Original articles

Comparison of hemodynamics during hyperthermal immersion and exercise testing in apparently healthy females aged 50-60 years

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Background. **Owing to excessive worries regarding adverse cardiac events, hyperthermal balneotherapy for patients with coronary artery disease is underprescribed. However, very few cardiac events occur in similar heat stress during Finnish sauna bathing. Exercise testing has proven to be a safe diagnostic procedure even in survivors of myocardial infarction.**

Methods. **We compared the effects of hyperthermal immersion and exercise testing on cardiac hemodynamics in 21 apparently healthy women aged 50-60 years. The maximal symptom-limited bicycle exercise test was performed according to the modified protocol of Wasserman. Hyperthermal immersion was carried out in 40°C water and was completed by increasing the core temperature by about 2°C. The left ventricular function was evaluated using continuous measurement of thoracic electric bioimpedance during both tests. The blood pressure, index of contractility and heart rate were measured directly, whereas the cardiac index, left cardiac work index and systemic vascular resistance index were calculated.**

Results. **The hemodynamic response, as assessed at continuous non-invasive monitoring, showed substantial differences between hyperthermal immersion and exercise testing. Overall, we found a significantly lower hemodynamic load during hyperthermal immersion in comparison with exercise testing. Entering the bath, there was a significant decrease in the left cardiac work, contractility and blood pressure. We recorded a slight increase in the heart rate towards peak hyperthermal immersion. However, other modulators such as the mean arterial pressure, index of contractility, cardiac index and left cardiac work index decreased even below resting values.**

Conclusions. **Excessive hyperthermal immersion induced a lower hemodynamic load in apparently healthy women than standard maximal exercise testing.**

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Introduction

Many physicians consider the cardiovascular functional capacity as a decisive factor when prescribing therapeutic head-out-water hyperthermal immersion (HOWI) in patients with coronary artery disease or hypertension[1]. To date, without the background of evidence-based medicine, hyperthermal balneotherapy is underprescribed in such patients to avoid possible adverse cardiac events. Therefore, owing to excessive precautions many patients with locomotor apparatus diseases and simultaneous cardiac disorders are loosing an unequivocal therapeutic benefit of hyperthermal immersion.

This approach contrasts with the widespread use of exercise testing (ET) which has proved to be safe even in myocardial infarction patients[2]. Besides, the same cardiological patients must surely take a hot bath at home without any control. Moreover, it has been shown that very few acute myocardial infarction, reinfarctions or sudden cardiac deaths occur during sauna bathing[3], which is a similar type of heat stress. Sauna bathing is well tolerated even by patients with stable coronary heart disease and their hemodynamic responses are similar to those of healthy subjects[4,5].

Therefore we compared the effect of HOWI and ET on cardiac hemodynamics, particularly on the peripheral vascular resistance and left cardiac work, in apparently healthy women to study the hemodynamic load on the circulation.

Methods

The study group consisted of 21 randomly selected women aged 50-60 years. The selection criteria included a negative history of cardiovascular diseases, physiological finding during routine physical check-up, normal basal biochemical analysis (sodium, potassium, glucose, urea, uric acid, creatinine, AST, cholesterol). No woman had been on drugs affecting hemodynamics.

To evaluate left ventricular function, we continuously monitored the thoracic electric bioimpedance (TEB) using the NCCOM3 R7 device (BoMed Ltd, Irvine, CA, USA). The device evaluated the TEB waveform beat-by-beat in an operator-independent mode with automatic rejection of incorrect beats. Every 16 accepted beats were averaged for one record.

For longitudinal monitoring of TEB special software was developed, allowing on-line collection of the records. Data were saved on disk together with real time acquisition. An off-line program was used to generate trend lines of individual TEB parameters.

Original spot electrodes were placed at the root of the neck and at the level of the diaphragm[6]. To protect the electrodes against moisture and maintain a constant electrode environment, we covered them with water-resistant surgical drape.

