. 2013 [19]	Visible muscle contraction	NA	25 Hz	QDC/GM	NA	30	5	6
Araújo et al. [20]	NA	Biphasic	20 Hz	QDC	200 µs	120	7	2
Banerjee et al. [21]	Maximum 300 mA	NA	4 Hz	QDC/HAM/GLUT/CM	NA	60	5	8
Karavidas et al. 2008 [22]	Visible muscle contraction	NA	25 Hz	QDC/GM	NA	30	5	6
Karavidas et al. 2006 [23]	Visible muscle contraction	NA	25 Hz	QDC/GM	NA	30	5	6
Nuhr et al. [24]	25%-30% of maximum voluntary contraction	Biphasic symmetric	15 Hz	QDC/HM	0.5 ms	240	7	10
Quittan et al. [25]	25%-30% of maximum voluntary contraction	Biphasic symmetric	50 Hz	QDC/HM	0.7 ms	2wk: 30; then 6 wk: 60	5	8
Groehs et al. [26]	Visible muscle contraction	Biphasic symmetric	10 Hz	QDC/HM	150	60	7	10
Sacilotto et al. [27]	Visible muscle contraction	Biphasic symmetric	50 Hz	QDC	NA	50	2	7
Kucio et al. [28]	Visible muscle contraction	Biphasic symmetric	35 Hz	QDC/TS	NA	40	6	3
Forestieri et al. [29]	Maximum tolerated	Biphasic symmetric	40Hz	QDC	400-µs	60	2	length of hospital stay
Kadoglou et al. [30]	visible muscle contractions	Biphasic symmetric	25 Hz	Gastrocnemius	NA	NA	NA	6
Ennis et al. [31]	produce rhythmical contractions	Biphasic symmetric	4-5Hz	Leg muscle groups	620 µs	NA	NA	8

NA = Not informed; QDC = Quadriceps; TS = triceps surae; GM = gastrocnemius; HAM = hamstrings; GLUT = gluteal

Functional capacity

Sixteen studies [14–29,31] analyzed the impact of neuromuscular electrical stimulation (NMES) on functional capacity. For the meta-analysis of this comparison, a random effects model was used ($I^2 = 74\%$; $df = 15$; $p = 0.00001$), indicating substantial heterogeneity between studies. The results did not demonstrate a statistically significant difference between the group undergoing NMES and the control group in relation to functional capacity (difference between means = 12.06 meters; 95% CI: -2.55 to 26.66; Figure 2).

Quality of life

Nine studies [14,18,19,22,24,26–28,31] analyzed the impact of neuromuscular electrical stimulation (NMES) on quality of life. For the meta-analysis of this comparison, a random effects model was used ($I^2 = 97\%$; $df = 8$; $p = 0.00001$), indicating high heterogeneity between the included studies. The results demonstrated a statistically significant difference between the group undergoing NMES and the control group in terms of quality of life (difference between means = 4.20 points; 95% CI: 2.79 to 5.62; Figure 3), suggesting the benefit of the intervention for this outcome.

