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Stair-climbing test as a physical performance tool in chronic heart failure: Association with left ventricular ejection fraction and pulmonary functions

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ABSTRACT

OBJECTIVE: The cardiopulmonary exercise test (CPET), which is used as the gold standard in the evaluation of exercise capacity in patients with chronic heart failure (CHF), is not always possible to perform in clinics and field tests are preferred. The aim of this study was to determine the effectiveness of the symptom-limited stair climbing test (SLSCT) in patients with CHF.

METHODS: Thirty-one patients (mean age: 65.52±7.57 years) with New York Heart Association (NYHA) Classification stage II-III CHF were included. Exercise capacity was assessed by SLSCT, 6-minute walk test (6MWT), and CPET. Predicted peak oxygen consumption (VO_{2peak}), heart rate (HR), blood pressure (BP), and left ventricular ejection fraction (LVEF), pulmonary functions were measured.

RESULTS: The predicted VO_{2peak} calculated from SLCT was significantly higher than that of 6MWT and CPET ($p<0.05$). On analyzing the HR changes, SLSCT increased HR by more than 6MWT and less than CPET ($p<0.05$). There were significant correlations between the predicted VO_{2peak} values by SLSCT and LVEF, BMI (Body Mass Index), FEV1 (Forced Expiratory Volume in One Second), and FVC (Forced Vital Capacity), predicted VO_{2peak} of CPET ($r=0.36$-0.55, $p\leq0.05$).

CONCLUSION: SLSCT was found to be effective and easy to use in assessing exercise capacity in CHF patients. Compared with 6MWT, SLSCT gives better results in determining the clinical status and hemodynamic responses of the patients. SLSCT can be an alternative method for assessing exercise capacity in the absence of CPET.

Keywords: Chronic heart failure; exercise capacity; left ventricular ejection fraction; stair-climbing test.

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Heart failure (HF) is a leading health problem worldwide due to increasing frequency and prevalence [1]. HF can be caused by abnormalities in myocardial function (systolic and diastolic function) or by valve or pericardial disease. Left ventricular disorder seen in chronic heart failure (CHF) causes fatigue owing to the worsening of the skeletal muscle perfusion during exercise [2].

Objective assessment of exercise intolerance in CHF patients is performed using different physical stress tests. Cardiopulmonary exercise test (CPET) provides an objective measurement of metabolic, respiratory and cardiovascular responses at anaerobic threshold and respiratory compensation [3]. In the absence of CPET, easy and cost-effective field tests are used in the clinic. When CPET is unavailable, 6-minute walk test (6MWT) and step test are alternatives for evaluating HF. 6MWT is an easy and quick test to evaluate submaximal capacity [4, 5]. However, the step test as an alternative field

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test for evaluating submaximal capacity requires minimal physical space, and the reliability of the test to estimate exercise tolerance has been proven [6]. Otherwise, there is no standardized protocol in the literature for the symptom-limited stair-climbing test (SLSCT) [7, 8]. In a study investigating alternative ways for prescribing aerobic exercise, literature on step tests was reported to be limited regarding CHF [9].

This study was planned to evaluate the effectiveness of SLSCT in determining the exercise capacities of patients with CHF and to interpret the relationship between the test results and exercise capacity, functional capacities, left ventricular ejection fraction (LVEF) and pulmonary functions.

MATERIALS AND METHODS

Study Design

6MWT and SLSCT were performed on the same day. After performing the first test, the patients were advised to rest for at least two hours. 6-minute walk test (6MWT) and SLSCT tests were performed in a random order to eliminate fatigue and learning effects. CPET was performed on a different day after 24 hours. The tests were performed in the morning and at least one hour after food consumption. Patients were asked to continue their standardized medications.

Written informed consent was obtained from all participants included in the study. The study protocol was authorized by the Dokuz Eylul University Non-interventional Research Ethics Committee (date: 12.12.2016, protocol number: 2961-GOA, approval number: 2016/31-27). The investigation conforms with the principles outlined in the Declaration of Helsinki.

