Research Article

Neuromuscular Electrical Stimulation and Exercise for Quality of Life in Hospitalized Chronic Heart Failure

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ABSTRACT

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

Materials and Methods: The present study included 40 hospitalized patients with chronic HF among the volunteers, who were randomly divided into two groups of 20 patients. The first group underwent cardiac rehabilitation that included resistance training (RT) and muscle electrical stimulation (RT+ES). The second group received only a RT program, which consisted of performing three leg presses, cuff presses, and triceps movements with a theraband. Functional capacity and quality of life were evaluated before and after the intervention.

Results: Quality of life index in the RT+ES group increased more than that in the RT group ($P \leq 0.05$). Although the functional capacity in both groups increased compared to the pre-test ($P \leq 0.05$), there were no significant differences between the two groups ($P \geq 0.05$).

Conclusion: RT with ES during hospitalization improves the quality of life and functional capacity of patients with CHF.

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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 (HF) 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 shown that the quality of life index in patients with CHF 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 is typically assessed through exercise tolerance tests [9]. Research indicates that patients with CHF 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 is disrupted, preventing patients from performing routine activities [11].

Today, it is well-established that rehabilitation programs incorporating therapeutic exercise can enhance functional capacity in cardiac patients, including those with CHF. This finding 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 resulted in a 25% reduction in mortality, accompanied by an increase in the quality of life [13].

Cardiac rehabilitation programs now include resistance training (RT) in addition to aerobic exercise training. Studies indicate that RT improves muscular strength and endurance, thereby enhancing both functional capacity and quality of life in patients with CHF [14]. Age-related or disease-related loss of muscle mass and strength can significantly limit daily activities, mobility, and participation in social activities, directly affecting quality of life. Research has shown that appropriate RT can increase muscle strength even in the elderly and frail populations. Thus, RT is 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 RT that strengthens peripheral muscles without imposing excessive cardiovascular stress [15].

In addition to exercise-based cardiac rehabilitation, neuromuscular electrical stimulation (NMES) is increasingly used in cardiac rehabilitation and physiotherapy centers to activate muscles. In recent years, NMES has been employed to enhance athletic performance, muscle strength, and muscle mass. NMES, a relatively new technology, can serve as a valuable adjunct to RT. 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 has been 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 patients with CHF. For instance, Poltavskaya et al. 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 then 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 patients with CHF. However, few studies have evaluated the combined impact of these two interventions on the quality of life and functional capacity in patients with CHF [22, 23]. Therefore, the objective of this study is to examine the effects of NMES and therapeutic exercise on functional capacity and quality of life in patients with CHF.

Materials and Methods

Study participants

This research is a controlled clinical trial study conducted with a pre-test and post-test. The statistical population of this study consisted of patients with CHF (with an ejection fraction of less than 40%) who were hospitalized at Hazrat Vali Asr Hospital in Qom Province, Iran. This study was conducted with the voluntary participation of individuals. Patients with CHF who met the inclusion criteria and did not meet the exclusion criteria were included in the study. From the volunteers, 40 participants who met the inclusion criteria were selected. The inclusion criteria were as follows: Aged between 40 and 70 years, body mass index (BMI) between 20 and 25, diagnosis of CHF and hospitalization, approval by a cardiologist for participation in the study (referral to a relevant physician), absence of other underlying diseases such as diabetes and respiratory diseases, and no movement-limiting injuries.

The exclusion criteria were as follows: High-risk patients with unstable angina, complex ventricular arrhythmias, myocardial infarction within the past 6 months, presence of a pacemaker, heart surgery within the past 6 months, lack of willingness to continue the study, discharge from the hospital before the completion of intervention sessions, and sinus rhythm disorders.

To determine the sample size, G*Power software, version 3.1 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. [24], which employed a 0.05 alpha level and 95% statistical power, resulting in the selection of 20 participants per group.

After obtaining ethical approval and patient consent, the 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 5 sessions.

