

Cardiorespiratory fitness and heart rate recovery in obese premenopausal women

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Post-exercise heart rate recovery (HRR) has been proposed as a measure of cardiac autonomic dysfunction in apparently healthy adults. We aimed to determine the effects of a lifestyle intervention on HRR among clinically obese premenopausal women. A randomized controlled trial was conducted to investigate the effects of a 3-month non-dieting lifestyle intervention program on cardiorespiratory fitness (CRF) and HRR among healthy clinically obese premenopausal women. Thirty-one were randomly assigned to 3-month intensive lifestyle intervention and 31 served as controls. Sixty-one participants performed a maximal treadmill walking test with metabolic gas exchange. Baseline anthropometric measures were closely related to HRR at 1 min, which may indicate

reduced parasympathetic reactivation. Post-exercise HRR at 60 s (HRR60) increased from 21.3 ± 6.2 to 27.8 ± 10.2 bpm in the intervention group compared with a smaller reduction (26.8 ± 12.3 to 24.5 ± 9.9 bpm) in controls (test for interaction $P = 0.0001$). HRR120 showed a significant effect of time ($P = 0.0002$) with no significant interaction with lifestyle intervention. A significant increase in $\dot{V}O_{2\text{peak}}$ was evident in the lifestyle group (21.6 to 23.6 mL/kg/min) compared with a modest reduction in the controls (22.6 to 21.6 mL/kg/min; test for interaction, $P = 0.001$). Clinically obese healthy premenopausal women achieved significant improvements in HRR60 and $\dot{V}O_{2\text{peak}}$ following a 3-month intensive lifestyle intervention.

It has been estimated that overweight and physical inactivity together could account for up to 59% of deaths from cardiovascular disease (CVD) among non-smoking women (ACSM, 1998). Increased body fat content may represent a stronger CVD risk factor in women compared to men. The higher CVD risk associated with high body mass index (BMI) or body fat content is often (Gray et al., 1989), although not always (Cole et al., 1999), attenuated by increased physical activity. Epidemiological reports indicate that physical activity and cardiorespiratory fitness (CRF) may be strongly independently predictive of CVD outcomes, especially among women. Improved CVD risk stratification has been demonstrated by exercise testing variables (Janssen et al., 2002), especially maximum oxygen consumption and post-exercise heart rate recovery (HRR). Despite methodological differences, both these measures have consistently been linked to increased CVD risk in women (Carroll et al., 2007). Moreover, a representative study in Caucasian women showed that low levels of both HRR and exercise capacity have a particularly poor CVD prognosis, even after adjustment for age and other risk factors (Lind & Andrén, 2002).

Post-exercise HRR (particularly in the first or second minute following strenuous exercise) has been proposed as a measure of cardiac autonomic dysfunction (Jae et al., 2009). Impaired HRR is associated with predominantly impaired vagal reactivation (Arena et al., 2010). HRR has been related to CVD risk factors, particularly central obesity and insulin resistance (Mora et al., 2005). Several randomized studies among overweight and obese women have shown lifestyle interventions (including structured aerobic exercise or physical activity), bring both short- and long-term improvements in CRF (Janssen et al., 2002; Ross et al., 2004). Recently, Nagashima et al. (2010) reported that exercise-induced improvements in cardiorespiratory function appeared to be the main contributor to the changes in HRR. Alternatively, HRR improves in weight loss (Brinkworth et al., 2006), with no change in physical activity levels or CRF. The short-term effects of lifestyle intervention (dietary modification without calorie restriction and increased physical activity/exercise) on maximal oxygen consumption and HRR measures among apparently healthy obese women remain to be adequately evaluated in randomized controlled studies.