Participants

Thirty-one patients (mean age: 65.52±7.57 years) with stage II-III CHF according to the NYHA classification, with an LVEF of ≤45% admitted to Cardiology Department of Turkish Red Crescent Konya Hospital were included. All patients were stable and continued their standardized medication. Age (years), gender, height (m), body weight (kg), Body Mass Index (BMI) (kg/m^2), smoking history, and respiratory symptoms (sputum, dyspnoea, chest pain, etc.) were recorded. Patients with uncontrolled cardiac arrhythmia, unstable angina, uncontrollable hypertension, acute myocarditis or pericarditis, acute pulmonary embolism or pulmonary infarction, severe symptomatic aortic stenosis, severe valve disease, visual, neurological, musculoskeletal, or orthopedic problems/diseases and who were unable to perform the exercise tests were excluded.

> **Highlight key points**
>
> - KPET is not always available as it is expensive, requires equipment and experienced people.
> - 6 MWT is an easy test that can be performed without equipment.
> - Different field tests are needed in chronic heart faliure to assess exercise capacity.
> - Our findings showed that, SLSCT had similar results to the CPET compared to the 6MWT.
> - SLSCT better adapts to the clinical features of the patients and can be applied safely.

Symptom-Limited Stair-Climbing Test (SLSCT)

Patients were given prior information about the test procedure. During the test, they were asked to climb stairs at their own pace. Being allowed to receive support from handrails only when there was a loss of balance. The test was conducted between the second and seventh floors of a seven-storey hospital. Each floor had a chair on which patients could sit and relax and call for emergencies. The patients were asked to climb up to five flights of stairs and were accompanied and encouraged by a clinician during the climbing. Verbal communication between the patients and clinician was continued for the evaluation of perceived exertion and symptoms. During the test, the patients' HR, and peripheral oxygen saturation (SpO_2) were monitored using a portable pulse-oximeter. HR, BP, perceived exertion (MBS), SpO_2 before and after the test, and the number of steps, duration of the test were recorded. After the test, work and predicted VO_{2peak} values were calculated through the formulae given below [10];

Work (W)=([step height in meters] x [steps/min] x [weight in kg]) x (conversion of kg/ml to watts)

Work (watts)=([0.174] x [steps/min] x [wt in kg]) x 0.1635

VO_2 ml/min=5.8 x wt in kg + 151 + (10.1 x work in watts)

Six-Minute Walk Test (6MWT)

The test was performed according to the American Thoracic Society guidelines [11]. 6MWT was performed in a 100-ft (30 m) long hallway. Only standardized phrases for encouragement were used during the test. Patients were asked to walk as far as they could in six minutes. Patients would be allowed to stop when they could not continue the test because of fatigue or dyspnoea and were asked to rest when necessary. HR, diastolic blood pressure (DBP), systolic blood pressure (SBP), perceived exertion, and SpO_2 were recorded. According to 6MWT, the predicted VO_{2peak} values of the individuals were calculated. Cahalin formula frequently used in literature was used to calculate predicted VO_{2peak} values in this study [12];

VO_{2peak} = 0.03 x 6MWT distance (m) + 3.98

Cardiopulmonary Exercise Test (CPET)

CPET was performed with Kardiosis ARS-treadmill (Ankara, Turkiye) device and the Bruce protocol was used. In Bruce protocol, the test starts at a speed of 2.7 km/h, with a slope of 10%, and increases in speed and inclination every three minutes. The test is in progress until the individual cannot continue the test [13]. VO_{2peak} was calculated indirectly by using VO_{2peak} calculation formulas.

The following formula is used for active and sedentary men [14]:

$VO_{2peak} = 14.76 - (1.379 \times T) + (0.451 \times T^2) - (0.012 \times T^3)$

The following formula is used for active and sedentary women [15]:

$VO_{2peak} = 4.38 \times T - 3.90$

T: Testing Time (min)

Pulmonary Function Test

Pulmonary function test was performed with a spirometer in the sitting position, with the patient's nose covered with a clip according to the American Thoracic Society guideline. The pulmonary function parameters: forced expiratory volume in one second (FEV1), forced vital capacity (FVC), FEV1/FVC ratio, mean forced expiratory flow between 25% and 75% of FVC (FEF 25-75), peak expiratory flow (PEF) values were recorded as percentage of expected values according to age, height, body weight and gender [16].

