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Comparison of Incremental Shuttle Walking Test, 6-Minute Walking Test, and Cardiopulmonary Exercise Stress Test in Patients with Myocardial Infarction

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Statistical Analysis C
Data Interpretation D
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Background: This study aimed to analyze the correlations among peak oxygen uptake (VO_2) in cardiopulmonary exercise test (CPX), incremental shuttle walking test (ISWT), and 6-minute walking test (6MWT) distances in patients with myocardial infarction (MI). Additionally, we aimed to determine the relationship between the maximum heart rate (HRmax) and the rate of perceived exertion (RPE) among the tests and compare the changes in heart rate to verify the clinical benefit of the submaximal stress test.

Material/Methods: We analyzed the correlation by using the ISWT and 6MWT at 30-min intervals after 24 h of CPX in patients with MI. The differences in HRmax and RPE between the tests were also compared. Additionally, changes in heart rate were analyzed using descriptive statistics.

Results: The ISWT distance was more strongly correlated with peak VO_2 (r=.823: 95% CI, 0.681-0.910) than was 6MWT (r=0.776: 95% CI, 0.683-0.870). HRmax in the CPX demonstrated a significant correlation with that in the ISWT and 6MWT ($P<0.05$), with the ISWT (r=0.815: 95% CI, 0.451-0.996) having a stronger correlation than the 6MWT (r=0.664: 95% CI, 0.146-0.911). The value of RPE was significantly different ($P<0.05$); however, there was no significant correlation. Changes in heart rate in the 6MWT plateaued after the initial increase, while the heart rate in the ISWT and CPX increased gradually.

Conclusions: We recommend the ISWT as a submaximal exercise test to evaluate exercise capacity in patients with MI.

Keywords: **Exercise test • Myocardial Infarction • Oxygen Consumption • Walk Test**

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Background

Myocardial infarction (MI) occurs when the blood vessels are narrowed and damaged by atherosclerosis, resulting in blood clot formation and blockage of a blood vessel [1]. Cardiac rehabilitation (CR) reduces the prevalence and mortality of cardiovascular diseases by recovering exercise capacity, providing psychological security, and managing risk factors in patients with MI [2]. Several countries, such as the United States, Canada, Europe, the United Kingdom, and Japan, have created and recommended a standard of clinical practice guidelines for CR [2-6]. Recently, Korea developed clinical practice guidelines for CR and has utilized these in clinical fields [7].

Clinical practice guidelines for CR recommend use of the cardiopulmonary exercise test (CPX) for assessment of patient cardiopulmonary exercise ability, exercise prescription, and prognosis prediction [7]. CPX is an exercise stress test combined with expired gas analysis, allowing for the simultaneous observation of cardiovascular and respiratory systems responses [8]. Medical assessment and CPX are performed with history-taking before starting the exercise. It investigates the risk of heart attack due to exercise, evaluates the progression of heart diseases and therapeutic effects, and evaluates functional ability to safely perform physical activities [8,9]. Exercise intensity at CR is determined using the peak oxygen uptake (VO_2) measured by CPX [10]. There are reasons the participants cannot continue CPX; peak VO_2 is defined as the peak oxygen uptake at the end of the exercise for any reason. Higher peak VO_2 means better exercise capacity [10,11]. However, CPX requires expensive equipment and facilities, as well as emergency equipment and well-trained experts [12].

The 6-minute walking test (6MWT) and shuttle walking test are submaximal exercise tests that can measure cardiovascular function in the healthcare setting. Clinical practice guidelines for CR recommend the 6MWT as a submaximal exercise test if patients are unable to perform CPX [7]. The 6MWT assesses the distance walked over 6 min. It is safe and reflects the functional exercise level for daily physical activities [13]. The shuttle walking test consists of the incremental shuttle walking test (ISWT) and an endurance shuttle walking test (ESWT). The ISWT is a field test where patients walk around a 10-m course at a pace dictated by pre-recorded audio signals. The speed of the signals increases every minute, and patients can stop the test if they experience dyspnea, their oxygen saturation level decreases below a certain level, or they cannot maintain their walking pace with the signal [14]. The ESWT assesses the distance patients cover at a constant speed [15].

