Research Article

Neuromuscular Electrical Stimulation and Therapeutic Exercise on Functional Capacity and Quality of Life in Patients with Chronic Heart Failure

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Running Title: NMES and Exercise on Functional Capacity and Quality of Life in Heart Failure

Abstract

Background: Heart failure (HF) is one of the most common cardiovascular diseases that considered as a progressive and debilitating disorder. One of the main problems in these patients is frequent hospitalizations due to the exacerbation of symptoms. Therefore, the aim of this study is to investigate the simultaneous effect of muscle electrical stimulation and exercise therapy on quality of life and functional capacity in hospitalized patients with chronic heart failure.

Material and Methods: The present study included 40 hospitalized patients with chronic heart failure among the volunteers and randomly divided into two groups of 20 patients. The first group underwent cardiac rehabilitation based on resistance training along with muscle electrical stimulation (RT+ES). The second group received only resistance training program (RT). Resistance training consisted of performing three leg presses, cuff presses, and triceps

movements with Traband. Functional capacity and quality of life evaluated before and after intervention.
Results: Quality of Life Index in the RT+ES increased more than RT ($P \leq 0.05$). Although the functional capacity in both groups had increased relative to the pre-test ($P \leq 0.05$). However, there were no meaningful differences between the two groups ($P \geq 0.05$).
Conclusion: Resistance training with electrical stimulation during hospitalization improves the quality of life and functional capacity of patients with chronic heart failure.
Keywords: Electrical stimulation; Exercise therapy; Heart failure; Quality of life.

Introduction

Chronic heart failure (CHF) is a clinical syndrome characterized by structural and functional impairment during either the filling or ejection phase of the ventricles, leading to inadequate blood flow to meet the metabolic demands of tissues and organs (1). Globally, cardiovascular diseases affect approximately 550 million people, of whom around 64 million suffer from CHF (2). In the United States, heart failure affects about 6 million people, with direct medical costs exceeding $53 billion (3).

Several factors contribute to the development of CHF, including myocardial damage due to ischemia, hypertension, and aortic stenosis. These conditions impair the contractile ability of the heart muscle, leading to myocardial dilation as an adaptive response to maintain stroke volume. However, the heart fails to generate sufficient cardiac output (4). CHF patients experience a wide range of symptoms, with exercise intolerance and dyspnea being among the most significant. The inability of the heart to adequately supply blood to the organs leads to symptoms such as shortness of breath, dizziness, angina, and tissue damage, which reduce exercise tolerance and significantly impact patients' lifestyles and quality of life (5).

Several studies have demonstrated that the quality of life index in CHF patients is lower than that of the general population. Functional limitations affect their occupational, family, and social lives, often leading to social isolation and depression. Additionally, these patients become increasingly dependent on others, losing their independence, which negatively affects not only their own quality of life but also that of their family members (6).

CHF affects multiple organ systems pathologically, with researchers identifying reduced functional capacity as the most critical factor contributing to a decline in quality of life. Decreased functional capacity leads to social isolation and lower life satisfaction (7). For example, Heo et al. (2013) found that poor physical performance significantly reduces quality of life in CHF patients (8). As mentioned, the primary cause of reduced quality of life in these patients is severe physical impairment. Functional capacity is a key indicator of physical activity capability and typically assessed through exercise tolerance tests (9). Research indicates that CHF patients have a significantly lower exercise tolerance threshold compared to their healthy peers. This reduction weakens their ability to engage in physical activities, creating a vicious cycle that exacerbates CHF progression (10). Essentially, the balance between workload and the body's capacity to meet metabolic demands disrupted, preventing patients from performing routine activities (11).

Today, it was well-established rehabilitation programs incorporating therapeutic exercise could enhance functional capacity in cardiac patients, including those with CHF. This is so crucial that studies have shown exercise training can alleviate CHF symptoms and even improve patients' quality of life (12). Some researchers have suggested that regular physical training could help reduce mortality rates. In one study, improving aerobic capacity in CHF patients led to a 25% reduction in mortality, along with an increase in quality of life (13).

Cardiac rehabilitation programs now include resistance training in addition to aerobic exercise training. Studies indicate that resistance training improves muscular strength and endurance, enhancing both functional capacity and quality of life in CHF patients (14). Age-related or disease-related muscle mass and strength loss can significantly limit daily activities, mobility, and participation in social activities, directly affecting quality of life. Research has shown that appropriate resistance training can increase muscle strength even in the elderly and frail populations. Thus, resistance training considered a vital component of rehabilitation programs across different age groups, regardless of the presence of heart disease. Since CHF patients often experience severe muscle atrophy, one of the main objectives of rehabilitation programs is resistance training that strengthens peripheral muscles without imposing excessive cardiovascular stress (15).