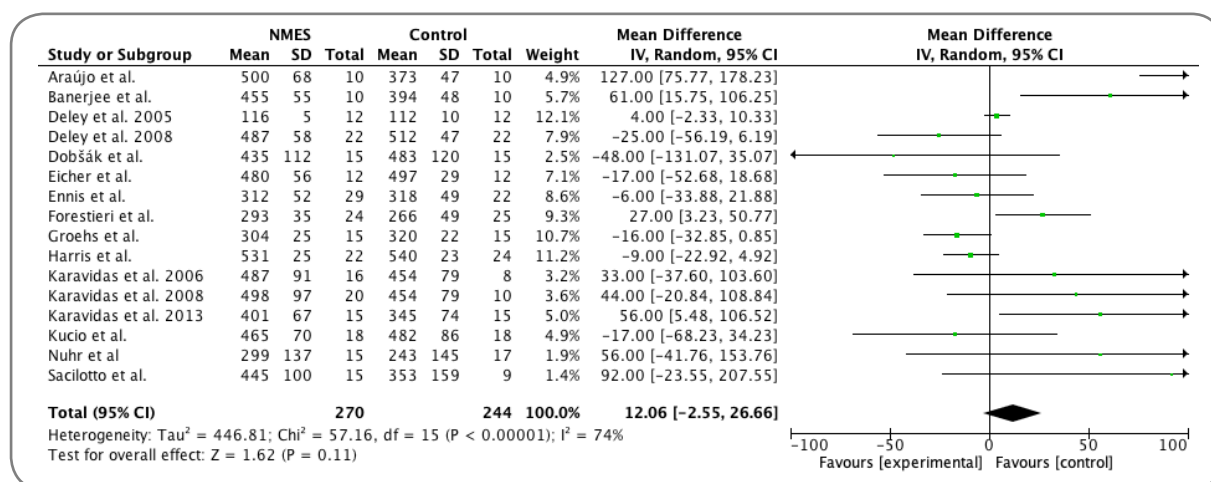


Figure 2 – Forest plot of the results of the meta-analysis

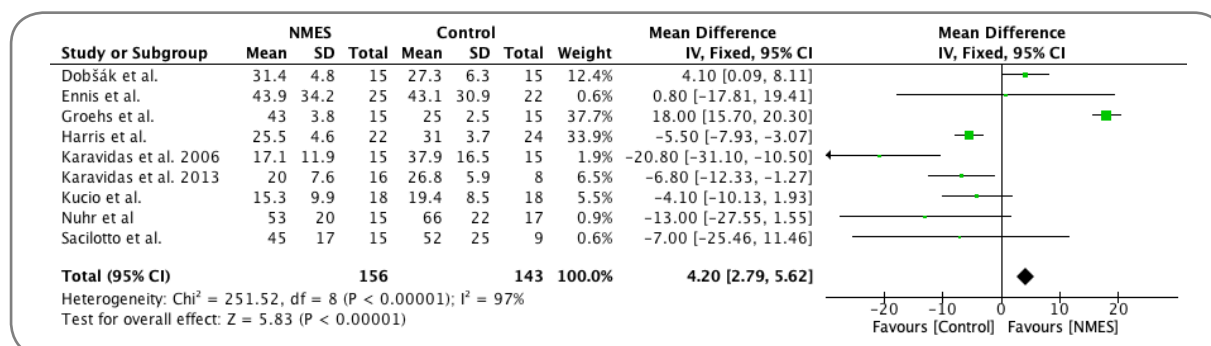


Figure 3 – Forest plot of the results of the meta-analysis

Furthermore, a specific analysis was carried out, separating the effect of neuromuscular electrical stimulation (NMES) on functional capacity during hospitalization and in phase 2 of cardiovascular rehabilitation (Figures 4 and 5).

Functional capacity in hospital

Three studies analyzed the impact of NMES on functional capacity in hospital settings. For the meta-analysis of this comparison, a fixed effects model was used ($I^2 = 94\%$; $df = 2$; $p < 0.00001$), showing high heterogeneity between the included studies. The results did not demonstrate a statistically significant difference between the group undergoing NMES and the control group in relation to functional capacity in the hospital environment (difference between means = 7.02 meters; 95% CI: -6.25 to +20.30; Figure 4).

