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Immersion in warm water induces improvement in cardiac function in patients with chronic heart failure

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Abstract

Background: The effects of immersion and training of patients with chronic heart failure (CHF) in warm water has not been thoroughly investigated. The aim of this study was to assess the acute hemodynamic response of immersion and peripheral muscle training in elderly patients with CHF.
Methods: Thirteen CHF patients and 13 healthy subjects underwent echocardiography on land and in a temperature-controlled swimming pool (33–34 °C).
Results: Rest. Heart rate decreased (CHF, $p = 0.01$; control, $p = 0.001$) and stroke volume increased (CHF, $p = 0.01$; control, $p = 0.001$) during water immersion in both groups, with no change in systolic or diastolic blood pressure. Ejection fraction ($p < 0.05$) and transmitral Doppler E/A ratio ($p = 0.01$) increased in the CHF group, with no changes in left ventricular volumes. The healthy subjects had similar responses, but also displayed an increase in cardiac output ($p < 0.01$) and left ventricular volumes ($p < 0.001$). *Exercise*. Cardiac output and systolic blood pressure increased significantly in water, in both groups.
Conclusion: A general increase in early diastolic filling was accompanied by a decrease in heart rate, leading to an increase in stroke volume and ejection fraction in most patients with CHF during warm water immersion. These beneficial hemodynamic effects might be the reason for the previously observed good tolerability of this exercise regime.

Keywords: Hemodynamic phenomena; Hydrotherapy; Echocardiography; Doppler; Heart function tests

1. Introduction

Hydrotherapy, (exercise in warm water) is seldom used for rehabilitation in patients with chronic heart failure (CHF) [1]. It is an alternative way of exercising, since the buoyancy effect reduces loading and is especially feasible for the elderly [2]. Exercises for mobility, strength and cardiovascular fitness can be easily performed in water [3]. However, hydrotherapy has been considered dangerous for patients with CHF, since water immersion causes an increased venous return and a possible adverse increase in ventricular filling pressure [4,5]. Hydrotherapy and water immersion in thermoneutral water seem to improve hemodynamics in healthy subjects [2], however there are few reports on the effect in patients with CHF. Gabrielsen et al. [6] assessed the effect of immersion in thermoneutral water (35 °C) in patients with CHF, they reported that cardiac output, stroke volume, and ejection fraction (EF) increased, whereas systemic vascular resistance decreased significantly. These hemodynamic effects have also been reported in other studies during immersion in water at 41 and 32 °C, respectively [7,8]. However, these previous studies have not given an accurate representation of the use of hydrotherapy in CHF, as the water temperatures used have either been too hot or too cold, patients have been younger than the average CHF patient, exercise in water has not been studied and few investigations have been performed in the standing position [6–8].

In a recent study, we described improved physical function and excellent tolerability during a 12-week hydro-

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therapy programme, which focussed on peripheral muscle training in patients with CHF [1]. In another study we found that the cardiorespiratory effects of water immersion, measured by gas analyses, seem to be similar in healthy persons and in patients with CHF [9].

The aim of this study was to assess acute hemodynamic responses during warm water immersion and hydrotherapy using peripheral muscle training, in elderly patients with CHF compared to healthy controls. The hypothesis was that there would be a beneficial hemodynamic response in patients with CHF. Our aim was to investigate patients in a situation that would be representative for hydrotherapy, that is, in a water temperature of 33–34 °C and in a standing position within the pool.

2. Methods

2.1. Patients

Thirteen patients (two women) were included in the study. Inclusion criteria were presence of CHF, age 60 or above, NYHA functional class II–III, EF ≤ 45% and stable medication during the previous 3 months. Exclusion criteria were diabetes, peripheral artery disease, chronic pulmonary disease and or previous stroke. The patients were recruited from the diagnostic database at Sahlgrenska University Hospital. The exclusion and inclusion criteria were assessed by a physician from medical history, physical examination and hospital records. Thirteen age- and sex-matched healthy subjects, recruited through an advertisement in the local newspaper were used as controls. An examination was performed by a physician to exclude hypertension (blood pressure > 160/90), reduced systolic function (EF < 50%) or significant cardiovascular morbidity. Baseline characteristics of patients and controls are given in Table 1. The protocol conformed with the principles set out in the Declaration of Helsinki and was approved by the Ethics Committee at the Medical Faculty, Göteborg University. All patients and controls gave written informed consent to participate in the study.