The 6MWT and shuttle walking test are submaximal exercise tests; hence, it is difficult to assess peak VO_2 as accurately as the CPX performed at maximal exercise capacity. The speed of 6MWT is regulated by the patient and is affected by motivation and encouragement [16]. Several reports demonstrated reliability problems and its lack of correlation with CPX [17,18]. Furthermore, the test-retest reliability of the 6MWT in patients requiring CR is low; hence, the need for a submaximal exercise stress test that can replace it has been addressed [19]. Currently, a protocol(s) for ISWT has been developed and distributed [20]. ISWT validity and reliability studies in patients with respiratory diseases, such as chronic obstructive pulmonary disease (COPD), have been reported; however, there are inadequate studies on patients requiring CR [21,22]. Therefore, the present study aimed to analyzed the correlations among CPX, ISWT, and 6MWT in patients with MI. Additionally, this study aimed to determine the relationship between the maximum heart rate (HRmax) and RPE as evaluation outcomes and to identify the clinical benefit of a submaximal exercise stress test by comparing changes in heart rate. We hypothesized that the peak VO_2 of CPX in patients with MI would have a stronger correlation with ISWT distance than with 6MWT and that HRmax of CPX would have a stronger correlation with ISWT than with 6MWT.

Material and Methods

Participants

This study was conducted from May 2021 to April 2022. We enrolled 30 patients who were diagnosed with acute MI and who received the percutaneous coronary intervention and participated in the outpatient cardiac rehabilitation program. Inclusion criteria were: (1) patients with acute MI aged ≥40 years and <75 years; (2) who had performed CPX on a treadmill; and (3) capable of performing both the ISWT and 6MWT. Exclusion criteria were: (1) contraindications of CPX [23]; (2) hearing impairment; (3) spinal and lower limb musculoskeletal disorders; (4) chest pain; (5) dizziness, or (6) other disorders such as COPD, asthma, peripheral vascular disease, or previous MI.

Study Design and Procedures

This was a prospective cross-sectional study. The sample size was calculated using the G*Power 3.1 program (Kiel University) [24]. Based on data from a previous study [25] in patients with heart failure, a sample size of 15 was required when a correlation coefficient between peak VO_2 and 6MWT was set as 0.67, a significance level of 0.05, and a power of 90%. Allowing for a 30% dropout rate, 20 participants were included in the study. All participants were informed of the study's purposes and procedures, and only those who signed informed consent participated in the study. This study was approved by the Ethics Committee of Chungnam National University Hospital Institutional Review Board and is registered

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in the World Health Organization (WHO) International Clinical Trials Registry Platform: KCT0007359.

Participants had a light meal 2-3 h before CPX and were not allowed to have intense physical activities, drink alcohol, smoke, or consume caffeine. CPX systems were calibrated, and the participants were educated on the procedures of test methods and emergency procedures [26]. In preparation for an emergency, participants were continuously monitored, and an emergency cart and a defibrillator were prepared. The ISWT and 6MWT, which are submaximal exercise stress tests, were performed 24 h after performing CPX. The participants were educated on the methods of each submaximal exercise test. Before the test, they warmed up for 10 min on a treadmill at a comfortable walking speed and then rested for 10 min. Each evaluation was conducted in a random order. A rest period of at least 30 min was provided between evaluations to minimize participant fatigue and to recover resting heart rate [27]. We assessed the correlation of the peak VO_2 measured using CPX with distances calculated using the ISWT and 6MWT. Additionally, HRmax, RPE, and changes in heart rate for each assessment were recorded to assess relationships and differences.

Assessment Methods and Procedures

Cardiopulmonary Exercise Testing

The modified Bruce protocol with a treadmill (T150DE, COSMED, Italy) was used in CPX. In this protocol, the exercise load increases every 3 min, whereas the speed is constant from Stage 1 to Stage 3 at 2.7 km/h and the incline increases by 5%. From Stage 4, the speed and incline increases. This is a modified Bruce protocol; hence, it is widely used for aged patients and patients with coronary artery diseases because it has a lower initial exercise load and load increment than the Bruce protocol [10]. A gas analyzer (Quark CPET, COSMED, Italy) assessed expired gas for each breath in a breath-by-breath analysis by wearing a facemask. CPX was performed according to the guidelines for exercise testing and prescription by the American College of Sports Medicine (ACSM) [10,23]. Electrocardiograms were monitored and changes in heart rate were recorded every 10 s using exercise testing equipment (StressVue, PHILIPS, The Netherlands). Peak VO2, HRmax, and RPE at the end of the test were recorded. CPX was performed by a clinical pathologist with 5 years' experience.