In addition to exercise-based cardiac rehabilitation, neuromuscular electrical stimulation (NMES) increasingly used in cardiac rehabilitation and physiotherapy centers to activate muscles. In recent years, NMES employed to enhance athletic performance, muscle strength, and muscle mass. NMES, a relatively new technology, can serve as a valuable adjunct to resistance training. It allows for the simultaneous activation of muscles through both voluntary contractions and externally applied electrical impulses. The combination of voluntary muscle contractions in traditional training with simultaneous activation via NMES enables shorter, more intense workouts (16, 17). While NMES has proven effective in strengthening muscles, excessive use can lead to pain and adverse effects, requiring careful integration with other dynamic rehabilitation methods. For example, NMES found to improve strength, aerobic performance, jumping height, and running speed, likely due to its selective recruitment of different muscle fibers (18).

Limited studies have investigated the effects of NMES in CHF patients. For instance, Poltavskaya et al (2022) examined the effectiveness of lower limb NMES (quadriceps, hamstrings, and calves) on quality of life and functional capacity in hospitalized CHF patients with acute decompensation. Their study assessed functional capacity (via the 6-minute walk test) and quality of life (using the Minnesota and Duke questionnaires) immediately post-discharge and again three weeks later. The NMES group showed significant improvements compared to the control group (19).

Most studies have examined the individual effects of exercise training (20) or NMES (19, 21)on CHF patients. However, few studies have evaluated the combined effects of these two interventions on quality of life and functional capacity in CHF patients (22, 23). Therefore, the objective of this study is to examine the effects of neuromuscular electrical stimulation and therapeutic exercise on functional capacity and quality of life in patients with chronic heart failure.

Materials and Methods

Participants

This is a controlled clinical trial study conducted with a pre-test and post-test. Ethical considerations were approved by the IR.SBMU.RETECH.REC.1404.006 code before conducting the research. The statistical population of this study consisted of patients with chronic heart failure (with an ejection fraction of less than 40%) who were hospitalized at Hazrat Vali Asr Hospital in Qom Province. This study was conducted with the voluntary participation of individuals. Patients with chronic heart failure who met the inclusion criteria and did not meet the exclusion criteria were included in the study. From among the volunteers, 40 participants who met the inclusion criteria were selected. The inclusion criteria were: Age between 40 and 70 years, Body mass index (BMI) between 20 and 25, Diagnosis of chronic heart failure and hospitalization, Approval from a cardiologist for participation in the study (referral to a relevant physician), Absence of other underlying diseases such as diabetes and respiratory diseases, no movement-limiting injuries.

The exclusion criteria included: High-risk patients with unstable angina, Complex ventricular arrhythmias, Myocardial infarction within the past six months, Presence of a pacemaker, Heart surgery within the past six months, Lack of willingness to continue the study, Discharge from the hospital before the completion of intervention sessions, Sinus rhythm disorders.

To determine the sample size, G Power software was used. The sample size was determined based on a mean difference of 9.533, a standard deviation of 3.572, and an effect size of 0.8, following the study by Andrade et al (2020) which used a 0.05 alpha level and a 95% statistical power, selecting 20 participants per group (24).

After obtaining ethical approval and patient consent, participants were divided into two groups of 20. In accordance with ethical considerations, all patients in both groups received standard clinical care during hospitalization. The intervention duration lasted until hospital discharge, with a minimum of five sessions.

Intervention Protocol

Group 1 Received cardiac rehabilitation based on resistance training combined with neuromuscular electrical stimulation (NMES). Group 2 followed the same exercise therapy program, but the NMES intensity was set at a level that did not induce muscle contractions, only providing tactile stimulation. On the first day of hospitalization, an initial assessment of dependent variables was conducted, and a physiotherapist provided necessary educational instructions. A familiarization session was conducted on days 1 and 2, where patients were instructed on: Exercise execution, perceived exertion scale (Borg scale), Breathing techniques during exercise, Stretching range, Proper movement execution and Use of resistance bands (TheraBand) Exercise positioning. Each exercise session included: Warm-up: Gentle stretching exercises for the upper and lower limbs Resistance training: 20 to 30 minutes and Cool-down: Walking exercises. Patients in the intervention group performed resistance training once daily under physiotherapist supervision from day 2 to day 10 of hospitalization. The exercises includes three main movements that performed using a TheraBand, 1) Leg Press: Performed in a supine position Hip and knee extension against the TheraBand resistance. 2) Triceps Extension: Performed in a standing position Holding the TheraBand with both hands, extending the arms backward while keeping the shoulders stable, 3) Calf Press: Performed in a seated position on the bed with knees extended Ankle plantarflexion (pointing the toes) against TheraBand resistance, moving from a 90-degree position to full range *(Figure 2 illustrates these exercises.)*