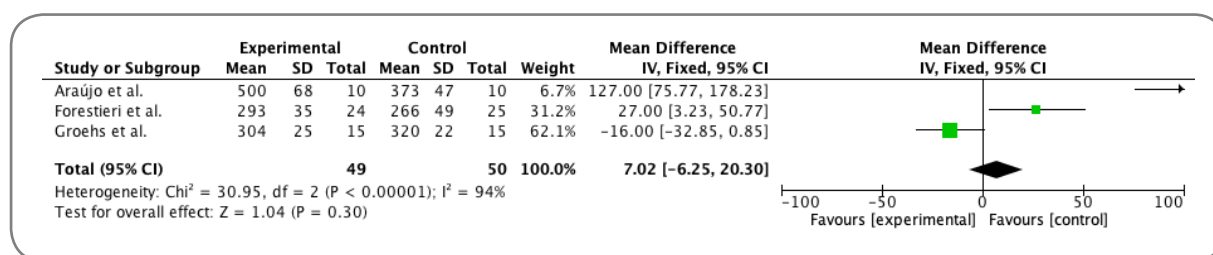


Figure 4 – Forest plot dos resultados da metanálise

Functional capacity in out-of-hospital scenario

Thirteen studies analyzed the impact of neuromuscular electrical stimulation (NMES) on functional capacity in out-of-hospital settings. For the meta-analysis of this comparison, a fixed effects model was used ($I^2 = 53\%$; $df = 12$; $p = 0.01$), indicating moderate heterogeneity between the included studies. The results did not demonstrate a statistically significant difference between the group undergoing NMES and the control group in relation to functional capacity in an out-of-hospital environment (difference between means = 2.12 meters; 95% CI: -3.20 to +7.45; Figure 5).

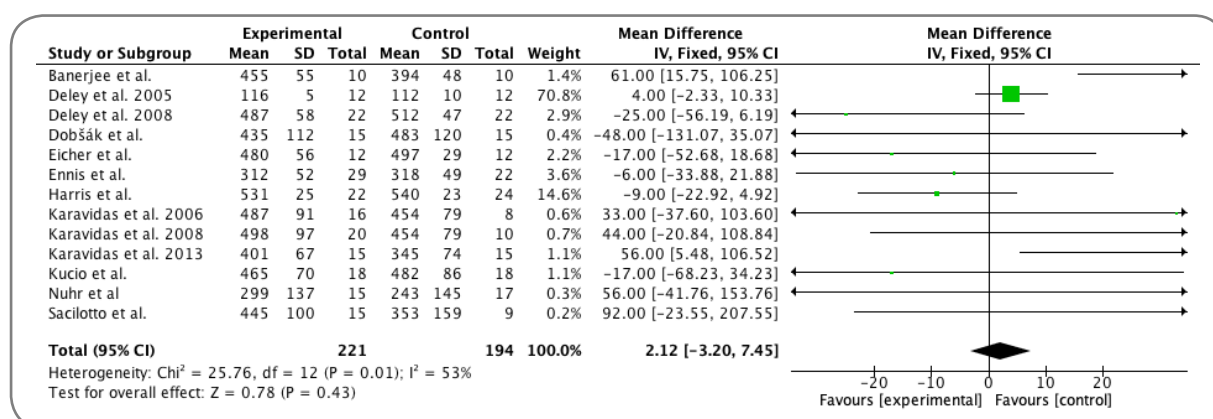


Figure 5 – Forest plot of the results of the meta-analysis

Discussion

Neuromuscular electrical stimulation (NMES) has been widely investigated as a therapeutic tool to improve functional capacity, muscle strength and quality of life in patients with chronic heart failure (CHF). This discussion analyzes the results

of the included studies, which evaluated the impact of NMES in patients with stable or decompensated CHF, addressing both the effectiveness of this approach and the factors that may influence the observed outcomes.

The results of the reviewed studies consistently demonstrate that the distance covered in the 6-minute walk test (6MWT) is a sensitive variable to the changes promoted by NMES. Most studies reported significant improvement in patients' functional capacity, highlighting the work of Deley et al. [15] and Eicher et al. [17], who demonstrated significant increases in the distance covered after using NMES. Deley et al. [15], for example, observed an increase of 13.8% in the group undergoing NMES, compared to 16.5% in the control group undergoing conventional exercise. Even more impressive results were found by Sacilotto et al. [27], who identified an average increase of 120 meters in the distance covered after treatment with NMES.