Intervention protocol

Group 1 received cardiac rehabilitation that combined RT with 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, during which patients were instructed on the following topics: Exercise execution, perceived exertion scale (Borg scale), breathing techniques during exercise, stretching range, proper movement execution, and the use of resistance bands (theraband) for Exercise positioning. Each exercise session consisted of the following components: a warm-up, including gentle stretching exercises for the upper and lower limbs; RT, lasting 20 to 30 minutes; and a cool-down, which involved walking exercises. Patients in the intervention group performed RT once daily under physiotherapist supervision from day 2 to day 10 of hospitalization. The exercises include three main movements that are performed using a theraband. The first is the leg press, which is performed in a supine position, with hip and knee extension against the theraband resistance. The second is triceps extension, which is performed in a standing position, holding the theraband with both hands, extending the arms backward while keeping the shoulders stable. The last is calf press, which is performed in a seated position on the bed with knees extended, ankle plantarflexion (pointing the toes) against the theraband resistance, moving from a 90-degree position to full range (Figure 1 illustrates the method of performing these exercises and Figure 2 illustrates these exercises).

Figure 1. Method of performing resistance exercises

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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 [22]. 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 a 5-minute rest was taken between completing one set of exercises and starting the next [16, 18, 23].

To prevent the Valsalva maneuver, the patients were instructed to exhale during the eccentric phase of the exercise [26]. For added safety, an oxygen therapy system was available for use if blood oxygen saturation dropped below 92% in room air. Systolic and diastolic blood pressure were 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 RT 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 RT (80% of 1-repetition maximum) has been