Modified Borg Scale (MBS)

MBS consists of ten items used to describe the severity of exertion and dyspnoea at rest [17]: Patients were asked to state the closest description or the number of their perceived exertion at rest and during exercise.

Table 1. Clinical characteristics of patients*

Demographic and clinic characteristics	Mean±SD
Age (years)	65.52±7.57
Height (m)	1.69±0.07
Weight (kg)	85.52±17.03
BMI (kg/m²)	29.78±5.39
LVEF, (%)	37.10±4.56
Pulmonary function test results	
FVC (l/sec)	3.33±0.74
FVC, %	82.13±19.24
FEV1 (l/sec)	2.65±0.59
FEV1, %	85.45±21.09
FEV1/FVC, %	79.20±7.39
FEF25-75 (l/sec)	2.77±0.85
FEF25-75, %	85.94±26.94
PEF (l/sec)	4.13±1.76
PEF, %	73.90±19.61
Comorbidities (n=44), %	
Hypertension	58.0
Diabetes mellitus	38.8
Hyperlipidemia	41.9
Arrhythmia	6.4
COPD	3.2

BMI: Body Mass Index; LVEF: Left Ventricular Ejection Fraction; NYHA: New York Heart Association; COPD: Chronic Obstructive Pulmonary Disease. *: Values, except mean and standard deviation, are presented as number and percentage.

Statistical Analysis

For determination of the sample size, it was found necessary to include 30 participants for 80% statistical power (α: 0.05, β: 0.20) after analysis of G Power (G* Power, Ver. 3.1.9.2 Heinrich Heine Universität Düsseldorf, Germany) [18, 19] program based on CPET and SLSCT predicted VO_{2peak} values. However, 31 patients who were admitted to the hospital and who met the study criteria could be included. The statistical analyses were performed using SPSS 20.0 (IBM SPSS® Statistics for Windows, Version 20.0. NY: IBM Corp, Chicago/USA) for Windows operating system. Kolmogorov-Smirnov test was used to analyze normality of the data. The descriptive statistics of the dependent and independent variables were depicted by frequency values, mean, standard deviation and percentages. In the

TABLE 2. Comparison of SLSCT, 6MWT and CPET results with each other

	6MWT Mean±SD	SLSCT Mean±SD	CPET Mean±SD	p[1]	p[2]	p[3]
VO_{2peak} (ml/kg/min)	15.16±2.24	25.27±3.42	16.29±2.84	0.002*	0.001*	0.030*
Recovery HR (beats/min)	81.19±15.59	77.90±14.56	90.69±19.40	0.041*	0.002*	0.030*
ΔHR (beats/min)	15.38±10.58	36.32±23.62	44.68±22.57	0.002*	0.003*	0.190
ΔSBP (mm/Hg)	6.77±9.08	12.90±10.22	–	0.004*	–	–
ΔDBP (mm/Hg)	2.90±7.39	6.77±8.90	–	0.090	–	–
$ΔSpO_2$ %	-0.09±2.32	-0.70±3.10	–	0.280	–	–
ΔMBS	1.32±1.56	2.40±1.80	–	0.003*	–	–

SLSCT: Symptom Limited Stair Climbing Test; 6MWT: 6 Minute Walk Test; CPET: Cardiopulmonary Exercise Test; SD: Standard Deviation; VO_{2peak}: Peak Oxygen Consumption; ΔHR: Heart Rate Change Before and After Exercise Test; ΔSBP: Systolic Blood Pressure Change Before and After Exercise Test; ΔDBP: Diastolic Blood Pressure Change Before and After Exercise Test; $ΔSpo_2$ %: Saturation of Peripheral Oxygen Change Before and After Exercise Test; ΔMBS: Modified Borg Scale Change Before and After Exercise Test; MBS: Modified Borg Scale; p[1]: Comparison of predicted VO_{2max} mean values of 6MWT and SLSCT; p[2]: Comparison of predicted VO_{2max} mean values of CPET and SLSCT; p[3]: Comparison of predicted VO_{2max} mean values of 6MWT and CPET. *: $P<0.05$.

measurement of the dependent variables, for normal distribution t-test, if the variable does not normally distribute, Wilcoxon signed-rank test was used to compare the repeated measures of each group. Correlation between the obtained data was calculated by Pearson correlation test. Correlation coefficient was considered as 0-0.19 very weak, 0.20-0.39 weak, 0.40-0.59 medium, 0.60-0.79 strong, and 0.80-1.0 very strong. The significance level was determined at a 95% confidence interval according to the value of $p<0.05$.