This improvement can be explained by the ability of NMES to promote direct muscle activation, without the need for significant voluntary effort. In patients with significant muscle weakness, a common condition in advanced stages of CHF, electrical stimulation allows activation of peripheral and respiratory muscles insufficiently recruited during conventional physical activities, such as walking. Furthermore, NMES can increase muscle efficiency, promote strength gains and reduce muscle fatigue. This mechanism makes the intervention particularly relevant for individuals who have difficulty activating muscles due to the limitations imposed by the disease.

Although both NMES and conventional exercise programs demonstrate benefits on functional capacity, the impact of NMES appears to be more pronounced in patients with reduced mobility or significant physical limitations. Studies such as those by Groehs et al. [26] and Deley et al. [18] observed greater increases in the 6MWT after the application of NMES when compared to conventional interventions, especially in individuals with advanced CHF or severe muscle weakness. These findings suggest that NMES may represent a more effective strategy for individuals unable to perform traditional exercises adequately, contributing to reducing the functional barriers imposed by the disease.

Despite the benefits observed in the preservation of muscle mass, muscle strength and cardiorespiratory function, gaps remain related to the cellular and molecular mechanisms involved in the effects of NMES. The investigation of aspects such as selective recruitment of muscle fibers, modulation of peripheral perfusion, influence on tissue oxygenation and impact on metabolic and inflammatory pathways may strengthen the scientific basis of this intervention. Furthermore, greater mechanistic understanding can contribute to the development of more specific therapeutic protocols, identification of subgroups of patients with greater potential for benefit and greater safety in clinical application.

On the other hand, in patients with greater functional preservation and better mobility, conventional training based on aerobic and resistance exercises, as described by Dobšák et al. [14], presented results similar to or even superior to those of NMES. The active mobilization provided by conventional exercise appears to be more

efficient in maintaining and improving aerobic capacity and muscular strength in individuals with less physical impairment. Therefore, although NMES may be particularly advantageous in patients with greater functional limitations, conventional exercise remains a relevant strategy in patients with less advanced CHF. Thus, the choice between NMES and conventional training depends mainly on the clinical stage of the disease and the physical limitations presented.

The variability of results observed between studies can be attributed to several factors, particularly differences in NMES application protocols. Studies that used higher stimulation frequencies, such as 50 Hz, as observed by Groehs et al. [26] and Sacilotto et al. [27], showed better results related to muscle strength gains and improved functional performance. Higher frequencies tend to produce more intense and visible muscle contractions, enhancing relevant physiological adaptations. In contrast, protocols with lower frequency or suboptimal intensity, such as those described by Nuhr et al. [24] and Ennis et al. [31], showed reduced or non-significant effects. Therefore, the appropriate balance between frequency, intensity and duration of stimulation seems to be crucial for maximizing therapeutic effects.

Additionally, the heterogeneity of NMES protocols identified among the included studies, involving differences in stimulation frequency, session duration, current intensity and total treatment time, makes it difficult to establish standardized recommendations and may explain, at least partially, the divergent results found in the literature.

Another factor potentially associated with results is the duration of the therapeutic protocol. Longer protocols, such as those used by Karavidas et al. [22] and Banerjee et al. [21], generally demonstrated more robust results. Continuity of stimulation over weeks or months appears to be essential to promote sustained muscular adaptations and lasting benefits. Short-term protocols can produce immediate effects, but they often do not maintain the gains obtained over time. Therefore, consistent and prolonged use of NMES seems necessary to obtain more stable clinical benefits in patients with CHF.

Improved quality of life also stood out as an important outcome identified in the included studies. Although NMES has demonstrated a positive impact on functional capacity, its effects on quality of life have shown greater variability. Studies conducted by Groehs et al. [26] and Sacilotto et al. [27] observed a significant improvement in this outcome, associated mainly with the reduction of symptoms such as dyspnea and fatigue. These benefits may be related to improved muscular efficiency and reduced functional overload. However, studies such as Harris et al. [18] and Ennis et al. [30] did not identify significant differences between the groups, suggesting that functional improvement alone may not be sufficient to promote significant changes in psychological and emotional aspects, which often require a multidimensional therapeutic approach.

