A Thesis for the Degree of Master of Science in Medicine

Peak Cardiorespiratory Responses during Aquatic and Land Treadmill Exercises in Patients with Coronary Artery Disease

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GRADUATE SCHOOL

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August, 2014

관상 동맥 질환 환자의 수중 및 지상 트레드밀 운동시 최고 심호흡계 반응

지도교수 주 승 재

최 준 환

이 논문을 의학 석사학위 논문으로 제출함

2014 년 6 월

최준환의 의학 석사학위 논문을 인준함

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제주대학교 일반대학원

2014 년 6 월

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Jun Hwan Choi
(Supervised by Professor Seung Jae Joo)

A thesis submitted in partial fulfillment of the requirement for the degree of Master of Science in Medicine

2014. 6.

This thesis has been examined and approved

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ABSTRACT

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Objective: To investigate cardiorespiratory responses during exercise s using an aquatic treadmill and a land-based treadmill in coronary artery disease (CAD) patients.

Methods: Twenty-one stable CAD patients were enrolled. All patients participated in two symptom-limited incremental exercise s using either an aquatic or a land treadmill. For the aquatic treadmill protocol, patients were submerged in 28 °C water to the upper waist. The treadmill speed was started at 2.0 km/h, and increased 0.5 km/h every minute thereafter. For the land treadmill protocol, the speed and gradient were started at 2.4 km/h and 1.5 %, respectively; the speed was increased by 0.3 km/h and grade by 1 % every minute thereafter. Oxygen consumption (VO_2), heart rate (HR), and respiratory exchange ratio (RER) were measured continuously and peak values were recorded. The rating of perceived exertion (RPE) was recorded, and the percentage of age-predicted maximal HR and total exercise duration were measured.

Results: The peak cardiorespiratory responses during both protocols were compared and the peak VO_2 and peak HR did not show any significant differences. The peak RER was significantly greater in the land treadmill than in the aquatic treadmill protocol. The RPE, the percentage of age-predicted maximal HR and total exercise duration were similar for both protocols. The linear relationship between HR and VO_2 during both protocols was highly significant.

Conclusion: This study demonstrated that aquatic treadmill exercise elicits similar peak cardiorespiratory responses as land treadmill exercise, suggesting that aquatic treadmill exercise may be effective for cardiac rehabilitation in CAD patients.

Keywords: coronary artery disease, cardiopulmonary exercise test, water, rehabilitation, treadmill.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACEi, angiotensin converting enzyme inhibitor

ARB, angiotensin receptor blocker

ATM, aquatic treadmill

BMI, body mass index

CAD, coronary artery disease

CCB, calcium channel blocker

CR, cardiac rehabilitation

ECG, electrocardiogram

HR, heart rate

LVEF, left ventricle ejection fraction

TM, land-based treadmill

MET, metabolic equivalent

RER, respiratory exchange ratio

RPE, rating of perceived exertion

STEMI, ST elevation myocardial infarction.

VO_2 , peak oxygen consumption

I. INTRODUCTION

Coronary artery disease (CAD) is one of the most common causes for mortality in industrialized countries (Rhee et al., 2007; Rosamond et al., 2012) and results in physical disability, loss of productivity and economic burden (Ades et al., 2001; Eisenstein et al., 2001; Giannuzzi et al., 2003). Comprehensive cardiac rehabilitation (CR) is the most effective approach for cardiovascular risk reduction and long-term care of CAD patients. CR has been associated with a 25 % reduction in overall mortality from cardiovascular causes after three years in myocardial infarction patients (O'Connor et al., 1989; Oldridge et al., 1988).

For CAD patients, CR programs assess the participants by obtaining the medical history of each patient, performing a physical examination, measuring risk factors, and obtaining electrocardiograms (ECG) at rest and during exercise. CR programs also require their participants to take part in physical exercise, and aim for a reduction of cardiovascular risk factors (Haskell et al., 1994).

Physical exercise is individually prescribed on the basis of the clinical profile of the patient, taking into consideration the presence of CAD risk factors, age and functional status (Oldridge et al., 1988), which is evaluated using the cardiopulmonary exercise test (Mezzani et al., 2009). The physical exercise improves cardiorespiratory function and returns patients to optimal levels of physical, psychosocial and social well-being.