Methods

Study population

The Weight, Healthy Eating and Exercise in Leeds (WHEEL) project was a randomised controlled trial (RCT) of lifestyle intervention in clinically obese premenopausal women. Healthy premenopausal obese adult women were recruited to this multidisciplinary program by local media advertisements and electronic media correspondence with local government and university employees. Initial respondents to the advertisements were contacted by letter and supplied with full information about the study and requested to complete personal, medical history, and physical activity questionnaires, including self-reported height and weight. All the participants provided individual written informed consent for study procedures and written approval from their family doctor. The study protocol was approved by the Research Ethics Committee of the Leeds Teaching Hospitals National Health Service (NHS) Trust (see Carroll et al. (2007) for full description of methods).

Eligible study participants had to be healthy, clinically obese ($\text{BMI} > 30.0 \text{ kg/m}^2$), and not previously diagnosed with cardiovascular disorders, a history of kidney or liver disease, and type I or 2 diabetes mellitus. Participants also had to be free of orthopedic problems likely to interfere with increased physical exercise. In addition, all participants were previously sedentary, defined as less than 2 days per week of physical activity (for less than 30 min per day) over the previous 6 months. Pregnant or breastfeeding women were excluded. Two eligible participants reporting a current light smoking habit were allowed to participate. A physician reviewed the applicants' medical history in relation to the study inclusion criteria. Prior to randomization and baseline measurements, family doctors were informed and were asked to approve their registered patients' intention to enroll in the study.

Participants were invited to a 2-h study orientation session. The study protocol involved 3 months of intensive lifestyle intervention, followed by 9 months maintenance for all eligible participants. The study design involved half of the participants randomly allocated to a 3-month control period. At the end of the orientation session, participants were randomly assigned to 3 months of lifestyle intervention or waiting list control (delayed start). Simple randomization involving sequential opening of numbered envelopes was utilized and balanced the number of participants in the lifestyle intervention and control groups. The allocation sequence for randomization was generated by the principal investigator (E. B.). Following randomization, all the participants underwent an exploratory interview appraising dieting histories, eating and exercise habits, and psychological status. The 31 participants assigned to the waiting list control group were requested to maintain their current lifestyle habits. This group was scheduled to start the intervention phase after 3 months.

Briefly, lifestyle intervention comprised of community-based supervised exercise, lifestyle physical activity, educational classes on healthy eating, and weight management. The intervention phase consisted of 12 weeks of "intensive" lifestyle intervention in which the participants were encouraged to undertake up to 4 h or more of physical activity per week, two of which had to be in a form of structured WHEEL exercise class. Participants negotiated to increase their regular walking and were advised to accumulate at least 30 min of moderate physical activity at most, preferably all days of the week, in a manner consistent with their lifestyle and daily schedules. Structured exercise sessions available included two circuit trainings, one Tai-chi and one aqua-aerobic class per week. Participants were expected to exercise between 40 and 85% of their heart rate reserve which was monitored by the exercise instructors during the cardiovascular conditioning component of the circuit training program. Program progression was reviewed on an ongoing basis by exercise instructors based on heart rate responses during specific stations within the circuit. These

community-based exercise classes were undertaken with a centrally located municipal leisure centre. Instruction in correct exercise techniques, monitoring of heart rate, and ratings of perceived exertion was provided in all exercise sessions. Supervised exercise training during the intervention phase was based on each participant's baseline cardiopulmonary fitness. Initial exercise intensities and the progression of all activities were consistent with the recommendations of the American College Sports Medicine Position Stand (1998). Researchers and qualified exercise instructors assisted participants in setting realistic physical activity goals, monitored their activity levels, and provided opportunities for social interaction. Thus, the intervention incorporated elements of both lifestyle physical activity and structured supervised aerobic exercise shown to offer long-term benefits in obese women.

Healthy eating and weight management education sessions were conducted weekly throughout the intervention period. A study educational booklet on healthy eating principles and the benefits of exercise was provided to all the intervention participants. All participants were provided with consistent dietary guidelines that did not place specific emphasis on calorie restriction. The healthy eating guidelines were delivered by a state-registered dietician. Participants were advised to consume a self-selected low-saturated fat, high-fiber diet, consistent with current dietetic guidelines.