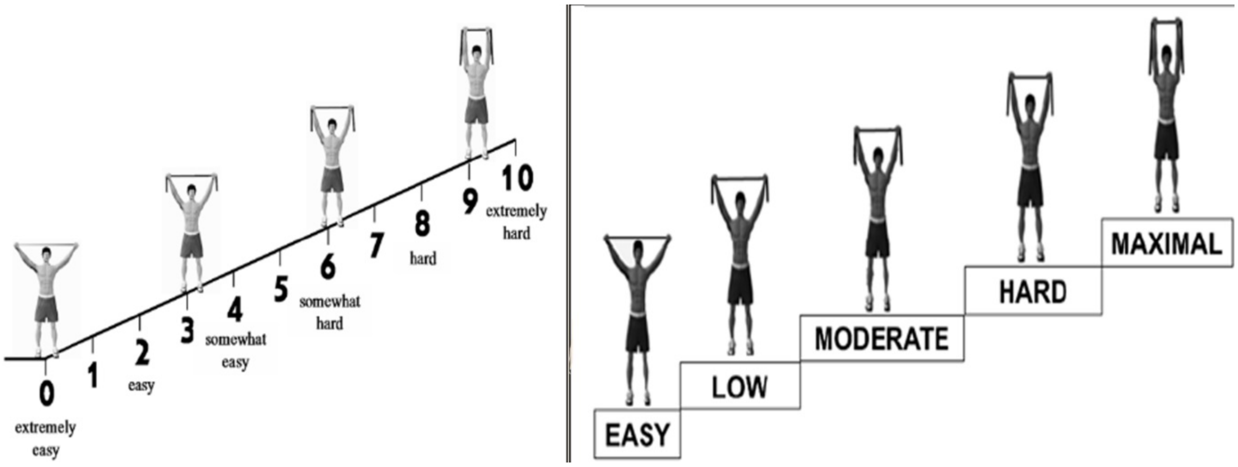

Figure 2. Exercise intensity range based on perceived exertion

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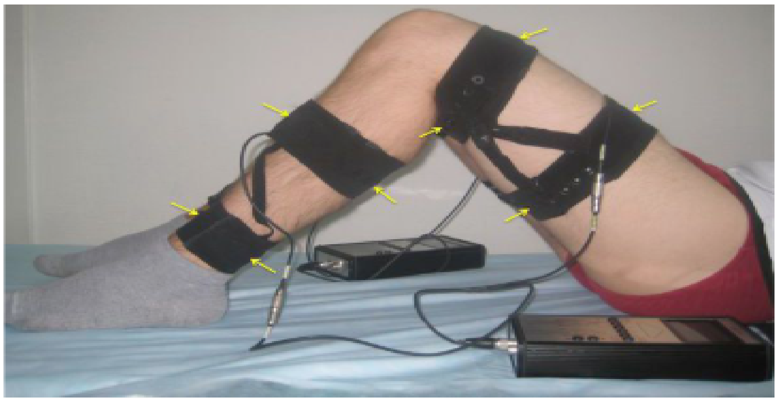

Figure 3. Method of applying electrical muscle stimulation [19, 31]

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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 1-repetition maximum) and progressively increase the intensity to 60%. RT phases should be short (less than 60 s) with appropriate recovery periods (a work-to-rest ratio of 1:2). The recommended duration for RT is between 20 and 30 min [25, 26]. 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 RT. However, moderate-risk patients (Groups II and III) should engage only in partial-body resistance exercises [27, 28]. Regarding repetitions and sets, recent studies comparing heart rate responses, systolic blood pressure, and the rate-pressure product after RT with different repetitions and inter-set intervals have found similar results [29]. Protocols with the most repetitions and lowest intensity (3 sets of 12 repetitions) produced significant cardiovascular changes compared to protocols with the highest intensity and the minimum repetitions (3 sets of 6 repetitions) [16, 23]. To induce ES 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 [16, 18, 30]. The first, second, and third sessions of NEMS duration lasted for 30, 45, and 60 min, respectively. The maximum duration for the subsequent sessions was capped at 90 min [19].

For quadriceps muscle stimulation, two electrodes were placed: One 5 cm below the center of the inguinal crease, and 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) and 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 (at the widest part of the upper arm) [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 were distributed among the patients. Each questionnaire was completed individually in the researcher's presence 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), and vitality and energy (3 questions). A 5-point Likert scale was used for responses, where 1 represented a poor condition and 5 represented an 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 the average scores for each dimension and overall quality of life are then 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 whether the variables followed a normal distribution. Analysis of covariance (ANCOVA) was employed to examine differences between groups. If a statistically significant difference was found, the Tukey post-hoc test was used to determine which means were significantly different. A significance level of $P \leq 0.05$ was considered statistically significant.

Results

Table 1 presents the demographic characteristics of the participants. According to the Shapiro-Wilk test, all dependent variables had a $P>0.05$, 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.

For hypothesis testing, parametric statistical tests were used. Using repeated measures ANOVA, the potential changes within each group were evaluated at two time points: Pre-test and post-test. A two-way mixed ANOVA (2×2 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 RT combined with ES group outperformed the RT 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. The results are presented in Table 3.

Discussion

The findings of the current study indicated a notable improvement in functional capacity due to both interventions, although no statistically significant difference was observed between the two types of exercise. Most studies confirm that exercise improves functional capacity. The results align with those of Kucio et al. [23] and Iliou et al. [22]. However, they contradict the findings of Puldavski et al. and Ennis et al. [19, 21] and Iliou et al. [22] The aligned studies examined the effect of only RT

Table 1. Demographic characteristics of participants

Variables	Mean±SD	
	Electrical Stimulation Group	Control Group
Age (y)	62.55±14.14	64.43±21.21
Height (m)	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

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Table 2. Analysis of covariance for the effect of intervention on quality of life and functional capacity

Dependent Variables	Source of Variation	Sum of Squares	df	Mean Squares	F	P	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	-	-	-
Functional capacity	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	-	-	-

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Table 3. Results of paired t-test for comparing quality of life and functional capacity between groups

Variables	Group	Mean±SD Difference	t	df	P*
Quality of life	Intervention	-16.7±4.64	16.07	19	0.001
	Learning	-11.3±4.76	10.66	19	0.001
Functional capacity	Intervention	-2.15±4.77	20.18	19	0.001
	Control	-1.47±7.15	9.21	19	0.001

*Significant values.