The physical exercises for CR and the cardiopulmonary exercise test are usually performed by ergometry or often by using land-based treadmill running. However, recently, the use of water-based exercise CR has been increased in congestive heart failure patients (Caminiti et al., 2011; Fernhall et al., 1992; Meyer et al., 2008; Schmid et al., 2007). Water-based exercise has several advantages over land-based exercise, as follows: it decreases the risk of injury due to overtraining because of the reduction of musculoskeletal loading; it provides a sense of comfort and security and has the psychological benefit of freedom from the risk of falling; the resistance of the water enables aerobic and resistance exercises to be combined; and it aids increasing energy expenditure (Shono et al., 2000; Teffaha et al., 2011).

The effects of water-based CR, and the cardiorespiratory responses to it, have been studied in CAD patients. Mourot et al. reported that short-term head-out water immersion in patients with CAD triggered a significant increase in cardiac output, stroke volume, pulse pressure and a decrease in heart rate (HR), diastolic blood pressure and systemic vascular resistance (Mourot et al., 2010). Water-based CR improves peak oxygen consumption (VO_2), peak HR and left ventricular ejection fraction (Teffaha et al., 2011); improves the time, VO_2 peak and total body strength (Tokmakidis et al., 2008); decreases total cholesterol, triglyceride and body mass index (Volaklis et al., 2007) and increases the plasma nitrite concentration (Laurent et al., 2009).

However, these studies either observed short-term water immersion or water-based exercises carried out in a swimming pool. Although Silver et al. reported that aquatic and land treadmill exercise induced similar cardiorespiratory responses in healthy college runners (Silvers et al., 2007). The cardiorespiratory responses of the cardiac patients were measured only on a land treadmill.

Because of the potential for acute responses during water immersion and swimming pool, there is some controversy regarding the safety of the use of water-based exercise for CAD patients (Meyer et al., 2004; Meyer et al., 2008). However, during CR, the rate of cardiovascular complications has been shown to be very low and the rate of adverse events in patients at increased CAD risk was not altered (Franklin et al., 1998; Van Camp et al., 1986). Water-based CR was found to be well-tolerated and improved cardiopulmonary function in CAD patients (Teffaha et al., 2011).

It is not known whether water-based exercise is able to elicit comparable cardiorespiratory stress in CAD patients to land-based exercise, and there are few comparisons of the cardiorespiratory responses elicited during aquatic treadmill and land treadmill exercise. Therefore, this study investigated the cardiorespiratory responses elicited during exercise using an aquatic treadmill and a land-based treadmill in CAD patients.

II. MATERIALS AND METHODS

Subjects

Twenty-four CAD patients were referred from the Department of Cardiology in Jeju National University Hospital between August 2012 and May 2013. The patients had all undergone percutaneous coronary intervention after presenting with acute CAD with or without ST elevation, and had been clinically stable for at least 1 month.

Subjects were recruited after application of the following exclusion criteria: advanced congestive heart failure, peripheral arterial disease with claudication, unstable angina, uncontrolled hypertension (> 190/110 mmHg), significant orthopedic or pain conditions that limited participation in the exercise s, water phobia, cutaneous infection, or urinary incontinence that limited participation in the water-based exercise.

Of the remaining patients, two were withdrawn because of lack of consent, and one patient did not continue in the study due to significant ECG ST depression during the land treadmill exercise. In total, 21 patients (17 males and 4 females) completed the two exercises.

For all patients, the usual medications were maintained throughout the screening period and exercise testing. All participants provided a written informed consent, and the local Ethics Committee approved the study protocol.

Exercise testing using aquatic and land-based treadmills

The peak exercise cardiorespiratory responses were measured using two symptom-limited exercise s. The land treadmill exercise was performed on a calibrated motorized, adjustable-incline treadmill (T-2100®, GE Healthcare Inc, , St Louis, USA) with monitoring of continuous ECG (CH 2000®, Cardiac Diagnostic System, Cambridge Heart Inc, USA) and vital signs (Fig. 1). The aquatic treadmill exercise was performed on a calibrated motorized aquatic treadmill (Focus®, HYDRO PHYSIO, Nottingham, UK) (Fig. 2) with HR monitoring using a water-resistant chest-strap transmitter (Polar T34®, Polar Electro, Inc., Kempele, Finland) (Fig. 3). No buoyancy devices or water jets were used during the aquatic treadmill exercise. Both of the tests were conducted in the presence of one physiatrist and one physical therapist.