Table 1
Baseline characteristics of CHF patients and healthy controls

n	CHF	Healthy controls	*p*
	13	13	
Females/males	2/11	2/11	ns
Age, years	72 (6)	72 (5)	ns
Weight, kg	74 (5)	74 (10)	ns
Length, cm	178 (6)	175 (9)	ns
EF, %	32 (7)	63 (7)	<0.001
NYHA, II/III	3/10	–	
Duration of CHF, years	6.5 (5)	–	
Etiology of CHF, ischaemic/nonischaemic	9/4	–	
Medical treatment, *n* (%)		None	
ACE-inhibitors	12 (92)		
Beta-blockers	12 (92)		
Digoxin	5 (38)		
Diuretics	10 (77)		

ACE = angiotensin converting enzyme, CHF = chronic heart failure, EF = ejection fraction. Data are given as mean (SD).

2.2. Protocol

Hemodynamic changes were assessed on land and in a temperature-controlled swimming pool (33–34 °C) using echocardiography, Acuson XP 128 or Acuson Sequoia 512 (Mountain View, CA, USA). The patients were first assessed in a standing position on land. The standing position was slightly tilted towards the left side with one hand on a rail. The echocardiographic equipment was checked by the engineers at the technical department to ensure it was safe for use near water. To ensure that the echo probe was not in direct contact with water, it was put inside a latex stocking as used during cardiac surgery. Echocardiographic measurements were performed according to the recommendations of the American Society of Echocardiography [10]. Two-dimensional biplan recordings (2- and 4-chamber views) were used to calculate left ventricular end diastolic and end systolic volume. Ejection fraction was calculated by the modified Simpson's rule). Pulsed wave Doppler was used to assess flow through the mitral and aortic valves. Blood pressure was measured, using an automatic sphygmomanometer on the right arm, every other minute (A0015, Hewlett Packard, USA), ECG was monitored continuously throughout the study. After 15 min of seated rest, subjects walked slowly down the steps into the swimming pool and then a further 12 m in the water to reach the investigational area. This was followed by seated rest for 5 min in a chair with an adjustable seat position. The echocardiographic measurements were performed in the swimming pool at rest, with subjects in a standing position with the water level up to the sternal notch and then after 5 min of standardised peripheral muscle training exercise. The peripheral muscle training sequence consisted of seated reciprocal unilateral knee-extensions with 60 extensions per minute. The Borg scale was used to rate perceived exertion (RPE) and the perceived level of dyspnoea was rated on the Borg category ratio scale (CR) [11]. The healthy controls and the CHF patients underwent the same protocol, however, controls performed an additional exercise session on land and then rested for 30 min before entering the water. Due to the rapid decrease in heart rate at the end of exercise, a limited number of measurements could be performed. The healthy subjects showed a higher perseverance, allowing a more complete set of recordings. Left ventricular (LV) volumes and EF were measured off-line on an Echo-Pac system (Vingmed, Horten, Norway), in a blinded fashion. Doppler recordings were digitised using a software program constructed in-house, CAS (Mednet, Göteborg, Sweden) [12].

2.3. Statistics

Ratio and interval data are given as means ± standard deviation (SD). Ordinal data are presented as median and range. Wilcoxon's rank sum test was used for comparisons of paired observations within each study-group. Mann Whitney *U*-test was used to assess inter-group differences. A p-value ≤ 0.05 was considered significant. Data was analysed using Statistical Package Software (SPSS) for Windows, version 12.0 (Chicago, Illinois, USA).

3. Results

3.1. Rest

In the resting state, immersion in warm water resulted in a decreased heart rate in both groups without any significant changes in blood pressure, as compared to land measurements (Table 2). In the CHF group, one patient had a slight increase in heart rate, two patients had unchanged heart rate, and all others had a reduced heart rate in water compared to measurements on land (Fig. 1A). Whereas mean LV volumes were unaltered following water immersion in CHF patients, a marked increase in end diastolic and end systolic volumes occurred in the healthy controls. Some CHF patients had increased LV volumes during water immersion, while others did not. EF increased significantly in patients with CHF, with a trend ($p = 0.07$) towards an increase in the healthy controls. A significant improvement in stroke volume (Fig. 1B), was found in both groups and a significant improvement in cardiac output was found in the healthy controls, while a trend towards an increase in cardiac output ($p = 0.1$) was noted among patients with CHF during water immersion as compared to measurements on land. Early diastolic filling increased in CHF patients as expressed by an increase in transmitral Doppler E wave VTI and in E/A ratio (Table 2). Different effects on cardiac function were noted among CHF patients. In patients with signs of relaxation abnormalities, including an E/A ratio below 1.0, warm water immersion appeared to be accompanied by a normalisation of the transmitral diastolic filling pattern, an example of which is shown in Fig. 2A. Patients with more compromised LV function, as expressed by a short diastolic filling with a single diastolic filling wave (summation of E and A), had a different pattern. These patients increased the size of the diastolic filling wave, but the restrictive filling pattern remained (Fig. 2B). In general, both patterns were accompanied by an increase in ejection fraction and stroke volume during water immersion.