The stroke volume was calculated using Sramek's formula[7] as corrected by Bernstein[8] and recalculated to the cardiac index.

We directly evaluated the following parameters: index of contractility (s^{-1}) and heart rate (b/min).

The following basic hemodynamic parameters were calculated and indexed to the body surface area where appropriate: cardiac index ($l/min/m^2$), left cardiac work index (LCWI) ($kg*m/m^2$), and systemic vascular resistance index (SVRI) ($dynes*s*cm^{-5}*m^{-2}$).

Blood pressure (BP) was measured at the brachial artery with an accuracy of 2 mmHg using a mercury sphygmomanometer and the auscultatory method. The mean arterial pressure (MAP) (mmHg) was calculated using the formula MAP = diastolic BP + 1/3 (systolic BP - diastolic BP).

Before ET, a history of exercise tolerance was taken and women were acquainted with the device. An upright bicycle ergometer (Jaeger, Austria) was used to perform maximal symptom-limited bicycle ET according to modified protocol of Wasserman[9]. The workload was started at 40 W and gradually increased by about 10 W every minute up to the subjective maximum or the development of symptoms. The resting period before and the recovery period after ET lasted 5 min. Only women who reached at least 85% of the maximal age-predicted heart rate were included in the study.

TEB was continuously recorded throughout the examination. A 3-channel ECG (EK 33, Hellige, Germany) was monitored throughout the test and a 12-channel one (Chirastar 63, Chirana, Czech Republic) was recorded in the third and fifth resting periods as well as every minute during exercise and recovery. All suspected arrhythmic or ischemic episodes were recorded.

BP was measured after 3 and 5 min of rest, every second minute of ET and every minute of the recovery period. Subjective exercise tolerance was questioned simultaneously with BP measurement in accordance with Borg scale for perceived exertion[10].

HOWI was carried out in a Hubbard tank filled with tap water maintained at 40°C. The water temperature and level were controlled automatically and maintained stable. The examination room temperature was 25ºC and the humidity 98-100%.

All women underwent 1-hour thermal stabilization in the supine position and at a room temperature of 26ºC. All women were interviewed regarding hyperthermal bath tolerance and their recent health status.

Prior to the bath, resting measurements were taken after a resting period of 5 min with the patient seated outside the Hubbard tank. TEB was recorded continuously throughout the study. Three-channel ECG, BP and Borg scale were measured at 0 and 5 min of the resting period. The sublingual core temperature was obtained.

Having entered the bath, the women sat on a small chair and were immersed up to their head. BP was measured every 2 min and the 3-channel ECG was continuously monitored. Subjective feelings were recorded together with BP. HOWI was terminated when the core temperature had risen by about 2ºC.

During the recovery period outside the Hubbard tank, BP, ECG and Borg scale were recorded every minute for 5 min. Then, as usual after routine balneological procedures, the women were asked to rest for 30 min in the supine position.

The study protocol was approved by the Ethical Committee. Following the advice of the Ethical Committee, written consent was not required because the protocol was based on and used a routine balneological procedure and since the measurement techniques were non-invasive. Enrolment was on a voluntary basis and all subjects were informed on the goals of the study.

Statistical analysis. TEB records were averaged for the 1-min means. The Bartlett-Box F was used to test the homogeneity of variance. For homogeneously distributed parameters, one-way ANOVA analysis for independent samples was used whereas heterogeneously distributed samples were analyzed using the Kruskall-Wallis test for independent samples.

Data are expressed as mean ± SD. We evaluated the pre-test data, the exercise or HOWI data and the recovery ones. Averages were evaluated using Friedman's test for related samples. Exercise and HOWI were compared using the Wilcoxon signed-rank test or paired Student's t-test as appropriate. A p value < 0.05 was considered statistically significant.

Results

HOWI lasted significantly more than ET (20.3 ± 7.07 vs 9.4 ± 1.59 min; $p < 0.01$). No woman developed ischemia or arrhythmic events during either test. Besides, despite the marked decrease in SVRI during both tests, we did not observe any case of collapse or symptomatic hypotension during either test. Females subjectively tolerated HOWI better (9.4 ± 2.9 vs 11.7 ± 3.3 points; $p < 0.05$ according to the 15-point Borg scale).