Figure 1. Method of Performing Resistance Exercises

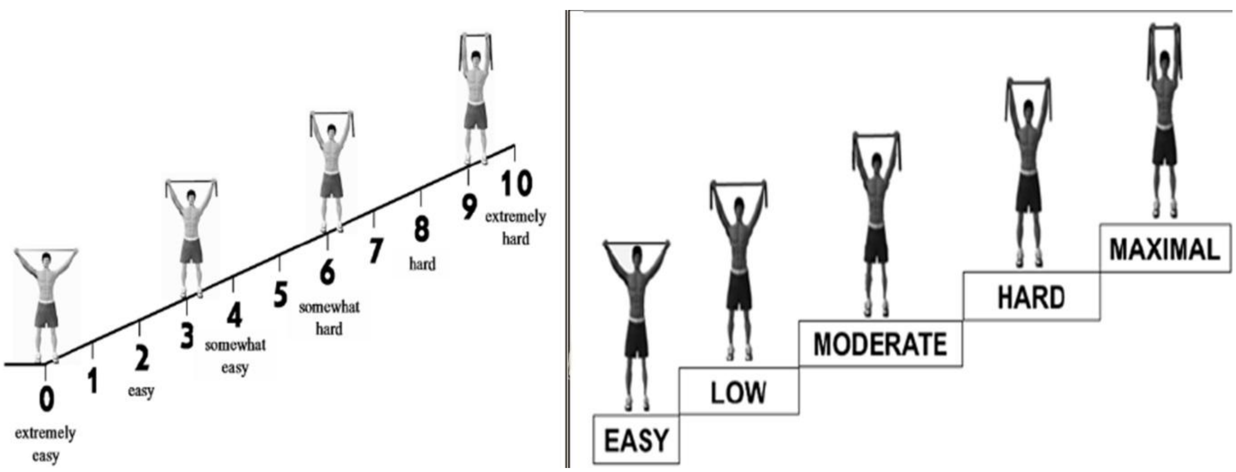

Figure 2. Exercise Intensity Range Based on Perceived Exertion

The intensity of the exercise was determined based on the type of Theraband, the number of repetitions, and the Borg Rating of Perceived Exertion (RPE) scale (25). To determine the exertion level, the patient was first asked to perform 15 maximum repetitions using a light Theraband (yellow). If the perceived exertion during these 15 repetitions fell within the moderate range (a score of 3 to 6), this intensity was considered the training intensity (Figure 3). However, if the perceived exertion was lower than this range, a heavier Theraband (red) was used. After sufficient rest, the test was repeated to confirm the appropriate exercise intensity (42). Once the exercise intensity was determined, the training group patients performed exercises for 20 to 30 minutes per session (25). Each movement was performed in 3 sets, with 12 repetitions per set. The rest interval between repetitions followed a 1:2 ratio, and there was a 5-minute rest between completing one set of exercises and starting the next (40).

To prevent the Valsalva maneuver, patients were instructed to exhale during the eccentric phase of the exercise (26). For added safety, an oxygen therapy system was available to be used if blood oxygen saturation dropped below 92% in room air. Systolic and diastolic blood pressure was measured before exercise in both lying and sitting positions, during exercise, immediately after completion, and again 5 minutes' post-exercise while seated (27).