Cardiopulmonary exercise testing protocol

At baseline, of the 62 participants enrolled in the study, 61 underwent maximal treadmill testing at the Non-Invasive Cardiology Unit of a large teaching hospital. The environmental conditions within the laboratory were maintained around 20°C and 40–60% humidity. The laboratory supervisors and technicians assessing CRF measures at baseline and post-intervention were not blinded to the participants' group allocation. Participants were informed of their exercise test results at each stage of the study. A modified graded treadmill walking protocol (Lehmann et al. 1997) was employed. Participants were verbally encouraged to exercise to the limits of tolerance. A total of 9×3 -min stages were used in which the speed and inclination were increased in an alternate fashion from 2.0 mph, 0% gradient, up to 4.0 mph with a 16.0% gradient. The test was ended when the participants were close to exhaustion according to ratings of perceived exertion (RPE 19 or 20) or when the increase in oxygen uptake with increasing workload was leveling off with a respiratory exchange ratio (RER) above 1.05.

Continuous breath-by-breath sampling of respiratory gases was carried out using the Medgraphics Cardio Cardiopulmonary Exercise Testing System (Medical Graphics Corporation, St Paul, Minnesota, USA), incorporating a flow/waveform module, oxygen, and infrared carbon dioxide gas analyzers, and a 12-lead electrocardiograph. Gas flow was measured through a disposable pneumotachograph (Medical Graphics Corporation), which was attached to the flow analyzer via a double-lumen umbilical tube. Flow was measured indirectly as a pressure differential by the pneumotachograph. Both the disposable pneumotachograph and gas analyzers were calibrated before each test. The pneumotachograph was calibrated using a 3-L syringe and the gas analyzers, using a reference gas (21% O_2 and balance N_2) and a calibration gas (12% O_2 , 5% CO_2 , and balance N_2). Based on breath-by-breath samples and using a rolling average of eight breaths, the following respiratory data were assessed: $\dot{V}\text{O}_2$ (oxygen consumption, mL/min and mL/kg/min), $\dot{V}\text{CO}_2$ (carbon dioxide production, mL/min), RER ($\dot{V}\text{CO}_2/\dot{V}\text{O}_2$), P_{ETCO_2} (end-tidal partial pressure of CO_2 , mmHg), $\dot{V}\text{E}$ [expired volume of gas, L/min body temperature and pressure saturated (BTPS)], and V_t (tidal volume, mL BTPS). Heart rate responses were derived from a 12-lead electrocardiogram (ECG) monitored throughout exercise. The ECG was monitored with three-channel (V_1 , V_5 , and aVF) recordings obtained throughout the exercise test. Twelve-