Despite the promising results, some limitations must be considered. Many included studies had a small sample size and high heterogeneity in stimulation pro-

protocols, making direct comparisons between findings difficult [30,31]. Furthermore, most investigations included patients in more advanced stages of heart failure, limiting the generalization of results to populations with less clinical severity.

Therefore, future research should include more heterogeneous samples, covering different stages of heart failure, in addition to investigating ideal protocols for intensity, frequency and duration of NMES. Additional studies should also explore rehabilitation programs combining NMES and conventional exercise, seeking more comprehensive and potentially more effective therapeutic strategies for this population.

Conclusion

The results of this review indicate that neuromuscular electrical stimulation (NMES) can provide benefits related to quality of life and, in some studies, promote improvement in functional capacity, particularly in outcomes such as the 6-minute walk test. However, when the data were grouped statistically, the impact on functional capacity was not consistent between studies, showing divergence between the narrative interpretation of individual findings and the results obtained through quantitative analysis.

NMES appears to be particularly useful for patients with reduced mobility or significant muscle weakness, offering therapeutic advantages not always achieved through conventional exercise programs. However, NMES application protocols—particularly regarding stimulation frequency and intensity—must be carefully adjusted to maximize potential clinical benefits. For patients with greater functional preservation, conventional training remains an effective and valid strategy, and combining it with NMES can enhance therapeutic outcomes. Thus, a multimodal approach—incorporating neuromuscular electrical stimulation, structured physical exercise programs, and continuous monitoring of quality of life—may represent a more comprehensive and appropriate strategy for the clinical management of patients with chronic heart failure

Conflict of interest

The authors declare no conflict of interest.

Sources of funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

Conception and design of the research: Nassif AS, Brito FLJ, Santos GSR, Cordeiro ALL; Data collection: Nassif AS, Brito FLJ, Santos GSR; Data analysis and interpretation: Cordeiro ALL; Manuscript writing: Nassif AS, Brito FLJ, Santos GSR; Critical revision of the manuscript for important intellectual content: Cordeiro ALL