Six-Minute Walking Test

The 6MWT is a submaximal exercise test that assesses the maximum distance that a patient can walk voluntarily in 6 min. The test was performed in an indoor corridor far away from other people. The track was 30 m in length, marked every 3 m, with the turn-around points marked with a cone. The participants were instructed to walk as fast as they can for 6 min. They were allowed to rest or stop the test depending on their conditions during the test [16], and radio electrocardiography (SHC-U8, Solmitech, Korea) was used to record changes in heart rate every 10 s. Total distance, RPE, and HRmax at the end of the test were recorded.

Incremental Shuttle Walking Test

The ISWT is a 10-m field-walking test in which patients walk around with signals at speeds that increase every minute. The start and end points of the course were marked with cones, and dotted lines were set 0.5 m from the course as additional marks. Patient oxygen saturation, pulse rate, and blood pressure were measured, and test methods were explained to the patients before the test.

The ISWT has 12 levels, and each level takes 1 min. An MP3 file pre-recorded with signals was played, consisting of a signal for evaluation initiation, a signal for level initiation, and periodic signals at every shuttle. Three consecutive signals indicated the beginning of each level, and patients tried to reach the opposite cone before 1 periodic signal. As the number of shuttles to walk gradually increased with level, and as the periodic signals became shorter, the patients walked faster and were encouraged to walk as many shuttles as possible. The test was ended if the patients experienced dyspnea or could not keep the walking pace at the signal, or if oxygen saturation level fell below 80%. However, when the beep sounds, if the patient reached within 0.5 m of the cone, they were provided an opportunity and encouragement to walk to the next shuttle. The ISWT protocol is shown in **Figure 1** [14]. Total distance was calculated using the level and number of shuttles at the end of the test. Radio electrocardiography (Solmitech) was used to record changes in heart rate every 10 s, and HRmax and RPE were recorded at the end of the test. The 6MWT and ISWT were performed by a physical therapist with 5 years of experience in cardiac rehabilitation.

Statistical Analysis

Descriptive statistics were used to present the participants' general characteristics, and data were presented as mean and standard deviation. The correlation between the peak VO_2 and ISWT and 6MWT distances was analyzed by Pearson correlation coefficient as the primary outcome. For secondary outcome, the difference between HRmax and RPE at the end of the assessment was analyzed by ANOVA, and the Bonferroni method was used for post hoc testing. Additionally, a correlation between the values measured in the CPX, ISWT, and 6MWT was analyzed.

Lastly, descriptive statistics were used to present the changes in heart rate recorded at an interval of 30 sec for each evaluation

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Level	Number of shuttles													
1	1	2	3											
2	4	5	6	7										
3	8	9	10	11	12									
4	13	14	15	16	17	18								
5	19	20	21	22	23	24	25							
6	26	27	28	29	30	31	32	33						
7	34	35	36	37	38	39	40	41	42					
8	43	44	45	46	47	48	49	50	51	52				
9	53	54	55	56	57	58	59	60	61	62	63			
10	64	65	66	67	68	69	70	71	72	73	74	75		
11	76	77	78	79	80	81	82	83	84	85	86	87	88	
12	89	90	91	92	93	94	95	96	97	98	99	100	101	102

Figure 1. Incremental shuttle walking test protocol.

Table 1. General and medical characteristics of participants.