HOWI produced a significantly lower peak cardiac load in all the parameters analyzed. BP and heart rate peak values were substantially lower despite the twice longer duration of HOWI. The cardiac index and index of contractility reached only about 50% of the exercise peak values (Table I).

Continuous monitoring (presented as bars for the 1-min averages of all the measurements) showed substantially different trends of the hemodynamic parameters during HOWI and ET.

Cardiac index and index of contractility. The cardiac index slightly increased upon entering the bath and then persisted at a level of about 4.2 ± 1.1 l/min/m^2. During ET, a gradual increase with a slow normalization in the recovery period was observed (Fig. 1).

Similar observations were made for the myocardial contractility. Upon entering the bath, the index of contractility increased steeply to a value of 0.054 ± 0.02 s^{-1} with a subsequent gradual decrease during whole immersion to the value of 0.040 s^{-1}. During ET, we observed a clear linear augmentation of the index of contractility until peak exercise. During recovery from the ET and from the fourth minute of HOWI, there was a gradual decrease in contractility from 0.061 to 0.046 s^{-1}. The exercise values stabilized at 0.048 s^{-1}.

Heart rate. A linear increase in heart rate was observed during both tests (Fig. 2). However, the slope was less steep for HOWI than for ET. The peak difference was 115 vs 151 b/min ($p < 0.001$). Upon terminating HOWI, the heart rate increased to 126 b/min and then gradually decreased to 104 b/min. The return to normal values was slower after HOWI, probably due to the prolonged dissipation of accumulated heat in hyperthermal HOWI.

Blood pressure. The resting period was characterized by oscillation of the MAP around a value of 102 mmHg in both tests.

Table I. Comparison between resting and peak values of the considered hemodynamic parameters during exercise testing and head-out-water hyperthermal immersion (HOWI).

	Exercise testing		HOWI	
	Rest	Peak	Rest	Peak
CI (l/min/m^2)	3.02 ± 0.52	8.7 ± 1.99	3.53 ± 0.95	4.6 ± 1.35
IC (s^{-1})	38.0 ± 6.86	76 ± 16.69	42 ± 13.4	42.0 ± 13.8
MAP (mmHg)	102.4 ± 10.27	134.8 ± 11.08	101.5 ± 13.16	90.2 ± 12.6
HR (b/min)	81.5 ± 9.97	151.3 ± 14.13	80.4 ± 9.4	115.1 ± 11.95
SVRI (dynes*s*cm^{-5}*m^{-2})	2632 ± 527.1	1285 ± 360.6	2426 ± 669.9	1632 ± 511.2
LCWI (kg*m/m^2)	4.23 ± 0.83	16.1 ± 3.89	4.8 ± 1.37	5.5 ± 1.59

Values are expressed as mean ± SD. CI = cardiac index; HR = heart rate; IC = index of contractility; LCWI = left cardiac work index; MAP = mean arterial pressure; SVRI = systemic vascular resistance index.