RESULTS

During the study period, 44 patients were assessed for eligibility but five of them were excluded due to orthopedic discomfort, five due to age criterion, and three due to their unwillingness to participate. A total of 31 patients suitable for undergoing CPET, SLSCT, and 6MWT were included. No complications were recorded due to the tests. The demographic and clinical characteristics of the patients were given in Table 1.

SLSCT was ended by patients because of dyspnoea (n=11), leg fatigue (n=10) and general fatigue (n=5). Among the three tests, the highest predicted VO_{2peak} belonged to SLSCT ($p<0.05$). HR changes were investigated before and after the test; SLSCT increased the HR more than 6MWT (20.93±22.14 beats/min, p=0.002) and less than the CPET (-7.48±30.14 beats/min, p=0.190). CPET was the test with the highest recovery HR ($p<0.05$). SLSCT had more changes in SBP than 6MWT (6.12±11.08 mmHg, p=0.041). Perceived exertion was found to be significantly different between 6MWT and SLSCT (p=0.003). The predicted VO_{2peak} values, the pre and post-test HR, SpO_2, perceived exertion, SBP and DBP differences of three different exercise tests were compared (Table 2).

Significant correlations were found between 6-minute walking distance (6MWD) and the SLSCT parameters: the number of workloads (watts) (r=0.50, p=0.010), the number of steps (r=0.66, p=0.002), the number of floors (r= 0.66, p=0.001). The predicted VO_{2peak} value of SLSCT was higher than 6MWT (p=0.002). There was a significant correlation between HR changes of SLSCT and 6MWT (r=0.36, p=0.050) and no correlation was detected in terms of the the BP changes. SpO_2 changes in all the three tests were similar ($p>0.05$). Positive correlations were found between CPET exercise workload (met) and SLSCT's number of steps (r=0.54, p=0.003), and number of floors (r=0.54, p=0.003).

Table 3 provides the intercorrelations among pulmonary functions, LVEF and test results of patients. Significant correlations were detected between SLSCT's number of floors and FEV1, FVC values. There were correlations between SLSCT workload and LVEF, BMI, FEV1, FVC values, and age (r=0.36-0.55, $p<0.05$). Correlations were detected between the predicted VO_{2peak} value of SLSCT and LVEF, BMI, FEV1, FVC, age (r=0.38-0.65, $p<0.05$). A correlation was found between 6MWD and the predicted VO_{2peak} value with FVC (r=0.35, p=0.040), and age (r=-0.48, p=0.004).

Table 3. The Relationship between pulmonary functions, LVEF and tests results of patients

	SLSCT number of floors	SLSCT workload (watt)	SLSCT VO_{2peak} (ml/kg/min)	6MWT VO_{2peak} (ml/kg/min)	CPET workload (MET)	CPET VO_{2peak} (ml/kg/min)
Age (years)	-0.53	-0.42	-0.38	-0.48	-0.40	-0.29
	0.002*	0.010*	0.031*	0.004*	0.030*	0.101
BMI (kg/m²)	-0.82	0.55	0.65	-0.11	-0.16	-0.12
	0.660	0.004*	0.006*	0.950	0.412	0.524
LVEF (%)	-0.01	0.36	0.40	0.07	-0.07	-0.07
	0.947	0.040*	0.020*	0.977	0.718	0.700
FVC (l/sec)	0.39	0.50	0.47	0.35	0.23	0.23
	0.020*	0.003*	0.004*	0.040*	0.224	0.218
FVC (%)	-0.03	-0.09	0.07	-0.04	0.16	0.19
	0.879	0.604	0.705	0.818	0.394	0.303
FEV1 (l/sec)	0.38	0.49	0.47	0.32	0.17	0.18
	0.030*	0.002*	0.003*	0.071	0.360	0.328
FEV1 (%)	0.14	0.22	0.25	0.03	0.33	0.40
	0.434	0.223	0.174	0.040*	0.081	0.020*
FEV1/FVC (%)	-0.12	-0.05	-0.00	-0.22	-0.29	-0.19
	0.484	0.773	0.972	0.234	0.131	0.315
PEF (l/sec)	0.30	0.27	0.27	0.27	-0.00	-0.11
	0.103	0.138	0.138	0.138	0.977	0.564
PEF (%)	0.01	0.17	0.19	0.05	-0.14	-0.09
	0.934	0.366	0.288	0.774	0.453	0.614