	Mild (n=6)	Moderate (n=8)	Severe (n=6)	Total (n=20)
Age, yr	58.83±9.70*	62.75±4.23	62.66±6.77	61.55±6.84
Height, cm	166.38±0.01	167.27±0.11	167.00±0.04	166.92±7.00
Weight, kg	68.82±3.91	72.57±9.20	68.43±8.04	70.20±7.49
BMI, kg/m^2	24.86±1.38	25.87±1.23	24.49±2.26	25.15±1.66
HR rest, beats/min	74.33±7.99	75.25±7.68	73.67±7.03	75.00±8.06
Peak VO_2, ml/kg/min	36.00±7.38	21.06±1.10	18.24±2.75	24.70±8.71
RER, point	1.15±0.07	1.14±0.06	1.10±0.03	1.13±0.05
ISWT, m	540.00±76.42	417.50±87.30	281.67±54.55	413.50±125.20
6MWT, m	611.00±37.18	535.50±19.91	383.83±56.74	512.65±99.357

* Data are presented as mean±SD. 6MWT – 6-minutes walking test; BMI – body mass index; HR – heart rate; RER – respiratory exchange ratio, ISWT – incremental shuttle walking test; VO_2 – oxygen uptake.

as a graph. Data collected from this study were analyzed using SPSS 26.0 (SPSS, Inc.). Statistical significance levels of all data were set at α=0.05

Results

We collected data from 20 patients with MI and stratified them into mild (n=6), moderate (n=8), and severe (n=6) groups in compliance with American Association of Cardiovascular and Pulmonary Rehabilitation (AACVPR) criteria for risk stratification. Participants' general and medical characteristics are presented in **Table 1**.

Primary and secondary outcomes are presented in **Tables 2 and 3**. The peak VO_2 in CPX had a significant correlation with distances of submaximal exercise tests (P<0.05). The ISWT (r=0.823: 95% CI, 0.681-0.910) had a stronger correlation with peak VO_2 than did 6MWT (r =0.776: 95% CI, 0.683-0.870). The tests revealed significant differences in HRmax among CPX, ISWT, and 6MWT (P<0.05); however, there was no significant difference between the ISWT and 6MWT (**Table 3**). HRmax in CPX had a significant correlation with HRmax in ISWT and 6MWT (P<0.05). The ISWT (r=0.815: 95% CI, 0.451-0.996) showed a stronger correlation than 6MWT (r=0.664: 95% CI, 0.146-0.911). A significant difference in RPEs between the test methods was observed (P<.05), but there was no significant correlation.

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Table 2. Comparison of correlations between the indicators of the Maximal Exercise Stress Test and the Submaximal Exercise Stress Test.

	CPX vs ISWT		CPX vs 6MWT	
	Pearson r	95% CI	Pearson r	95% CI
Peak VO_2 vs distance, m				
Mild (n=6)	.813*	.301~1.000	.737	.294~.999
Moderate (n=8)	.808*	.466~.988	.745*	.113~.977
Severe (n=6)	.855*	.477~1.000	.817*	.103~1.000
Total (n=20)	.823*	.681~.910	.776*	.683~.870
HRmax, beats				
Mild (n=6)	.940**	.759~.999	.929**	.714~1.000
Moderate (n=8)	.488	.293~1.000	.600	.276~1.000
Severe (n=6)	.987**	.954~1.000	.698	.509~1.000
Total (n=20)	.815*	.451~.996	.664*	.146~.911
RPE, scores				
Mild (n=6)	.632	.316~1.000	.250	-.500~1.000
Moderate (n=8)	-.025	-.698~.920	-.525	-.851~.224
Severe (n=6)	-.632	-1.000~.316	-.250	-1.000~.500
Total (n=20)	.297	-.203~.717	.296	-.185~.742

* p<.05. 6MWT – 6-minute walking test; CPX – cardiopulmonary exercise test; HRmax – maximum heart rate; ISWT – instrumental shuttle walking test; RPE – rating of perceived exertion; VO_2 – oxygen uptake.

Table 3. Comparison of differences in HRmax and RPE according to evaluation methods.

	CPX	ISWT	6MWT	F (p)
HRmax, beats	132.35±18.69*	114.90±15.39#	103.80±12.09#	16.964 (.000)
RPE, scores	16.10±1.02	14.10±1.02#	12.30±0.97#,##	71.266 (.000)

* Data are presented as mean±SD. 6MWT – 6-minutes walking test; CPX – cardiopulmonary exercise test; HRmax – maximum heart rate; ISWT – instrumental shuttle walking test; RPE – rate of perceived exertion. # Significant difference compared to CPX; ## significant difference compared to ISWT.