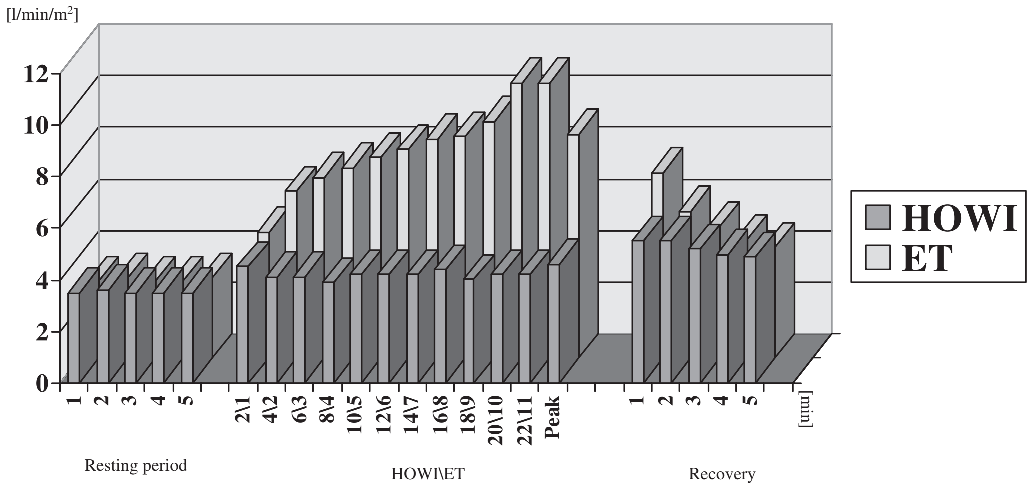

Figure 1. *Cardiac index during exercise testing (ET) and head-out-water hyperthermal immersion (HOWI). The time scale differs for the two tests: the first number refers to the duration of HOWI, the second to the duration of ET.*

During HOWI, BP gradually and linearly decreased to 80.1 mmHg and increased slightly to 97.3 mmHg after leaving the bath. During ET, MAP increased in a linear fashion from 102.4 to 134.8 mmHg. After ET, MAP linearly decreased to 98.1 mmHg (Fig. 3).

Left cardiac work index. During HOWI, LCWI exhibited small non-significant deviations ranging between 4.0 to 5.5 kg*m/m^2 (Fig. 4). Upon leaving the bath, the average value of LCWI temporarily increased from 5.5 to 7.4 kg*m/m^2 ($p < 0.001$) with a subsequent mild decrease to 6.3 kg*m/m^2.

During ET, LCWI increased in a linear but steep manner. The peak value was 16.1 kg*m/m^2 which is almost 3 times higher than in HOWI.

Systemic vascular resistance index. SVRI decreased similarly both during HOWI and ET (Fig. 5). However, the nadir of SVRI was reached upon leaving the bath and during recovery in HOWI, and at the peak of exercise for ET. The recovery was characterized by a mild increase in SVRI after ET and by relatively stable values after HOWI.

Discussion

Hyperthermal HOWI is believed to be a potent hemodynamic stressor with a potentially dangerous impact on cardiac performance, especially in subjects with an impaired cardiac function[1,11,12]. On the other hand, ET is considered as a safe procedure even in patients with chronic heart failure or during the early stages of myocardial infarction. For this reason, we compared the effects of HOWI and ET on cardiac hemodynamics. However, we are aware of the limitation that maximal symptom-limited ET is performed for clear clinical indications under medical control and is not used as a tool of rehabilitation.