According to recommendations, the perceived exertion level during resistance training should fall within the very light to somewhat heavy range (2 to 5 on the 10-point Borg scale) until fatigue is reached. It is worth noting that higher-intensity resistance training (80% of one-repetition maximum) has been reported in studies related to patients with CHF. While this intensity has been well tolerated, most CHF patients should start with lower-intensity activity (beginning at 40% of one-repetition maximum) and progressively increase the intensity to 60%. Resistance training phases should be short (less than 60 seconds) with appropriate recovery periods (a work-to-rest ratio of 1:2). The recommended duration for resistance training is between 20 and 30 minutes (25). Regarding training methods, it is suggested that as long as guidelines are available, low-risk patients (Group I based on the New York Heart Association classification) can perform full-body resistance training. However, moderate-risk patients (Groups II and III) should engage only in partial-body resistance exercises (28). Regarding repetitions and sets, recent studies comparing heart rate responses, systolic blood pressure, and the rate-pressure product after resistance training with different repetitions and inter-set intervals have found similar results (29). Protocols with the highest repetitions and lowest intensity (3 sets of 12 repetitions) produced significant cardiovascular changes compared to protocols with the highest intensity and the lowest repetitions (3 sets of 6 repetitions) (40).

To induce electrical stimulation in the muscles, a 710P Plus (Class I; Type BF; S/N AX251202) stimulator from Novin Medical Engineering Company was used. The current waveform was a symmetrical biphasic rectangular pulse with a frequency of 10 Hz (19), a pulse duration of 200 milliseconds, and an on-to-off ratio of 1:2 (36). The first, second, and third sessions of NEMS duration lasted for 30, 45, and 60 minutes, respectively. The maximum duration for the subsequent sessions was capped at 90 minutes (19).

For quadriceps muscle stimulation, two electrodes were placed: One 5 cm below the center of the inguinal crease, The other 3 cm above the superior edge of the patella for calf muscle stimulation, the electrodes were positioned at: 2 cm below the knee joint line (posteriorly), At the beginning of the Achilles tendon. The patient’s position during these stimulations was lying on their back with hip and knee flexion, as shown in Figure 3 (19, 30).

For triceps muscle stimulation, the patient was seated with their elbow flexed at 90 degrees, resting on a surface. The electrode placement was: 2 cm above and below the mid-inner point of the muscle, This point is 2 cm medial to the intersection of the longitudinal line (from the olecranon process to the acromion) and the transverse line (widest part of the upper arm) (31).

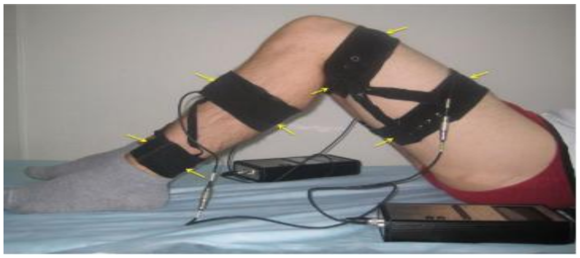

Figure 3. Method of Applying Electrical Muscle Stimulation (19, 31)

Exercise Tolerance Test (Functional Capacity)

To measure this variable, the 6-minute walk test was used. In this test, the individual walks at a comfortable pace for 6 minutes along a 30-meter pathway, marked at 3-meter intervals. The total distance covered was recorded and analyzed (12).

Quality of Life Questionnaire

All participants were literate. After explaining the entire research process to the patients and obtaining written informed consent, the quality of life questionnaires was distributed among the patients. Each questionnaire was completed individually in the presence of the researcher to clarify any ambiguities and was then collected by the researcher. The SF-36 questionnaire was used to assess quality of life, whose validity and reliability have been confirmed through multiple studies in our population. This questionnaire consists of two sections: The first section includes 18 questions regarding personal characteristics. The second section contains 36 questions categorized into 8 dimensions: General health (6 questions), Physical health (10 questions), Mental health (6 questions), Social activity (2 questions), Bodily pain (2 questions), Role limitations due to physical health (4 questions), Role limitations due to mental health (3 questions), Vitality and energy (3 questions), A 5-point Likert scale was used for responses, where 1 represents poor condition and 5 represents excellent condition. As mentioned, this questionnaire evaluates 8 indicators. The scoring method ranges from 0 to 100, where each question is scored from 0 to 100, and then the average scores for each dimension and overall quality of life were analyzed (31).

Data Analysis

Data were analyzed using SPSS software version 25. Descriptive statistics were used to present means and standard deviations. The Shapiro-Wilk test was used to determine the normal distribution of variables. Analysis of covariance (ANCOVA) was employed to examine differences between groups. If a statistically significant difference was found, Tukey's post-hoc test was used to determine which means were significantly different. A significance level of $P \leq 0.05$ was considered statistically meaningful.