Each exercise had a warm-up lasting 5 min before the walking exercises started. For the aquatic treadmill protocol, the water temperature was 28 °C and the water level used was determined by the upper waist level of each patient. Upper waist level was defined as midline of xyphoid and umbilicus. The aquatic treadmill speed was started at 2.0 km/h and was increased incrementally by 0.5 km/h every minute thereafter. For the land treadmill, the modified ramp protocol was used. The speed and grade were started at 2.4 km/h and 1.5 %, respectively, and the speed was increased by 0.3 km/h and the gradient was increased by 1 % every minute thereafter. The exercise test was terminated on patient request, or if gait instability or cardiovascular decompensation determined according to the guidelines of the American College of Sports Medicine (Thompson et al., 2009). The test protocols for each exercise are shown in Table 1. The land treadmill exercise was performed before the aquatic treadmill test, and patients had a rest interval between the testing sessions of at least 7 days to reduce the side effects of the test and to maximize performance on each protocol.

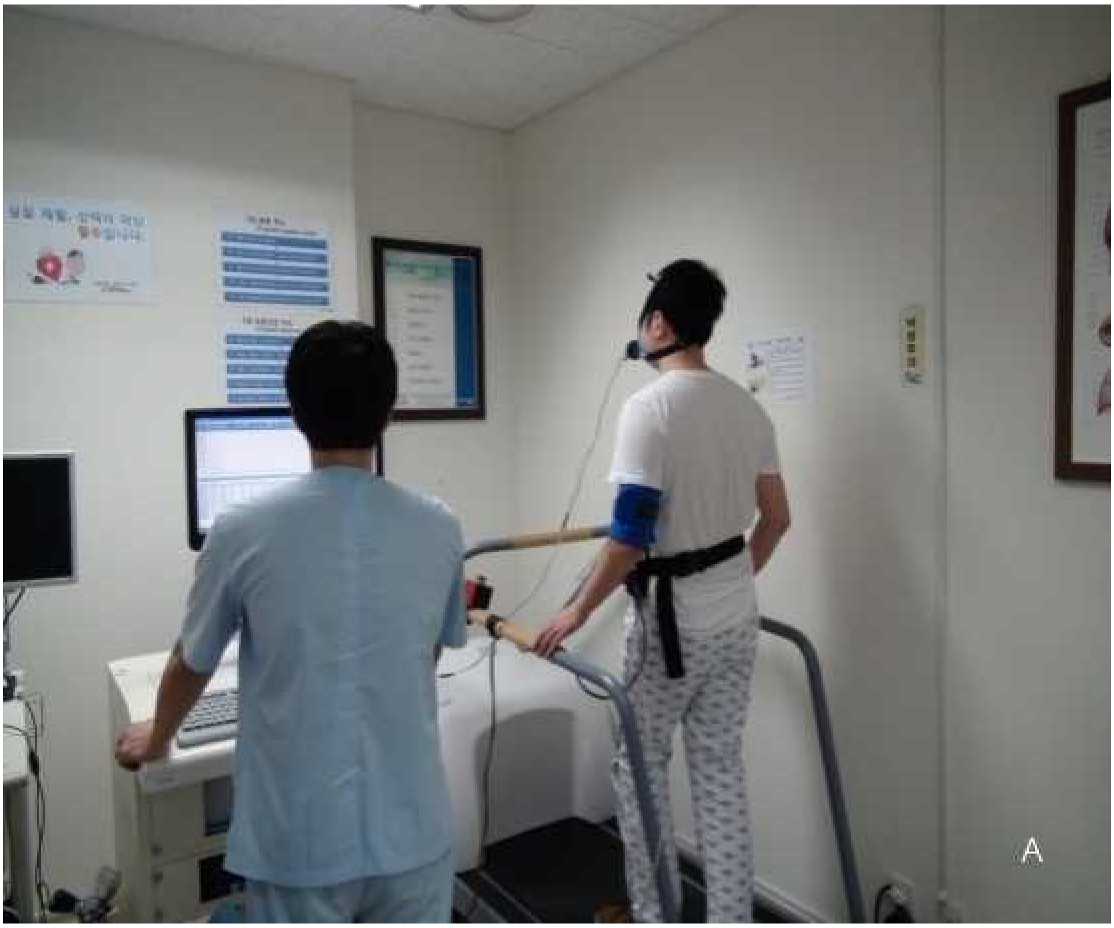


Figure 1. Land treadmill exercise was performed on a motorized, adjustable-incline treadmill with monitoring of continuous electrocardiogram