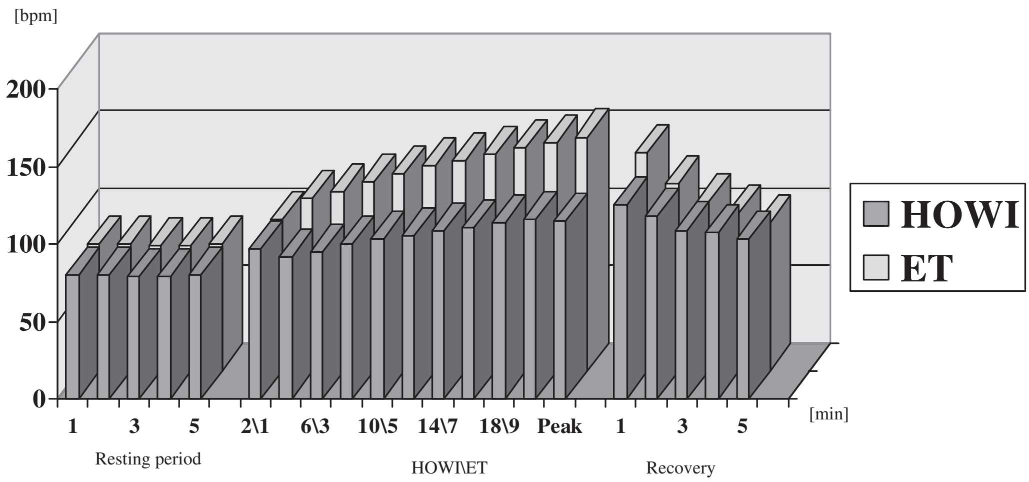

Figure 2. *Trend lines of heart rate during exercise testing (ET) and head-out-water hyperthermal immersion (HOWI). The time scale differs for the two tests: the first number refers to the duration of HOWI, the second to the duration of ET.*

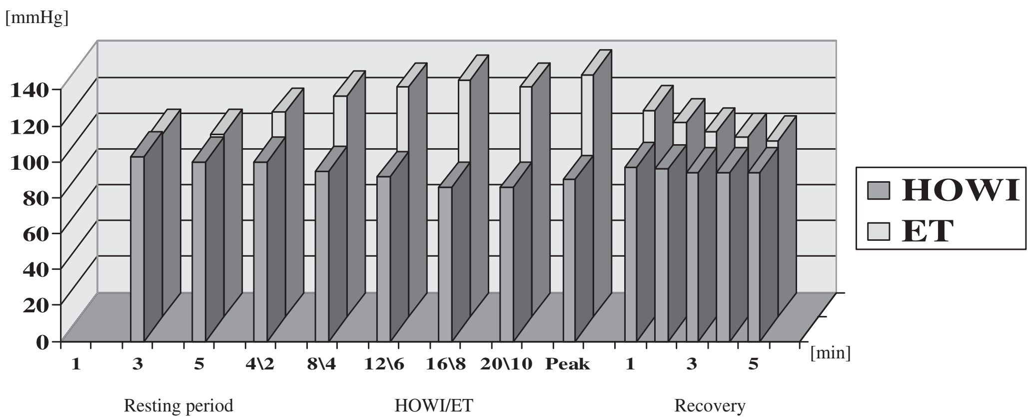

Figure 3. *Trend lines of the mean arterial pressure during exercise testing (ET) and head-out-water hyperthermal immersion (HOWI). The time scale differs for the two tests: the first number refers to the duration of HOWI, the second to the duration of ET.*

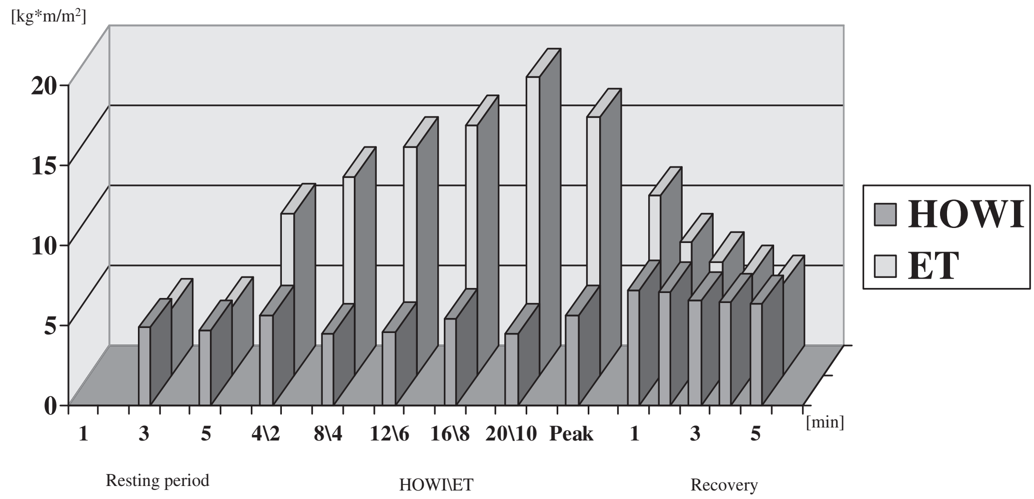

Figure 4. *Trend lines of the left cardiac work index during exercise testing (ET) and head-out-water hyperthermal immersion (HOWI). Averaged data from continuous beat-by-beat recording and corresponding blood pressure measurements. The first number in the time scale indicates the duration of HOWI and the second one the duration of ET.*