Results:

Table 1 presents the demographic characteristics of the participants. According to the Shapiro-Wilk test, all dependent variables had a p-value greater than 0.05, indicating no significant differences. Additionally, the Levene's test was conducted to examine homogeneity of variances, confirming that the assumption of variance homogeneity was met. Therefore, parametric statistical tests were used to analyze the hypotheses. Here is the translated content of the table:

Table 1. Demographic Characteristics of Participants

Variable	Electrical Stimulation Group	Control Group
Age (years)	62.55 ± 14.14	64.43 ± 21.21
Height (meters)	164.80 ± 4.97	165.90 ± 4.49
Weight (kg)	74.56 ± 45.63	74.10 ± 3.99
Average Blood Pressure	94.83 ± 13.92	95.61 ± 9.20
Physical Performance (m)	175.70 ± 73.60	178.75 ± 51.37
Quality of Life Score	197.25 ± 73.02	193.50 ± 51.48

For hypothesis testing, parametric statistical tests were used. Using repeated measures ANOVA, the potential changes within each group were evaluated at two points in time: pre-test and post-test. A two-way mixed ANOVA (2x2 between-within groups) was conducted to assess the effects of two different types of training (two interventions) on quality of life and functional capacity over two periods (pre- and post-training). The results are presented in Table 2.

The results of the ANOVA for the variable quality of life showed a significant between-group difference. The resistance training combined with electrical stimulation group outperformed the resistance training group. However, no significant between-group difference was observed in terms of functional capacity. The results of the paired t-test for within-group comparisons and the differences between pre-test and post-test scores in both groups were significant. This indicates that the intervention in both groups led to significant improvements in quality of life and functional capacity variables. Combining the findings of these two analyses, it becomes evident that both interventions improved the quality of life and functional capacity of these patients. However, the combined intervention had a more pronounced effect on quality of life.

Table 2: Analysis of Covariance for the Effect of Intervention on Quality of Life and Performance Method

dependent Variable	Source of Variation	Sum of Squares	df	Mean Squares	F	p-value	Eta Squared
Quality of Life	Intervention	3934.01	1	3934.01	617.355	0.001	0.90
	Time	195.31	1	195.31	11.10	0.001	0.21
	Group	143.11	1	143.11	12.93	0.001	0.25
	Interaction	420.37	38	11.06	-	-	-
Performance Method	Intervention	6588.45	1	6588.45	617.355	0.001	0.90
	Time	2.45	1	2.45	0.99	0.98	0.001
	Group	231.20	1	231.20	12.49	0.001	0.24
	Interaction	3735703	38	18.50	-	-	-

Table 3: Results of Paired t-test for Comparing Quality of Life and Performance Method Between Groups

Variable	Group	Mean Difference	Standard Deviation	T	df	p-value
Quality of Life	Intervention	-1.67	4.64	16.07	19	*0.001
	Learning	-1.13	4.76	10.66	19	*0.001
Performance Method	Intervention	-2.15	4.77	20.18	19	*0.001
	Control	-1.47	7.15	9.21	19	*0.001

* Significant values

Discussion

The findings of the current study indicated a notable enhancement improvement in functional capacity because of both interventions, although no statistically significant difference observed between the two types of exercise. Most studies confirm the improvement of functional capacity through exercise. The results align with those of Saeidi et al. (2022), Fukuda et al. (2019), Mahmoudi et al (2020), Kucio et al (2018), and Ilio et al (2017) (22), but they contradict the findings of Ennis et al. (2018) and Puldavski et al (2022) (34). Ilio et al (2018) The aligned studies examined the effect of only resistance training intervention or combined with electrical stimulation on improving aerobic power and functional capacity, for instance Ilio et al (2018) and Kucio et al (2018) examined the effect of exercise training combined with electrical stimulation on improving functional capacity, results showed that exercise training with and without electrical stimulation improved functional capacity (23). In contrast, Ennis et al (2018) puldavski (2022) investigated electrical muscle stimulation on functional capacity in heart failure patients. While in the present study, resistance training with and without electrical stimulation was applied (32).