3.2. Exercise

During exercise in water, heart rate and blood pressure increased significantly in both patients and healthy controls, as compared to measurements during rest in water. Among patients with CHF, there was a significant increase in cardiac output. A similar increase was demonstrated in the healthy controls (Table 2).

4. Discussion

This is the first study to measure hemodynamic changes using echocardiography during water immersion and hydrotherapy in patients with CHF. Warm water immersion was well tolerated by patients with CHF and hemodynamic data implied increased diastolic filling, reduced heart rate and, possibly, unloading during LV contraction.

The observation of significantly increased early diastolic filling, EF and stroke volume, suggests that the net effects of warm water immersion were dominated by increased venous return, balanced by peripheral vasodilatation and unloading of the left ventricle. A further important effect

Table 2
Hemodynamic data, mean (SD), obtained by echocardiography in patients with CHF and healthy controls on land and in warm water (at rest and after exercise)

	Patients with CHF ($n = 13$)			Healthy controls ($n = 13$)			
	Rest	Rest	Exercise	Rest	Rest	Exercise	
	Land	Water	Water	Land	Water	Water	
HR beat/min	78 (16)	66 (12)**	72 (12)†	76 (14)	59 (8)***	62 (6)†	
SBP, mm Hg	124 (21)	127 (21)	145 (25)††	141 (19)	149 (23)	152 (17)†	
DBP mm Hg	73 (11)	71 (9)	80 (15)†	86 (8)	82 (12)	84 (10)†	
MAP, mm Hg	90 (14)	90 (12)	102 (17)††	104 (11)	104 (15)	107 (12)†	
RPE-scale			2 (0–4)			0 (0–2)	
CR-scale			13 (7–15)			9 (6–14)	
EF, %	24 (7)	27 (5)*	–	55 (5)	59 (6)	61 (7)	
LVESV, mL	158 (77)	160 (70)	–	30 (11)	40 (12)**	36 (13)	
LVEDV, mL	204 (91)	216 (87)	–	67 (21)	100 (33)***	93 (27)	
SV, mL	38 (9)	52 (17)**	66 (22)	48 (14)	79 (17)***	84 (17)	‡‡
CO, L/min	2.9 (0.7)	3.3 (1.0)	4.6 (1.4)††	3.5 (0.8)	4.6 (0.7)***	5.1 (1.1)†	‡
E/A ratio	0.87 (0.64)	1.34 (0.79)*	–	0.91 (0.17)	1.10 (0.45)	1.17 (0.27)	

*$p<0.05$, **$p<0.01$, ***$p<0.001$ rest on land vs. water; †$p<0.05$, ††$p<0.01$, rest in water vs. exercise in water, ‡$p \leq 0.05$, ‡‡$p<0.01$, rest on land vs. water between groups, rest in water vs. exercise in water. –, not done. Data are given as mean (SD) or median and range. BP = blood pressure, CO = cardiac output, CR = category ratio, E/A ratio = mitral peak flow E-wave/A-wave ratio, HR = heart rate, LVESV = left ventricular end systolic volume, LVEDV = left ventricular end diastolic volume, RPE = rate of perceived exertion, SV = stroke volume.