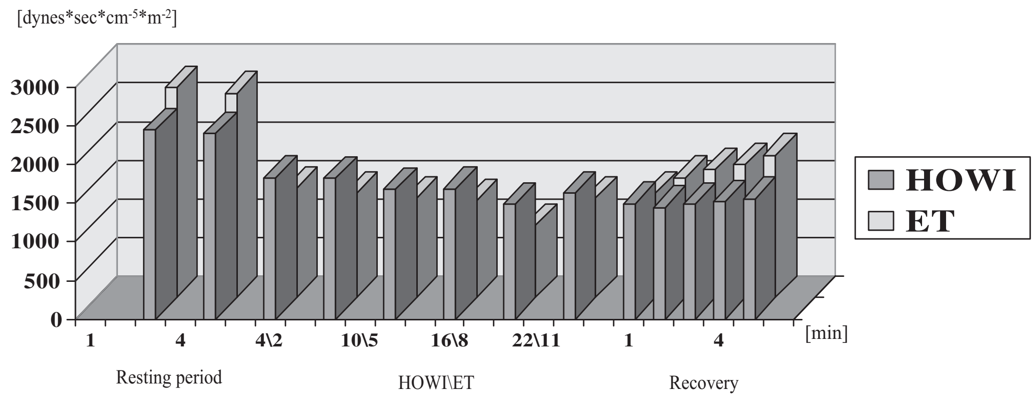

Figure 5. *Trend lines of the systemic vascular resistance index during exercise testing (ET) and head-out-water hyperthermal immersion (HOWI). Averaged data from continuous beat-by-beat recording and corresponding blood pressure measurements. The first number in the time scale indicates the duration of HOWI and the second one the duration of ET.*

In view of the above, we expected to find an increased hemodynamic load in HOWI. Therefore, we selected a study group of apparently healthy middle-aged women, who are known, from balneological practice, to tolerate HOWI well. To be certain of inducing a significant and detectable hemodynamic response in HOWI, we used a water temperature of 40°C, which is even higher (by about 1°C) than that usually employed.

Upon entering the bath, there was a significant decrease in the trend lines of the left cardiac work, contractility and BP. This implies that factors which may induce myocardial ischemia were decreased. The heart rate increased only slightly and towards the peak of HOWI. However, other parameters such as MAP, the index of contractility, the cardiac index and LCWI decreased to levels even lower than resting values (Figs. 1, 3 and 4). Thus HOWI was associated with a significant reduction in hemodynamics.

The decrease in SVRI and the increase in LCWI upon leaving the bath may suggest that the critical moment of HOWI may be just when one leaves the bath. After a period of relatively stable hemodynamics, upon leaving the bath, a powerful vasodilation must be counteracted by an increase in contractility preventing orthostatic collapse. Theoretically, subjects with impaired hemodynamics should fail to increase their contractility and should develop circulatory insufficiency or collapse upon leaving the hyperthermal bath. Besides, the hemodynamic response to HOWI may also be exaggerated, in ischemic heart disease patients, by the concomitant use of vasoactive drugs.

However, the study subjects were apparently healthy women; for this reason, we cannot directly apply the results of our study to a different population, and the risk-benefit ratio of ET has not yet been compared to that of hyperthermal bathing.

In conclusion, excessive HOWI induced a lower hemodynamic load in apparently healthy women than standard maximal ET. The cardiac contractility, one of the main determinants of myocardial ischemia, was decreased even when compared with resting values. These results addressed the recent precaution, for reasons of hemodynamics, in the application of HOWI[1,11]. However, only apparently healthy women were studied and further research in patients with coronary artery disease is necessary.

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