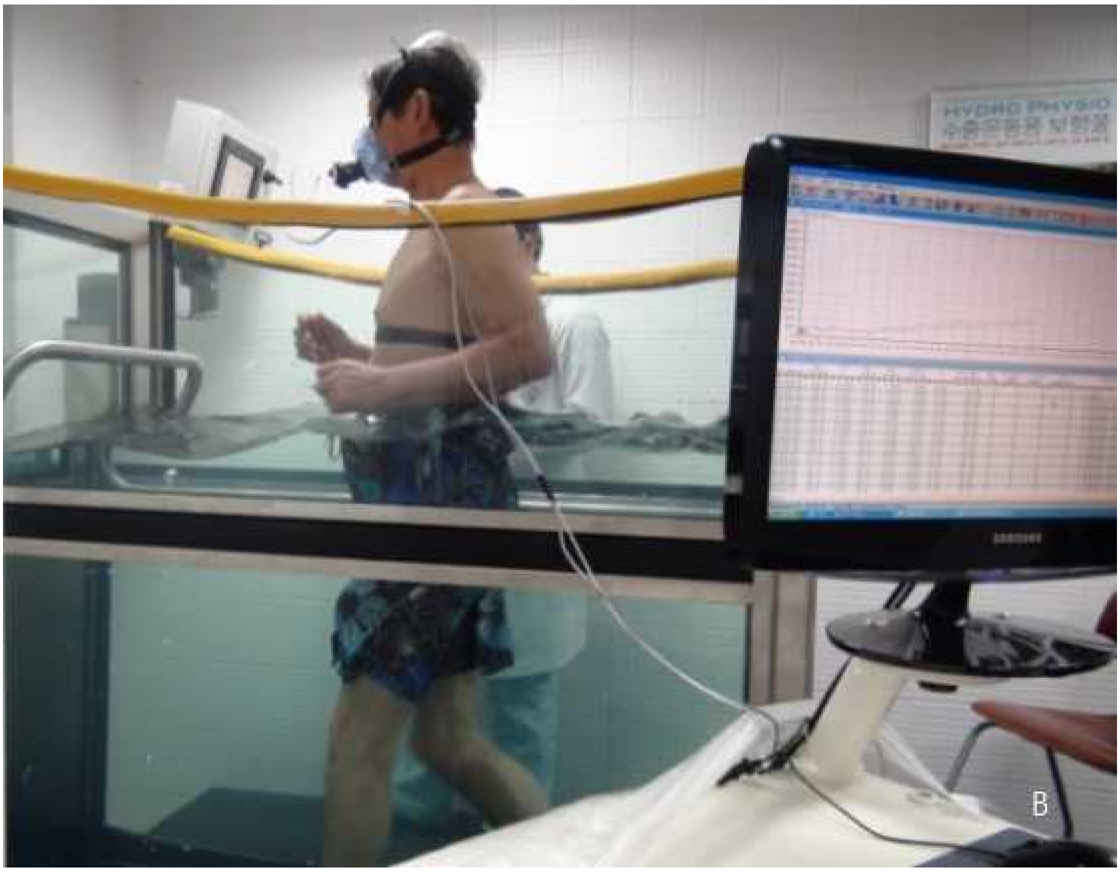


Figure 2. Aquatic treadmill exercise was performed on a calibrated and motorized aquatic treadmill

Figure 3. Heart rate (HR) was monitored with water-resistant chest-strap

Table 1. Testing protocols for aquatic treadmill and land-based treadmill cardiopulmonary exercise tests

	Initial workload	Progression
ATM	Speed : 2.0 km/h	Increased speed 0.5 km/h every minute thereafter
TM	Speed : 2.4 km/h, Grade : 1.5 %	Increased speed 0.3 km/h, increased grade 1% every minute thereafter

Abbreviations: ATM, aquatic treadmill; TM, land-based treadmill

Outcome measurements

VO_2 and the respiratory exchange ratio (RER) were determined by expired-gas analysis by the breath-by-breath method using a portable telemetric system (Cosmed CPET, COSMED Inc, Rome, Italy) (Fig. 4). VO_2 was also expressed in metabolic equivalents to describe exercise intensity. The peak values for the exercise parameters (VO_2 peak, metabolic equivalents peak, HR peak, RER peak and rating of perceived exertion (RPE) were calculated as the averages of the values recorded during the last 30 s of the test.