To assess changes in heart rate detected by the test methods, the changes in mean heart rate of 10 patients are presented in **Figure 2**. Heart rate in CPX gradually increased as the assessment progressed. A gradual increased heart rate in ISWT was observed and was similar to CPX. Unlike CPX and ISWT, a pattern of increased heart rate in the 6MWT plateaued after the initial increase.

Discussion

CPX is the most accurate test, and is the criterion standard, among various tests used to evaluate exercise capacity and cardiopulmonary function in patients with MI [28]. However, since it requires expensive equipment and professional reading by well-trained experts, relatively simple and applicable submaximal exercise tests are more widely used.

We found that peak VO_2 in CPX had a strong correlation with the ISWT (r=0.823) and a fair correlation with the 6MWT (r=0.776), showing that the ISWT has a stronger correlation with peak VO_2 than does the 6MWT. The ISWT and 6MWT are similar in that they are submaximal exercise tests performed in the field. However, the 6MWT can adjust the pace to internal factors, such as patient condition and willingness, motivation, endurance, encouragement, and learning effect, while the ISWT is less affected by internal factors because it is a standardized test and adjusts pace by external signals. Previous studies reported that the ISWT has a stronger correlation with peak VO_2 than the 6MWT in patients with COPD

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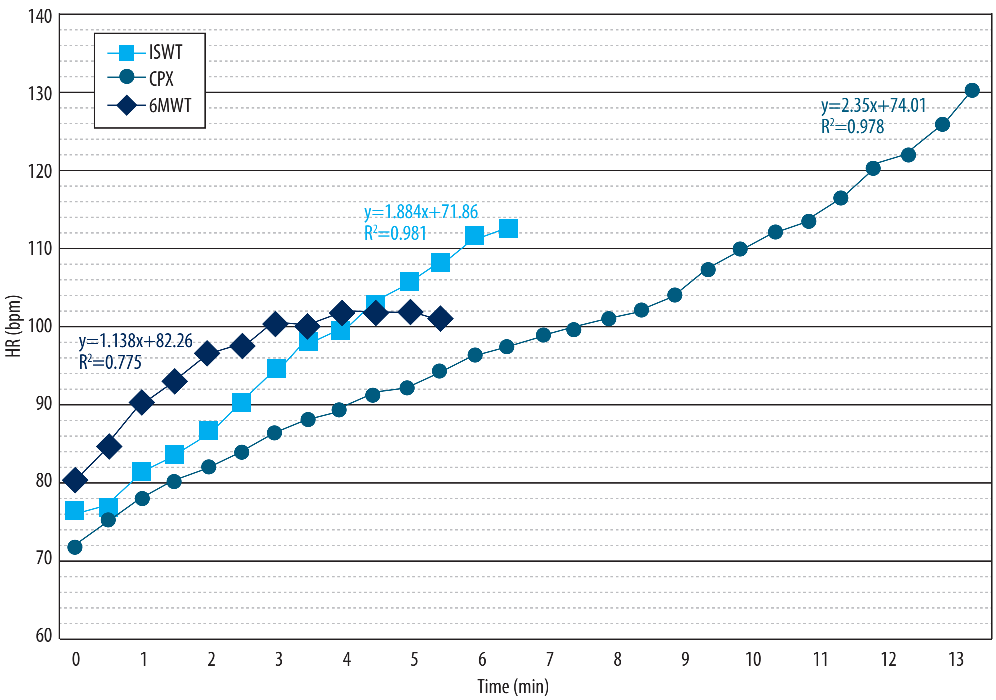

Figure 2. Heart rate responses to the CPX, ISWT, and 6MWT. HR – heart rate; CPX – cardiopulmonary exercise test; ISWT – incremental shuttle walking test; 6MWT – 6-minute walking test.

and heart failure [25,29,30]. Considering the controlling factors of the 2 submaximal exercise tests, our results support those of previous studies.