SLSCT: Symptom Limited Stair Climbing Test; 6MWT: 6 Minute Walk Test; CPET: Cardiopulmonary Exercise Test; VO_{2peak}: Peak Oxygen Consumption; BMI: Body Mass Index; LVEF: Left Ventricular Ejection Fraction; FEV1: Forced Expiratory Volume in One Second; FVC: Forced Vital Capacity; PEF: Peak Expiratory Flow. r value is given in the first row and p value is given in the second row of the table. *: P<0.05.

DISCUSSION

This study was planned to evaluate the usability of the SLSCT to evaluate exercise capacity in chronic heart failure patients by comparing it with the 6MWT and CPET. SLSCT test was found to cause a change in heart rate close to the CPET. In addition, it was determined that SLSCT revealed better exercise responses than the 6 MWT in the measurement of exercise capacity, since it required a higher MBS score and more systolic blood pressure change compared to the 6 MWT. Also, SLSCT is closely associated with clinical parameters and LVEF of patients compared with other tests.

CPET is the gold standard for prescribing individualized exercise program and achieving systemic responses regarding exercise tolerance [20]. However, it is not always possible to use CPET because it requires a lot of equipment and a specialist to perform the test [21]. Therefore, there is a need for easy and tolerable field tests [8].

SLSCT is an important field test used especially in lung diseases to determine postoperative complications [22]. Routine clinical use of the test for HF is not common [9]. In a study by Doutrelau et al. [23], hemodynamic responses of a 6MWT and graded cycling exercise test in patients with heart transplantation were evaluated. During 6MWT, initial and post-test values of oxygen saturation in the control and heart transplantation group were reported to be unchanged and the HR increased in both groups, but the chronotropic response obtained by excising exercise HR from resting HR decreased in patients undergoing transplantation. The predicted 6MWT's peak VO_2 value calculated using the Cahalin formula was lower than that measured during the cycling exercise test. In this study, the SpO_2 value before and after the 6MWT and SLSCT did not change, which was similar to the findings in the literature. HR increased after both tests, but this increase was higher in SLSCT than in 6MWT. However, contrary to these findings, in a study evaluating hemodynamic responses to different exercise tests (stair climbing, 6MWT, cycling ergometry) 13 patients with LVEF<35 in stage II, III, IV according to NYHA classification were included, it was reported that HR changes in SLSCT and 6MWT were similar [24]. In this study, the peak HR value by CPET was significantly higher than that by SLSCT. The lowest peak HR value of the three tests was seen by 6MWT. Thus, SLSCT is more like CPET compared with the 6MWT, and it gives better results in terms of chronotropic response. SLSCT can be used in patients who do not reach the maximal level during CPET.

In the absence of CPET, 6MWT and stair-climbing tests were an alternative to the evaluation of patients with CHF [9]. 6MWT as submaximal [25], and SLSCT as maximal [26] tests were accepted for patients with CHF. In a study by Oliveira et al. [9], (83 patients with LVEF≤40%, NYHA stage II), HR responses by 6MWT and SLSCT were evaluated. Heart rates during cycling exercise and stair-climbing test were found to be similar. No significant relationship was found between peak exercise HR and 6MWT HR. Although there was no correlation with the perceived exertion as assessed by the Borg scale during the 6MWT and stair-climbing test, there was a significant relationship between the cycling exercise test and stair-climbing test. In our study, SLSCT had a peak HR response more similar to CPET than 6MWT. Moreover, the MBS score after SLSCT was significantly higher than 6MWT. This shift in MBS score has shown that stair-climbing activity is more challenging than walking. SLSCT revealed the symptoms that caused exercise intolerance and showed similar characteristics with the purpose and results of CPET.