Peak HR was the average heart rate during the last 30 s of exercise and was additionally expressed as a percentage of the age-predicted maximal HR: (HR peak / [220 – age]) × 100 (Tompson et al., 2009). The RPE was recorded immediately after each test, and the total exercise duration was measured. After finishing both the tests, each patient filled in a questionnaire on the relative satisfaction of the aquatic and land treadmill tests.

Figure 4. Expired-gas analysis was measured by the breath-by-breath method using a portable telemetric system

Statistical analysis

All statistical analyses were performed using SPSS for windows version 20 (IBM-SPSS, Inc., Chicago, IL, USA). All measurements were analyzed using descriptive statistics. Paired t-tests were used to compare the peak cardiorespiratory responses between the aquatic treadmill and land treadmill tests. Pearson's correlation analysis was used to assess the relationship between the HR and VO_2 according to stage. A p-value < 0.05 was considered statistically significant.

III. RESULTS

General characteristics of the participants

The baseline demographics and disease-related characteristics of the patients are presented in Table 2. The average age of the patients was 59.9 ± 9.1 years, and the average disease duration from onset to first evaluation was 25.3 ± 39.7 months. Eleven of the 21 (52.4 %) patients were diagnosed with ST elevation myocardial infarction, five (23.8 %) patients were non ST elevation myocardial infarction, and five (23.8 %) patients were diagnosed with stable angina.

Table 2. Demographics and disease-related characteristics of the participants

Variables	Values
Age (years)	59.9 ± 9.1
Sex, males / females	17 (81.0) / 4 (19.0)
Disease duration (months)	25.3 ±39.7
Height (cm)	164.6 ±7.7
Weight (kg)	69.9 ±11.5
BMI (kg/m^2)	25.7 ±3.1
Diagnosis	
STEMI	11 (52.4)
NSTEMI	5 (23.8)
Stable Angina	5 (23.8)
LVEF (%)	60.1 ± 11.7
Comorbidities	
Hypertension	13 (61.9)
Diabetes mellitus	10 (47.6)
Medication	
Antiplatelets agent	21 (100)
β-blocker	16 (76.2)
ARB / ACEi	13 (61.9)

CCB	5 (23.8)
Diuretics	6 (28.6)
Digoxin	1 (4.8)
Statin	21 (100)
Isosorbide dinitrate	5 (23.8)

Abbreviations: BMI, Body Mass Index; STEMI, ST elevation myocardial infarction; LVEF, left ventricle ejection fraction; Anti-PLT, anti-platelet; ARB, angiotensin receptor blocker; ACEi, angiotensin converting enzyme inhibitor; CCB, calcium channel blocker

Values represent mean ± standard deviation or number (%) of cases

Comparison of peak cardiorespiratory responses during the aquatic treadmill and land-based treadmill protocols

The mean final workload for the aquatic treadmill test was 8.1 ± 1.9 km/h and mean final workload for the land treadmill test was 6.2 ± 0.6 km/h and 13.4 ± 0.4 %, respectively. The data for the peak cardiorespiratory responses are presented in Table 3.

There were no statistically significant differences in the cardiorespiratory responses including VO_2 peak, metabolic equivalents peak, HR peak, RPE peak, percentage of age-predicted maximal HR, or total exercise duration between the aquatic treadmill and land treadmill protocols. In the aquatic treadmill test, the peak values of VO_2 and HR were 95.8 % and 96.9 %, respectively, of the equivalent values in the treadmill test. The peak RER was significantly greater in the land treadmill test than in the aquatic treadmill test (1.02 ± 0.09 vs. 0.97 ± 0.07, $p = 0.02$).