Additionally, we analyzed the results by dividing them into sub-groups of mild (n=6), moderate (n=8), and severe (n=6) in compliance with the AACVPR criteria for risk stratification. The results demonstrated that ISWT and 6MWT had higher correlation coefficients in the severe risk group (ISWT: r=0.855; 6MWT: r=0.817) than in the mild risk group (ISWT: r=.813; 6MWT: r=.737) or moderate risk group (ISWT: r=0.803; 6MWT: r=0.745). In the 6MWT, the correlation coefficient in the low-risk group was insignificant. This suggests that participants with low exercise capacity or in the high-risk group may show a stronger correlation with the results of submaximal exercise tests. A previous study confirmed that the group with higher exercise capacity had a lower correlation, and suggested that in the 6MWT, a ceiling effect occurs if participants have higher exercise capacity [30].

There was a significant difference in HRmax between the maximal exercise test and the submaximal exercise test. The modified Bruce protocol is a peak load test performed on a treadmill, in which the incline is progressively increased with speed. The participants performed up to their maximum load, and the respiratory exchange ratio showed their effort. In contrast, the 6MWT and ISWT are submaximal tests performed under voluntary maximal effort by auditory cues. There was no significant difference in HRmax between the ISWT and 6MWT. However, HRmax in the ISWT demonstrated a better correlation with CPX (r=0.815) than the 6MWT (r=0.664).

Unlike CPX, submaximal exercise tests can be terminated early due to multiple controlled factors, so in many cases, the tests are terminated without reaching the patient's maximum heart rate. Therefore, several formulas that can predict the maximal exercise test results based on the results of the submaximal exercise test are provided. Our study confirmed that the ISWT requires more effort by the participants due to external factors had a relatively higher intensity of exercise, unlike the 6MWT, which is affected by participants' internal factors. This is similar to results reported by previous studies that the ISWT had a stronger correlation of exercise response with CPX than the 6MWT [25,31]. With regard to the difference in RPE that the patients self-evaluated the load and difficulty of exercise intensity between the groups, the intensity in the 6MWT was significantly different from the ISWT and CPX [32].

Excluding data from 10 patients who terminated the ISWT early, the changes in heart rate by a test method in 10 patients with MI were investigated. The change in heart rate gradually increased during CPX and ISWT. However, in the 6MWT, the

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heart rate plateaued following the initial increase. **Figure 2** shows the change slope and the linear relationship between time and heart rate according to the evaluation methods. The gradual increase in heart rate observed in the ISWT confirmed that an increase in load of the test method induces a gradual physiological response, the same as the response of CPX [25]. However, the change in heart rate observed in the 6MWT is a result of the intensity control caused by internal factors of the assessment tool. These results were identical to the graph of VO_2 compared in the previous study. In CPX and ISWT, VO_2 continuously increased as the test progressed [8,18]. In the 6MWT, VO2 increased until 3 min of walking and then remained static [18].

The 6MWT is a submaximal exercise test that is clinically and widely used to evaluate the cardiopulmonary function of patients before and after CR [33]. However, a previous study proposed the need for a submaximal exercise test that can replace the 6MWT, because the test-retest reliability in patients requiring CR was low [19]. Studies on the validity and reliability of ISWT in Korea are needed. A protocol for the shuttle walking tests was recently published [20]. However, there are still insufficient studies on the validity and reliability of the ISWT in patients with heart diseases. Therefore, our study assessed the use of ISWT in patients with MI.

This study has some limitations. First, the variables of participants' general and medical characteristics that might affect peak VO_2 were not considered. We propose comparison and analysis by the severity of participants' condition, sex, age, body mass index, or left ventricular ejection fraction. Second, the study revealed that the ISWT had a higher correlation with CPX than the 6MWT in patients with MI; hence, it is necessary to improve the ISWT with factors that can affect the study and data, including a larger sample size. A more accurate peak VO_2 prediction formula can be prepared using values of the ISWT and 6MWT according to the participants' general and medical characteristics. Our findings revealed that ISWT is an appropriate tool to assess exercise capacity in patients with MI.

Conclusions

This study aimed to analyze the correlation among CPX, ISWT, and 6MWT in patients with MI. Our study observed that the incremental shuttle walking test, a submaximal exercise test, can evaluate exercise capacity in these patients.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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