References

1. Murphy SP, Ibrahim NE, Januzzi JL Jr. Heart failure with reduced ejection fraction: a review. *JAMA*. 2020;324(5):488-504. doi: 10.1001/jama.2020.10262. Erratum in: *JAMA*. 2020;324(20):2107. doi: 10.1001/jama.2020.21736
2. Dawson A, Bonner C, Donald M, et al. The role of physical activity in heart failure rehabilitation: an update. *Eur J Prev Cardiol*. 2020;27(2):123-33. doi: 10.1016/j.jacc.2011.04.020
3. Mounsey LA, Guo M, Lau ES, Ho JE. Exercise training in heart failure: clinical benefits and mechanisms. *Circ Res*. 2025 Jul 7;137(2):273-89. doi: 10.1161/CIRCRESAHA.124.325533
4. Coletti RH. The ischemic model of chronic muscle spasm and pain. *Eur J Transl Myol*. 2022;32(1):10323. doi: 10.4081/ejtm.2022.10323
5. Ploesteanu RL, Nechita AC, Turcu D, Manolescu BN, Stamate SC, Berteau M. Effects of neuromuscular electrical stimulation in patients with heart failure - review. *J Med Life*. 2018;11(2):107-18
6. Carraro U, Rigatelli G, Rossini K, Barbiero M, Rigatelli G. Demand dynamic bio-girdling in heart failure: improved efficacy of dynamic cardiomyoplasty by LD contraction during aortic out-flow. *Int J Artif Organs*. 2003;26(3):217-24. doi: 10.1177/039139880302600307
7. Jones S, Man WD, Gao W, Higginson IJ, Wilcock A, Maddocks M. Neuromuscular electrical stimulation for muscle weakness in adults with advanced disease. *Cochrane Database Syst Rev*. 2016;10(10):CD009419. doi: 10.1002/14651858.CD009419.pub3
8. Guilherme D, Ferreira M, Oliveira E. Tailoring neuromuscular electrical stimulation protocols in heart failure patients: A review. *J Cardiopulm Rehabil Prev*. 2022;42(3):159-67. doi: 10.18103/mra.v10i12.3369
9. Gomes Neto M, Oliveira FA, Reis HF, de Sousa Rodrigues- E Jr, Bittencourt HS, Oliveira Carvalho V. Effects of neuromuscular electrical stimulation on physiologic and functional measurements in patients with heart failure: A systematic review with meta-analysis. *J Cardiopulm Rehabil Prev*. 2016;36(3):157-66. doi: 10.1097/HCR.0000000000000151
10. Maddocks M, Gao W, Higginson IJ, Wilcock A. Neuromuscular electrical stimulation for muscle weakness in adults with advanced disease. *Cochrane Database Syst Rev*. 2013;(1):CD009419. doi: 10.1002/14651858.CD009419.pub2. Update in: *Cochrane Database Syst Rev*. 2016;10:CD009419. doi: 10.1002/14651858.CD009419.pub3
11. Maher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med*. 2009;6(7):e1000097.
12. Santos CMC, Pimenta CAM, Nobre MR. The PICO strategy for the research question construction and evidence search. *Rev Lat Am Enfermagem*. 2007;15(3):508-11. doi: 10.1590/s0104-11692007000300023
13. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther*. 2003;83(8):713-21. PMID: 12882612
14. Dobsák P, Nováková M, Fiser B, Siegelová J, Balcáková P, Spínarová L, et al. Electrical stimulation of skeletal muscles. An alternative to aerobic exercise training in patients with chronic heart failure? *Int Heart J*. 2006;47(3):441-53. doi: 10.1536/ihj.47.441
15. Deley G, Kervio G, Verges B, Hannequin A, Petitdant MF, Salmi-Belmioub S, et al. Comparison of low-frequency electrical myostimulation and conventional aerobic exercise training in patients with chronic heart failure. *Eur J Cardiovasc Prev Rehabil*. 2005;12(3):226-33. doi: 10.1097/01.hjr.0000166455.23346.a5
16. Deley G, Eicher JC, Verges B, Wolf JE, Casillas JM. Do low-frequency electrical myostimulation and aerobic training similarly improve performance in chronic heart failure patients with different exercise capacities? *J Rehabil Med*. 2008;40(3):219-24. doi: 10.2340/16501977-0153
17. Eicher JC, Dobsák P, Berteau O, Walker P, Verges B, Maillefert JF, et al. Rehabilitation in chronic congestive heart failure: comparison of bicycle training and muscle electrical stimulation. *Scr Med (Brno)* 2004;77(5-6): 261-70.
18. Harris S, LeMaitre JP, Mackenzie G, Fox KA, Denvir MA. A randomised study of home-based electrical stimulation of the legs and conventional bicycle exercise training for patients with chronic heart failure. *Eur Heart J*. 2003;24(9):871-8. doi: 10.1016/s0195-668x(02)00822-9
19. Karavidas AI, Raisakis KG, Parissis JT, Tsekoura DK, Adamopoulos S, Korres DA, et al. Functional electrical stimulation improves endothelial function and reduces peripheral immune responses in