Table 3. Comparison of peak cardiorespiratory responses during the aquatic treadmill and land-based treadmill protocols

	ATM	TM	*p*-value
VO_2 peak ($mL \cdot kg^{-1} \cdot min^{-1}$)	29.8 ± 4.8	31.1 ± 5.3	0.11
MET peak	8.5 ± 1.4	8.9 ± 1.5	0.11
HR peak (bpm)	131.9 ± 13.7	136.1 ± 16.8	0.25
RER peak	0.97 ± 0.07	1.02 ± 0.09	0.02*
RPE peak	17.0 ± 0.9	17.0 ± 1.3	1
Percentage of age-predicted maximal HR (%)	82.5 ±8.6	85.1 ± 10.4	0.26
Total exercise duration (min)	12.4 ± 3.7	12.5 ± 1.8	0.87

Abbreviations: VO_2, oxygen consumption; MET, metabolic equivalent; HR, heart rate; RER, respiratory exchange ratio; RPE, peak rating of perceived exertion

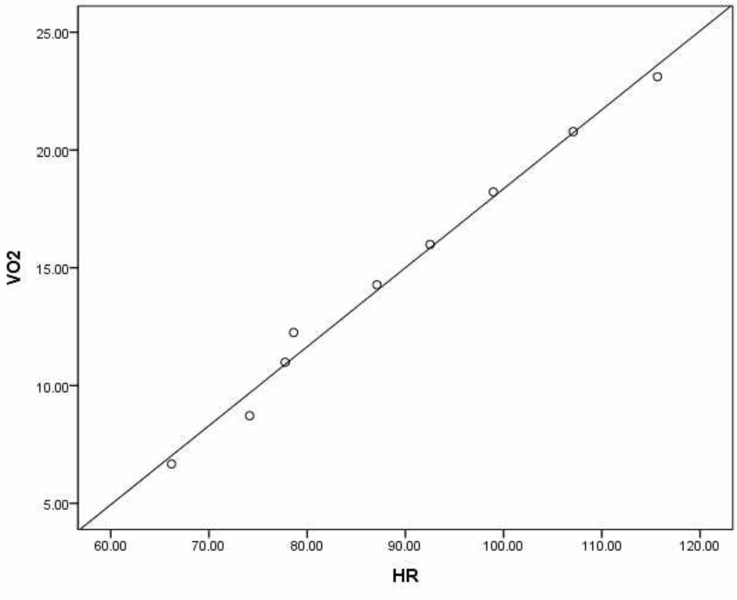
Values represent mean ± standard deviation or number (%) of cases

* $p < 0.05$

Relationship between heart rate and oxygen consumption during aquatic treadmill and land-based treadmill protocols

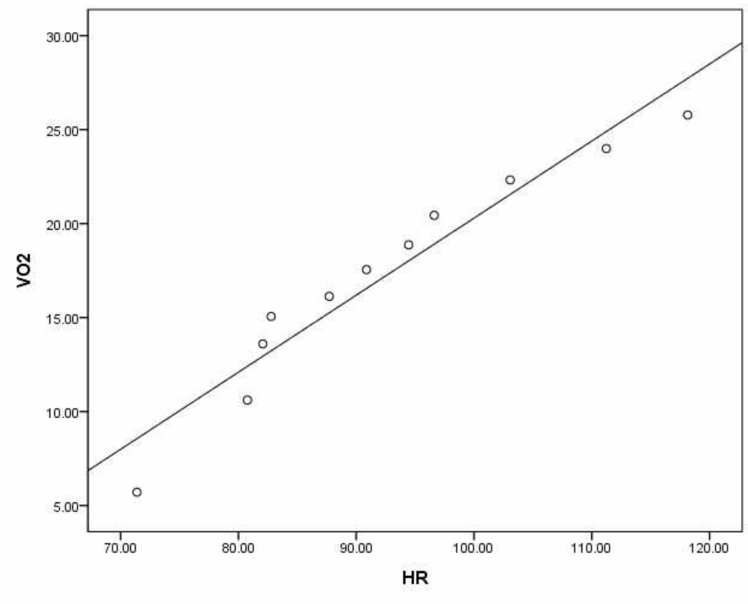
The relationship between HR and VO_2 during both the aquatic and land treadmill protocols showed a highly positive linear correlation (r = 0.997 vs. 0.966; $p \leq 0.01$) (Fig. 5 and 6).

Regarding the satisfaction of each exercise, in answer to the question, 'Which exercise method did you feel was more comfortable?', 16 of the 21 (76.2 %) patients said that the water-based exercise was more comfortable than the land-based exercise.



r = 0.997, $p < 0.01$

Figure 5. Linear correlations between heart rate (HR) and peak oxygen consumption (VO_2) in cardiopulmonary exercise tests using an aquatic treadmill according to stage



r = 0.966, $p < 0.01$

Figure 6. Linear correlations between heart rate (HR) and peak oxygen consumption (VO_2) in cardiopulmonary exercise tests using a land-based treadmill according to stage

VI. DISCUSSION

This study demonstrated that in CAD patients, aquatic treadmill exercise could elicit similar peak cardiorespiratory responses as land treadmill exercise. There were no significant differences in the VO_2 peak and the HR peak between aquatic and land treadmill exercises. The fluid resistance of water in an aquatic treadmill elicits cardiorespiratory responses comparable to those seen with a land-based inclined treadmill.