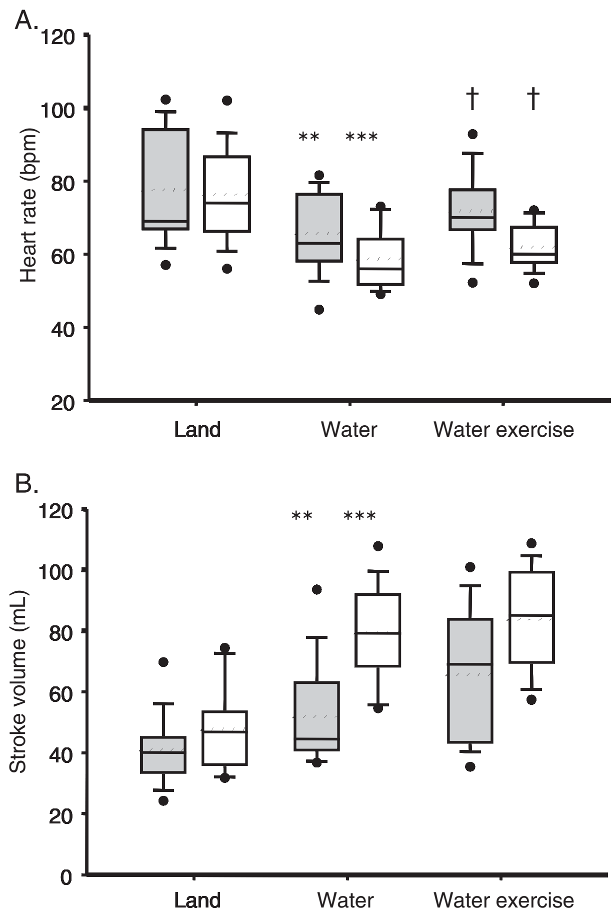

Fig. 1. Heart rate (A) and stroke volume (B) during water immersion and exercise in water, in 13 patients with CHF (filled bars), and 13 healthy control subjects (empty bars). Data are given as box-plots, in which the box encompasses the 25th to 75th percentile, middle line is the median and broken line is the mean value. Whiskers represent the 10th and 90th percentile, and dots are values outside this range. $^{**}p<0.01$, $^{***}p=0.001$, rest on land vs. water. $^{\dagger}p<0.05$, exercise vs. rest in water, $^{\dagger\dagger}p$.

might be the reduction in heart rate, which should promote diastolic filling and allow the increase in venous return to be handled by the ventricles without an adverse increase in preload. Such an effect has been reported using invasive cardiac catheterisation by Gabrielsen et al. [6], and by Tei et al. [7] in hotter water (41 °C). However, Meyer and Bücking [8] recently found an increase in stroke volume and cardiac output in patients with CHF, in 32 °C water, except for a few patients with severe CHF, in whom stroke volume was unchanged or decreased. Whether the unchanged or decreased stroke volume was an effect of LV overload or a consequence of less peripheral vasodilation due to lower water temperature needs further investigation. Further, in contrast to other investigators we investigated patients in the standing position. This was an important aspect of our study, because we wanted to assess hemodynamic changes in the same body position to that in which patients were exercising in the swimming pool. The difference in posture could explain some differences in the observations.

LV volumes increased significantly during water immersion in healthy persons but not in patients with CHF. The lack of LV dilatation in some CHF patients might indicate less preload reserve than in healthy persons. LV filling pressure was not measured. However, there was a consistent increase in early diastolic filling, as expressed by an increase in transmitral E wave. Although this has not been observed previously, our results are supported by the reverse