- patients with chronic heart failure. *Eur J Cardiovasc Prev Rehabil.* 2006;13(4):592-7. doi: 10.1097/01.hjr.0000219111.02544.ff
20. Araújo CJ, Gonçalves FS, Bittencourt HS, dos Santos NG, Mecca Junior SV, Neves JL, *et al.* Effects of neuromuscular electrostimulation in patients with heart failure admitted to ward. *J Cardiothorac Surg.* 2012;7:124. doi: 10.1186/1749-8090-7-124
 21. Banerjee P, Caulfield B, Crowe L, Clark AL. Prolonged electrical muscle stimulation exercise improves strength, peak VO₂, and exercise capacity in patients with stable chronic heart failure. *J Card Fail.* 2009;15(4):319-26. doi: 10.1016/j.cardfail.2008.11.005
 22. Karavidas A, Parissis J, Arapi S, Farmakis D, Korres D, Nikolaou M, *et al.* Effects of functional electrical stimulation on quality of life and emotional stress in patients with chronic heart failure secondary to ischaemic or idiopathic dilated cardiomyopathy: a randomised, placebo-controlled trial. *Eur J Heart Fail.* 2008;10(7):709-13. doi: 10.1016/j.ejheart.2008.05.014
 23. Karavidas A, Driva M, Parissis JT, Farmakis D, Mantzaraki V, Varounis C, *et al.* Functional electrical stimulation of peripheral muscles improves endothelial function and clinical and emotional status in heart failure patients with preserved left ventricular ejection fraction. *Am Heart J.* 2013;166(4):760-7. doi: 10.1016/j.ahj.2013.06.021
 24. Nuhr MJ, Pette D, Berger R, Quittan M, Crevenna R, Huelsman M, *et al.* Beneficial effects of chronic low-frequency stimulation of thigh muscles in patients with advanced chronic heart failure. *Eur Heart J.* 2004;25(2):136-43. doi: 10.1016/j.ehj.2003.09.027
 25. Quittan M, Wiesinger GF, Sturm B, Puig S, Mayr W, Sochor A, *et al.* Improvement of thigh muscles by neuromuscular electrical stimulation in patients with refractory heart failure: a single-blind, randomized, controlled trial. *Am J Phys Med Rehabil.* 2001;80(3):206-14. doi: 10.1097/00002060-200103000-00011
 26. Groehs RV, Antunes-Correa LM, Nobre TS, Alves MJ, Rondon MU, Barreto AC, *et al.* Muscle electrical stimulation improves neurovascular control and exercise tolerance in hospitalised advanced heart failure patients. *Eur J Prev Cardiol.* 2016 Oct;23(15):1599-608. doi: 10.1177/2047487316654025
 27. Sacilotto MCB, Lavagnoli CFR, Silveira-Filho LM, Vilarinho KAS, Oliveira ESB, Carvalho DD, *et al.* A simpler and shorter neuromuscular electrical stimulation protocol improves functional status and modulates inflammatory profile in patients with end-stage congestive heart failure. *Int. J. Cardiovasc. Sci.* 2017;30(6):484-95. doi: 10.5935/2359-4802.20170064.
 28. Kucio C, Stastny P, Leszczyńska-Bolewska B, Engelmann M, Kucio E, Uhler P, *et al.* Exercise-based cardiac rehabilitation with and without neuromuscular electrical stimulation and its effect on exercise tolerance and life quality of persons with chronic heart failure. *J Hum Kinet.* 2018;65:151-64. doi: 10.2478/hukin-2018-0045
 29. Forestieri P, Bolzan DW, Santos VB, Moreira RSL, de Almeida DR, Trimer R, *et al.* Neuromuscular electrical stimulation improves exercise tolerance in patients with advanced heart failure on continuous intravenous inotropic support use-randomized controlled trial. *Clin Rehabil.* 2018;32(1):66-74. doi: 10.1177/0269215517715762
 30. Ennis S, McGregor G, Hamborg T, Jones H, Shave R, Singh SJ, *et al.* Randomised feasibility trial into the effects of low-frequency electrical muscle stimulation in advanced heart failure patients. *BMJ Open.* 2017;7(8):e016148. doi: 10.1136/bmjopen-2017-016148
 31. Kadoglou NP, Mandila C, Karavidas A, Farmakis D, Matzaraki V, Varounis C, *et al.* Effect of functional electrical stimulation on cardiovascular outcomes in patients with chronic heart failure. *Eur J Prev Cardiol.* 2017;24(8):833-39. doi: 10.1177/2047487316687428