Studies that compared the peak cardiorespiratory responses of healthy adults participating in shallow water running and land running, however, have reported inconsistent results. Silvers et al. reported that peak cardiorespiratory responses in shallow water running in patients submerged to the level of the xyphoid process were similar to those seen on land (Silver et al., 2007). Dowzer et al. reported that shallow water running in waist-level water produced peak VO_2 and HR responses that were 84 % and 94 %, respectively, of those of land treadmill running (Dowzer et al., 1999). Town and Bradley also reported that shallow water running in waist-level water produced a peak VO_2 of 90 % and an HR response of 89 % of the land treadmill running result (Town et al., 1991).

Dowzer et al. reported that deep water running increased venous return, cardiac output and stroke volume because of increased hydrostatic pressure. On the other hand, shallow water running reduced the effect of hydrostatic pressure as abovementioned (Dowzer et al., 1999). Town and Bradley also reported similar results of cardiovascular effect of hydrostatic pressure (Town et al., 1991).

However, it appears that the level of water used in the aquatic tests is important. Because of the increased magnitude of water resistance, a greater metabolic demand for a given workload is needed in water-based exercise, and the metabolic demand can be varied by the water level. With deeper water, the effect of buoyancy is increased and the magnitude of water resistance is decreased. With head-out water immersion exercise, the effect of buoyancy is more pronounced than the effect of water resistance; thus the workload is smaller than with land-based exercise. According to Reilly et al., deep-water running increases cardiac output and decreases HR (Reilly et al., 2003), and produces a low VO_2 peak, HR peak and a reduced workload demand. However, when the water level is shallower, the effect of buoyancy is decreased and the magnitude of water resistance is increased. Compared with deep-water running, shallow water running could increase weight bearing and muscle recruitment, producing a more demanding physical activity for the cardiovascular system. Water immersion to the level of the xyphoid process unloaded up to 28 % of body weight in females and 35 % of body weight in males, and water immersion to the anterior superior iliac spine-level unloaded up to 47 % of body weight in females and 54 % of body weight in males (Harrison et al., 1987). Therefore, it could be predicted that immersion to upper waist level, as done in this study, would unload up to approximately 40% of body weight. Aquatic treadmill exercises performed in upper waist water level should, therefore, produce similar peak cardiorespiratory responses to exercises on land-based treadmill.

In this study, the VO_2 peak and HR peak for the aquatic treadmill exercises were 95.8 % and 96.9 %, respectively, of the land treadmill values; these comparative values are slightly greater than those found in studies conducted with waist-level water. There are several possible explanations for these findings. The water exercises were carried out in an aquatic environment using a calibrated motorized aquatic treadmill. It is possible that this equipment could decrease frontal resistance better than a static aquatic environment such as a swimming pool, as used in the studies quoted above, and facilitate more effective running that requires a larger metabolic demand than exercises performed in a swimming pool. In addition, during the aquatic treadmill exercises carried out in this study, portions of the arms and forearms were submerged throughout the arm swing, requiring additional energy expenditure.

A significant difference in RER peak was observed between the two exercises (0.97 vs. 1.02, aquatic treadmill vs. land treadmill, $p = 0.02$). This could be because the buoyancy and hydrostatic pressure properties of water could reduce the workload of water-based exercises, compared with land-based exercise, meaning that even though similar VO_2 peak and HR peak levels were observed, the RER peak observed in the aquatic treadmill exercises would be lesser than the land treadmill RER peak.

The observation that HR and VO_2 showed a highly positive linear correlation throughout both the aquatic treadmill and land treadmill protocols is consistent with previous reports. In women of middle and advanced age, Shono et al. reported a significant linear relationship between HR and VO_2 during aquatic walking (Shono et al., 2000). A significant linear relationship between heart rate reserve and VO_2 reserve has been reported in patients with myocardial infarction and heart failure (Brawner et al., 2002). Therefore, HR and VO_2 could be effective indices for aquatic treadmill exercise just as they are for land treadmill exercise.