Our study indicated that resistance training, combined with electrical stimulation, could also improve functional capacity in these patients. In most studies, the effects of electrical muscle stimulation (EMS) was primarily been examined in outpatients with stable moderate heart failure (21). However, existing knowledge on this subject indicates that EMS serves as a promising alternative to traditional physical exercise training for severely deconditioned patients suffering from heart failure (32). Regarding the effect of electrical stimulation on functional capacity, Ennis et al. (2018) and Puldavski et al (2022) observed no significant impact (34). In contrast, interventions examining the effect of resistance training on functional capacity supported the findings of this study. For example, Saeidi et al (2023) examined the impact of two different intensities of resistance training on functional capacity in heart failure patients. While functional capacity improved in both groups, no significant difference was observed between them (33). Similar comparative studies on the effects of resistance training with and without electrical stimulation on functional capacity by Cassio et al (2018) (36) and Elio et al (2017) confirmed the results of this study. Both found that functional capacity improved in both groups without significant differences between them (35). Various mechanisms have been proposed for improving aerobic capacity through resistance training. One plausible mechanism is increased muscular strength and endurance, which enhances walking performance. Other suggested mechanisms include intracellular signaling processes. Physical exercise can increase AMPK activity in muscle cells, thereby upregulating PGC1α expression. Increased mRNA and mitochondrial protein expression enhance aerobic capacity. Another mechanism involves increased blood flow and arterial wall pressure during exercise, improving endothelial dysfunction through cellular and molecular adaptations (31). The present study revealed that both interventions improved the quality of life scores, but this improvement was greater in the exercise + electrical stimulation group. This finding aligns with the results of Poltavskaya et al (2022) and Neto et al (2019), this authors found that Short-term in-hospital EMS leads to improvements in functional quality of life scores in selected patients early after HF decompensation that are retained over 1month after (19). Furthermore, Neto et al (2019) indicated that the conducting of resistance training could enhance the quality of life scores among patients with heart failure (33). Exercise therapy can improve patients' quality of life in various ways. Enhancing functional capacity is a key factor in elevating the quality of life for these patients (19). In a comprehensive study, German et al (2021) investigated the relationships between objectively measured physical activity, exercise capacity, and quality of life in older patients with obese heart failure and preserved ejection fraction, concluding that patients had low levels of objectively measured physical activity as well as decreased exercise capacity and poor quality of life (34). Gary et al (2020) found that exercise training have positive effect on quality of life in CHF patient (32). Cohen (2016) compared the roles of BMI and aerobic capacity in patients' quality of life, revealing that aerobic capacity had a stronger correlation with quality of life (53). In addition to intervention studies that examined the effect of exercise or electrical stimulation on quality of life, some correlational studies have also been conducted in this field. Correlational studies suggest a relationship between improved functional capacity and quality of life. In some cardiac rehabilitation research, it was showed that enhancement in functional capacity is significantly and directly correlated with general health, physical function, and mental health (35). For instance, Reddy et al (2020) noted that improving functional capacity leads to an increase in the quality of life in CHF patients (36). Buendía et al (2011) studied the relationship between functional capacity and quality of life in patients,

observing that there is direct relationship between enhanced functional capacity and improvement of quality of life (37).
These findings, in most cases, support the results of the present study, suggesting that higher aerobic capacity leads to improved quality of life. This finding has also been reported in etiology studies, even though some studies focused on healthy or athletic individuals. For instance, Häkkinen (2010) examined the relationship between physical fitness factors and quality of life among Finnish youth, finding that quality of life was strongly associated with physical activity, especially recreational activities. This study classified participants into three groups based on cardiopulmonary fitness (poor, moderate, and fit), with fitter individuals scoring higher on various quality-of-life dimensions (38). Sener et al (2016) investigated the relationship between physical fitness factors and quality of life, finding a positive and significant correlation, albeit not very strong. The results suggest that quality of life improves with enhanced physical fitness (10).
Although no significant difference observed between the two interventions' effects on functional capacity in this study, calculating the change ratio revealed that exercise combined with electrical stimulation had a greater impact. This finding aligns with most previous studies. However, this research had limitations, including the inability to control participants' motivation, psychological factors, precise joint loading across different angles, sleep schedules, and dietary quality.

Conclusion

The study concluded that both resistance training with electrical stimulation and resistance training alone interventions improved quality of life variables and functional capacity. However, quality of life increased more significantly in the combined intervention group. Based on these findings, it is recommended to use resistance training with precautions during the hospitalization phase of CHF patients for rehabilitation.

Ethical Considerations

Ethical considerations were observed in accordance with the guidelines of the Shahid Beheshti University of Medical Sciences and Health Services Ethics Committee, and the ethical code IR.SBMU.RETECH.REC.1403.271 was obtained.

Authors contributions:

All authors approved the final manuscript; the first author was as student and conducted Investigation, Data Curation and Project Administration (Submission & Revisions). Second author was as supervisor, Reviewer and Editor of article and third author was as advisor, Reviewer and Editor of article.

Conflict of interest:

The authors declare that there is no conflict of interest regarding the publication of this paper.

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