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intervention or combined with ES on improving aerobic power and functional capacity. For instance, Iliou et al. and Kucio et al. examined the effect of exercise training combined with ES on improving functional capacity. The results showed that exercise training with and without ES improved functional capacity [22, 23]. In contrast, Puldavski et al. and Ennis et al. investigated the effect of electrical muscle stimulation (EMS) on functional capacity in patients with HF. In the present study, RT with and without ES was employed [19, 21, 32].

Our study indicated that RT, combined with ES, could also improve functional capacity in these patients. In most studies, the effects of EMS have been primarily examined in outpatients with stable moderate HF [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 HF [32, 33]. Regarding the effect of ES on functional capacity, Puldavski et al. and Ennis et al. observed no significant impact [19, 21, 34]. In contrast, interventions examining the effect of RT on functional capacity supported the findings of this study. For example, Sloan et al. [35] examined the impact of two different intensities of RT on functional capacity in patients with HF. While functional capacity improved in both groups, no significant difference was observed between them [33]. Similar comparative studies on the effects of RT with and without ES on functional capacity, conducted by Reddy et al. [36] and Ilio et al. confirmed the results of this study. Both groups found that functional capacity improved, with no significant differences between them [22]. Several mechanisms have been proposed to enhance aerobic capacity through RT. One plausible mechanism is increased muscular strength and endurance, which improves 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 quality of life scores, but the improvement was greater in the exercise plus ES group. This finding aligns with the results of Poltavskaya et al. and Gomes-Neto et al. The authors found that short-term in-hospital EMS leads to improvements in functional quality of life scores in selected patients early after HF decompensation, which are retained over 1 month after [19, 33]. Furthermore, Gomes-Neto et al. indicated that conducting RT could enhance quality of life scores among patients with HF [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. investigated the relationships between objectively measured physical activity, exercise capacity, and quality of life in older patients with obese HF 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. found that exercise training has a positive effect on quality of life in CHF patients [32]. The roles of BMI and aerobic capacity in patients' quality of life were compared, and it was revealed that aerobic capacity had a stronger correlation with quality of life [22, 23, 30]. In addition to intervention studies that examined the effect of exercise or ES 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 has been demonstrated that an improvement in functional capacity is significantly and directly correlated with overall health, physical function, and mental health [35]. For instance, Reddy et al noted that improving functional capacity leads to an increase in the quality of life in CHF patients [36]. Buendía et al. studied the relationship between functional capacity and quality of life in patients, observing a direct correlation between enhanced functional capacity and improved quality of life [37].

These findings, in most cases, support the results of the present study, suggesting that higher aerobic capacity is associated with an 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 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]. Soer et al. investigated the relationship between physical fitness factors and quality of life, finding a positive and significant correlation, albeit one that is not very strong. The results suggest that quality of life improves with enhanced physical fitness [10].

Although no significant difference was observed between the effects of the two interventions on functional capacity in this study, calculating the change ratio revealed that exercise combined with ES had a greater impact on functional capacity. This finding aligns with the majority of 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 RT with ES and RT 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 that RT be used with caution during the hospitalization phase of CHF patients for rehabilitation.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Shahid Beheshti University of Medical Sciences, Tehran, Iran (Code: IR.SBMU.RETECH.REC.1404.006).

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Authors' contributions

Investigation, data collection, and project administration: Samaneh Dezhbarar; Review & editing: SedighehSadat Naimi and Soulmaz Rahbar; Conceptualization and supervision: SedighehSadat Naimi; Methodology: Soulmaz Rahbar; Final manuscript: All authors.

Conflict of interest

The authors declared no conflict of interest.

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