More patients reported a greater satisfaction with the aquatic treadmill exercise than for land treadmill exercise (16 vs. 5). Psychological problems such as anxiety and depression are common in patients with CAD (Thombs et al., 2006; Mayou et al., 2000) and the beneficial psychological effects of water-based exercise could decrease anxiety and help patients feel relaxed. In addition, the buoyancy of the water could reduce joint stress and musculoskeletal pain.

Study limitations

This study had several limitations. First, it used a symptom-limited protocol and the patients could stop the test before the maximal values of cardiorespiratory responses were reached. The peak RER of our study is < 1.10 – 1.15, which means that the results of the study reflect the achievement of maximal effort (Howley et al., 1995). Approximately two-thirds of the patients had moderate to high cardiovascular risk on the exercise according to the guidelines of the American College of Sports Medicine. Therefore, the patients could have low exercise tolerance, and could also terminate the tests before maximal values were achieved.

Second, in the aquatic treadmill test we could not monitor ECG and blood pressure because of an absence of equipment appropriate for use in an aquatic environment. Therefore, cardiorespiratory responses, such as blood pressure and rate pressure product, were not used and could not be compared. In addition, these problems could limit the availability of an aquatic treadmill exercise for patients with a high cardiovascular risk who require ECG and blood pressure monitoring for CR.

Third, the land treadmill exercise protocol increased gradient and speed, whereas the aquatic treadmill protocol only increased speed, meaning that only the peak values could be compared and not the cardiorespiratory responses for each stage. The aquatic treadmill protocol had speed limit by water resistance but no gradient increment, so the peak values obtained could have been less than for the land treadmill protocol. Future studies are required to determine whether the use of additional water resistance, such as water jets, could affect the cardiorespiratory responses. In addition, the sample size was too small to enable subgroup analysis to be performed.

V. CONCLUSION

This study demonstrated that aquatic treadmill exercise can elicit similar peak cardiorespiratory responses to land treadmill exercise. The fluid resistance created by water in an aquatic treadmill elicits peak cardiorespiratory responses comparable with those seen using an inclined treadmill. These findings suggest that in CAD patients, aquatic treadmill exercise may be as effective as land treadmill exercise for CR.

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VII. ABSTRACT IN KOREAN

관상동맥 질환 환자의

수중 및 지상 트레드밀 운동 부하 운동시

최고 심호흡계 반응

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목적: 본 연구는 관상동맥 질환 환자에서 수중 및 지상에서 운동 부하 운동을 시행하였을 때 심호흡기계 반응을 알아보고자 한다.

방법: 총 21 명의 안정된 관상동맥 질환 환자들이 연구에 모집되었다. 모든 환자들은 수중과 지상에서 증상 제한적 점증부하 운동을 시행하였다. 수중 트레드밀 운동은 섭씨 28 도의 온도의 물에 위 허리까지 높이의 물에서 2.0 km/h 속도에서 분당 0.5 km/h 속도를 올리는 방법으로 진행하였다. 지상에서 트레드밀 운동부하는 2.4 km/h 속도와 1.5 도의

기울기에서 시작하여 분당 0.3 km/h 및 1 도 기울기를 증가시키는 방법을 이용하였다. 산소 소모량, 심장 박동수, 호흡 교환율을 연속적으로 그리고 최고값을 측정하였다. 운동 자각도를 기록하였고 연령에 따른 최대 심장 박동수 백분율과 총 운동시간을 측정하였다.

결과: 두 가지의 운동 부하 방법을 통해 나온 최고 심호흡기계 반응을 비교하였다. 최고 산소 소모량과 최고 심장 박동수는 두 운동간에 유의한 차이를 보이지 않았다. 최고 호흡 교환율은 지상 트레드밀 운동 방법에서 수중 트레드밀 운동 방법과 비교하여 유의하게 높았다. 운동 자각도, 연령에 따른 최대 심장 박동수 및 총 운동 시간은 두 방법간에 유의한 차이를 보이지 않았다. 심장 박동수와 산소 소모량 간에는 두 방법 모두에서 유의한 선형관계를 보였다.

결론: 이 연구는 수중 트레드밀 운동이 지상 트레드밀 운동과 유사한 최고 심호흡기계 반응을 보여주었다. 이는 심장 재활에 있어 수중 트레드밀 운동이 관상동맥 질환 환자에게 효과적으로 사용될 수 있을 것으로 생각된다.