VO_2 measurements can be calculated directly and indirectly by means of formulas. In a study by Maldonado-Martin et al. [27], a significant correlation was found between peak VO_2 values measured directly in patients with CHF via the cycling exercise test and those calculated by Cahalin formula after 6MWT. In our study, SLSCT had a significantly higher predicted VO_{2peak} value than both 6MWT and CPET. Based on this finding, it is justified that stair-climbing activity requires more oxygen consumption than walking activity. Consequently, muscle activation and hemodynamic stress are more likely to be caused by more oxygen consumption during climbing stairs than walking. The goal of the patients to reach the next level or step was motivated during SLSCT. There was a target to be reached in the step test, unlike walking in a standard corridor in 6MWT that encouraged patients to climb more stairs. Moving the body to the next step requires more energy than walking. In a study by Beckles et al. [28], the stair climb test was found to be effective in determining the VO_{2max} value although it did not have a standard procedure and the VO_{2max} value in patients who could climb five floors was ≥20 ml/kg/min and in those who could not climb one floor, it was ≤10 ml/kg/min. In our study, there was a moderate correlation between the predicted VO_{2peak} value and the number of steps. The results of SLSCT may vary from the number of stairs where the test is conducted, the number of floors and the height of the steps. To standardize this test and determine its normal values in future studies, a comparison of the results of the test in different disease groups and healthy individuals may be useful.

The main problem is the reduction of the pump capacity of the heart in patients with CHF. LVEF used in the evaluation of the pump capacity is an important predictor of clinical monitoring, decision-making and determining the type of disease [29]. It was found that only SLSCT parameters were related to LVEF. Particularly, there was a moderate correlation between LVEF and predicted VO_{2peak} value of SLSCT. This result showed that due to the sensitivity of SLSCT to the severity of the disease, it can be used in the clinical follow-up of CHF patients.

Our study had limitations. Most of the people included in the study are men, which makes it difficult to interpret the results for both genders due to the lack of equal distribution. Failure to measure with the help of a gas analyzer affected the results. Although the formulas used in the calculation of VO_{2max} have validity, they only give estimated results.

SLSCT, which we found to be associated with LVEF, BMI, age, and pulmonary functions and required more effort than 6MWT, increased hemodynamic responses and provided more accurate measurement in determining exercise capacity of patients. In addition, it was comfortable to use the daily stair-climbing activity that the patients are familiar with. SLSCT results were closer to the maximal tests than 6MWT. SLSCT causes less hemodynamic stress than maximal exercise tests and therefore is safer than maximal tests. In patients who cannot perform CPET with both bicycle ergometry and treadmill, the use of SLSCT in the planning of medical treatment and exercise programs for clinical follow-up will be effective.

Conclusion

CPET is the most objective method for measurement of exercise capacity, but since it is not found in each clinic, different field tests are needed to assess a patient's exercise capacity. For this need in our study, evaluating SLSCT in detail, the feasibility of the test and its tolerability in this patient group were proven. In this group of patients, 6MWT had less hemodynamic stress than SLSCT. It can be concluded that the reason for the increase in heart rate and oxygen consumption during the SLSCT test may be due to the use of different muscle groups such as the gluteus maximus muscle weakened due to long-term inactivity in patients with CHF. SLSCT yielded a maximal level of exercise capacity like CPET and 6MWT and provided submaximal exercise capacity measurement results. SLSCT has been applied to a small number of disease groups in the literature and has not been standardized. More studies are needed in the future to expand the use of this test and perform it in a standard manner.

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Authorship Contributions: Concept – SO; Design – SO, BA; Supervision – SO; Data collection and/or processing – BA; Analysis and/or interpretation – SO; Literature review – BA; Writing – BA, SO; Critical review – SO.

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