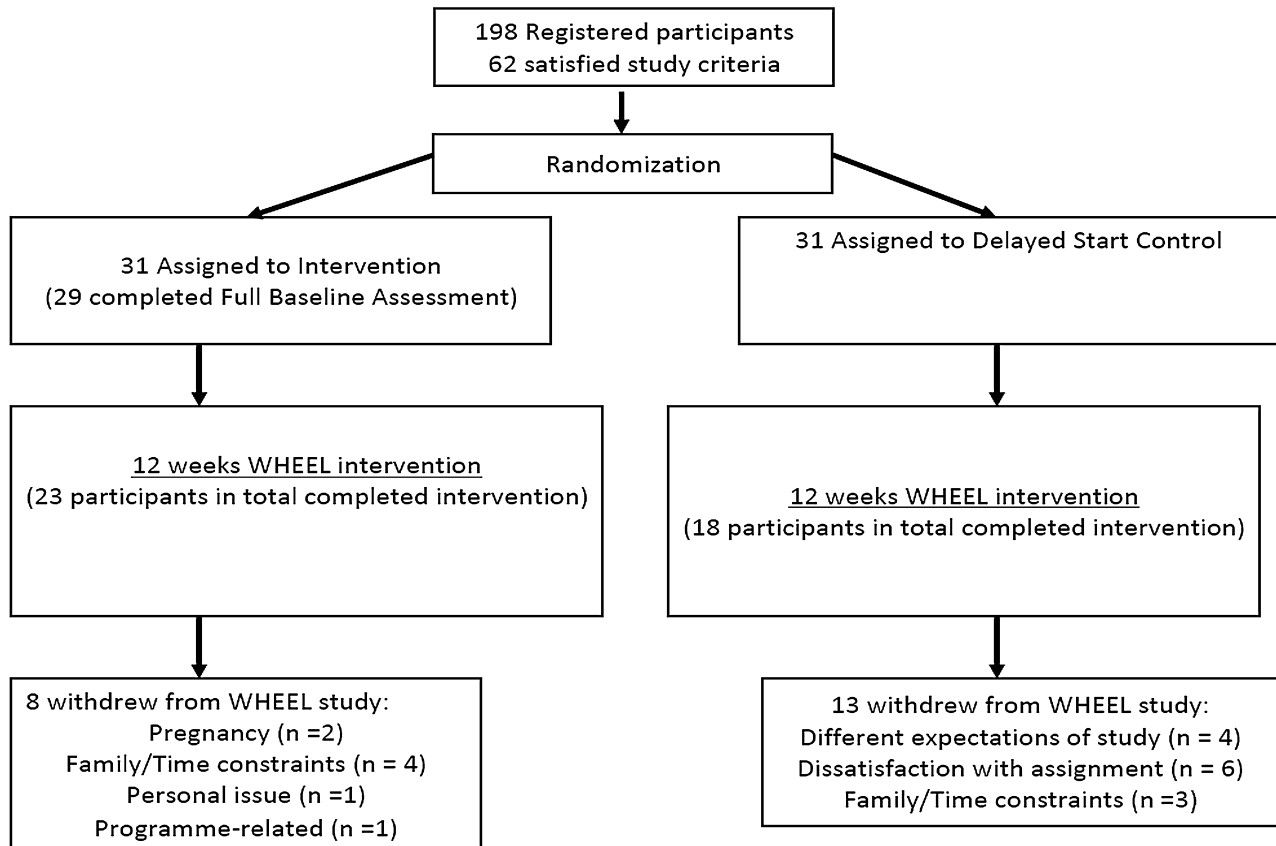


Fig. 1. Flowchart showing participant progression through the study.

lead ECGs were recorded at the end of each exercise test stage, at peak exercise, and at the end of each minute of recovery. Participants' body position was kept unchanged from the pre-exercise resting period to the end of the recovery period.

Most investigators quantifying HRR have measured the decline in heart rate from peak exercise to 60 or 120 s of recovery or considered the slope of the decline (Robinson et al., 1966). In the present study, HRR was measured in all participants 60 (HRR60) and 120 s (HRR120) after exercise termination. Delta-HRR60 (Δ HRR60) was calculated by subtraction of the heart rate 60 s after exercise termination from the peak heart rate attained during the exercise test (Carroll et al., 2007). HRR at 120 s (Δ HRR120) was calculated in the same manner. Furthermore, in addition to expressing HRR as absolute values, the relative (%) decline in heart rate at 60 and 120 s after exercise cessation was also calculated. Furthermore, we also evaluated the Cardiac Autonomic Index, a ratio integrating both resting heart rate and post-exercise HRR (Imai et al., 1994). Systolic and diastolic blood pressures were obtained at rest and during each stage of treadmill exercise and peak exertion from the brachial artery using manual sphygmomanometry.

Body composition was assessed indirectly through changes in body mass, BMI, waist, and hip circumferences. Participants wore only underclothes when body weight, height, and waist circumference measurements were performed. Body weight was assessed using an electronic scale (Seca α 770 digital low form scale, Birmingham, UK). Standing height was determined without shoes using a wall-based stadiometer. BMI was calculated as weight in kilograms divided by height in meters squared. Waist circumference was measured at the level midway between the lower rib margin and the iliac crest with the participant breathing out gently. The participants' fat-free body mass was estimated using bioelectrical impedance analysis (Maltron; BF-906 Rayleigh, UK) using

the conventional arm-to-leg approach. Before body composition testing, participants were requested to adhere to standard bioelectrical impedance testing guidelines. Fat-free mass and body fat proportion were estimated using relevant equations for overweight/obese women (D'Amore & Mora, 2006).