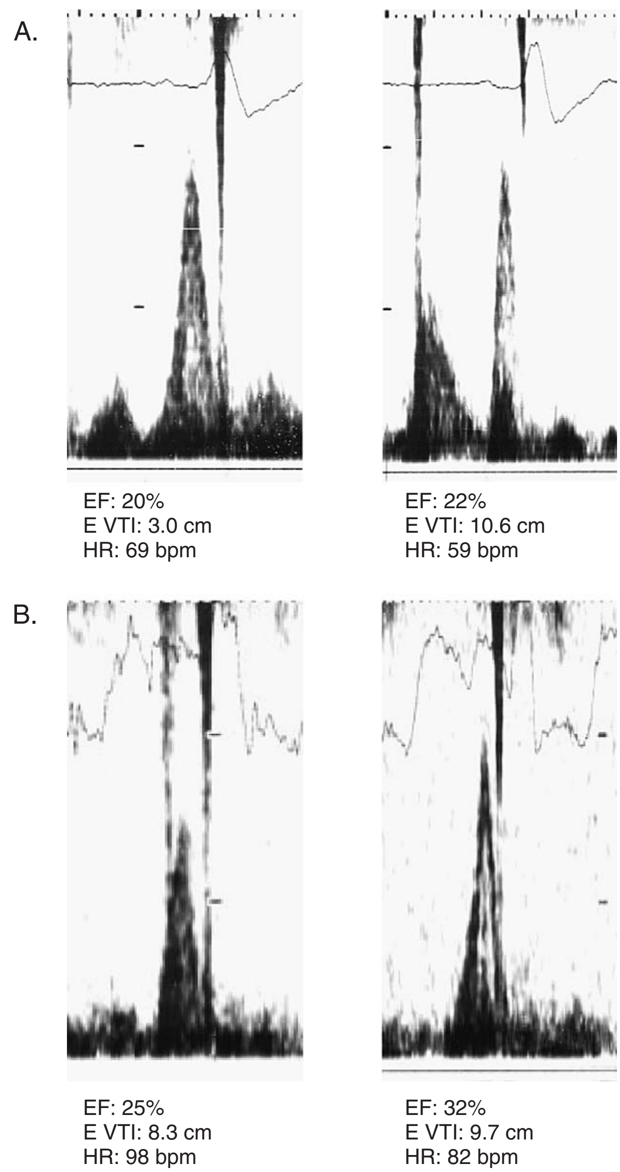

Fig. 2. Examples of hemodynamic changes during immersion in warm water in patients with CHF. Diastolic transmitral pulsed wave Doppler recordings are shown for two patients with different filling patterns. Left panel depicts measurements on land and right panels during water immersion. Panel (A), male patient, 68 years old. A typical pseudonormalisation pattern due to increased preload. A dominating A wave pattern on land is followed by an increase in E wave and increased E/A ratio in water. Panel (B), male patient, 79 years old. A restrictive filling pattern with a summation wave is maintained in water, with an increase in diastolic VTI and EF. EF = ejection fraction, E VTI = early filling velocity time integral, HR = heart rate, bpm = beats per min.

effect which has been reported in studies where venous return has been reduced. Both lower body negative pressure and nitroglycerine infusion causes reduced early diastolic filling [13,14]. In our study, venous return seemed to be increased due to peripheral venous compression by hydrostatic water pressure [6,15,16].

Thus, a possible increase in venous return and a decrease in afterload had beneficial effects on cardiac performance in patients with CHF. A very important effect might be the significant decrease in heart rate. Both hydrostatic pressure and water temperature influence heart rate during water immersion in healthy persons [2]. The hydrostatic pressure was higher in this study due to the standing position with the water level to the sternal notch which might influence heart rate to a greater extent compared to a sitting position [9]. The reduction in heart rate in patients with CHF in this study was similar to the effect in healthy persons, despite the fact that 92% of patients were on treatment with beta-blockers. If temperatures above thermoneutral levels are used, this might cause an increase in heart rate, as shown in the study by Tei [7]. Lower heart rates might be an important effect that could explain why patients show such good tolerance during water immersion.

The effect of warm water immersion on blood pressure has not been thoroughly studied [6,8,16,17]. Direct measurement of systemic vascular resistance was not performed in this study, therefore we cannot be certain that a reduction in afterload occurred. However, it has been shown, in both healthy persons and patients with CHF, that systemic vascular resistance decreases during warm water immersion [2,7,8,17,18]. Blood pressure did not change in either group during water immersion; these results are contrary to the findings of one study in younger patients [6] but are in accordance with another recent study [8]. The absence of blood pressure reduction, despite a decrease in systemic resistance [6,7], might be explained by the increase in cardiac output in the healthy controls and the trend towards an increase in patient with CHF. We have found a smaller increase in VO_2 in CHF patients compared to healthy controls during water immersion [9], which might correspond to a smaller increase in stroke volume and cardiac output as observed in the present study. It is not clear why CHF patients have less ability to increase their cardiac output, but a reduced cardiac reserve is a hallmark of the failing heart. In general, patients in the CHF group had larger variations in the hemodynamic response compared to healthy persons (Figs. 1 and 2). Besides differences in cardiac function, variations in circulating neurohormones might influence hemodynamics. An increase in natriuretic peptides and a reduction in angiotensin levels could enhance the temperature-induced vasodilatory effect of warm water [19].

Workload was based on peripheral muscle training principles and therefore the oxygen uptake during exercise was low. However, this is the training technique we have used previously for exercise sessions for patients with CHF [1,20]. This type of muscle training facilitates strong stress on a small muscle mass without excessive systemic circulatory reactions. During peripheral muscle training, exercise, heart rate, blood pressure, and cardiac output increase appropriately. However, further studies of exercise with a higher oxygen demand are needed to better understand the acute hemodynamic effect of hydrotherapy in patients with CHF.

5. Limitation of the study

The workload used in this study was low and was not adjusted to maximal exercise capacity. It was chosen to investigate the effect of peripheral muscle training which allowed all patients to conduct 5 min of standardised exercise. The hemodynamic reaction to a longer training session cannot be evaluated from these data. It was anticipated that patients with CHF would need a long period of recovery after exercise, and therefore they did not perform exercise on land. Echocardiography has to our knowledge not previously been performed in the standing position in a swimming pool. Hemodynamics changed rapidly after termination of exercise, limiting the amount of recordings that could be obtained.

6. Conclusions

Warm water immersion induced beneficial hemodynamic effects in patients with CHF, and there were no signs of adverse reactions. Our findings indicate that an increased venous return is balanced by a reduction of heart rate and a probable decrease in afterload, promoting an increase in LV output. These positive hemodynamic effects of short-term immersion support our previous experience of positive effects during training in warm water.

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