Statistical analysis

Group data for each variable at rest and peak exercise are presented as mean $\pm$ standard deviation. Baseline characteristics of participants randomly assigned to intervention and control groups and those participants who did not complete the 3-month treatment phase compared with those who did were compared with independent *t*-tests. Changes in variables across the intervention study, over time and between groups, were assessed using analysis of covariance with repeated measures. Statistical comparisons between groups were made using all available data with participants grouped as originally randomized, regardless of the degree of intervention compliance. Statistical analyses were performed using SPSS software (IBM, NY, USA, version 17), and statistical significance was assumed at $P < 0.05$.

Results

From 198 initial applications, 62 participants met the study inclusion criteria. A Consort-type flow chart of participant progression through the study is shown in Fig. 1 (see Carroll et al., 2007). Seventeen participants did not begin or failed to complete the 3-month randomized intervention phase and therefore did not re-attend

Table 1. Baseline anthropometric and peak hemodynamic/metabolic measurements from the graded treadmill walking test in participants randomized to lifestyle intervention ($n = 30$) and control groups ($n = 31$)

Variable	Intervention	Control
Age, years	39.3 $\pm$ 7.8	41.0 $\pm$ 7.7
Weight, kg	108.4 $\pm$ 21.6	100.1 $\pm$ 20.7
BMI, kg/m ²	39.9 $\pm$ 7.4	41.0 $\pm$ 7.7
Waist circumference, cm	126.7 $\pm$ 16.8	121.9 $\pm$ 18.7
$\dot{V}O_2$, mL/min	2317.4 $\pm$ 353.4	2197.2 $\pm$ 354.2
$\dot{V}O_2$, mL/kg/min	21.6 $\pm$ 3.4	22.6 $\pm$ 3.1
RER	1.10 $\pm$ 0.05	1.08 $\pm$ 0.06
Peak heart rate, bpm	170.8 $\pm$ 10.2	168.7 $\pm$ 16.2
Systolic BP, mmHg*	181.4 $\pm$ 19.5	179.1 $\pm$ 27.2
Diastolic BP, mmHg*	79.6 $\pm$ 10.6	78.6 $\pm$ 12.6

*Data available in 26 intervention and 25 control participants.

BMI, body mass index; RER, respiratory exchange ratio.

Table 2. Resting and maximal heart rate and heart rate recovery (HRR) measurements following graded treadmill walking test in obese premenopausal women randomized to lifestyle intervention ($n = 30$) and control groups ($n = 31$)

Variable	Intervention	Control
Resting heart rate, bpm		
Peak exercise heart rate, bpm	170.5 $\pm$ 10.5	168.7 $\pm$ 16.2
Heart rate at 60 s post-exercise, bpm	147.0 $\pm$ 11.4	143.0 $\pm$ 18.6
Heart rate at 120 s post-exercise, bpm	123.9 $\pm$ 11.1	123.5 $\pm$ 17.0
HRR, 60 s post-exercise (HRR60)	23.5 $\pm$ 8.1	25.1 $\pm$ 10.7
HRR, 120 s post-exercise (HRR120)	46.5 $\pm$ 11.2	44.4 $\pm$ 8.1
Percent HRR, 60 s post-exercise (%HRR60)	13.7 $\pm$ 4.6	14.9 $\pm$ 6.1
Percent HRR, 120 s post-exercise (%HRR120)	27.2 $\pm$ 5.8	26.4 $\pm$ 5.0

for exercise testing. The non-completion rate was similar in the lifestyle intervention and the control groups, namely 9 and 10 participants, respectively (chi-squared analysis; $P = 0.837$).

Of the 62 participants randomized, one did not complete baseline exercise testing. For the anthropometric, CRF, and HRR variables, the baseline characteristics of participants who completed the 3-month randomized phase were not significantly different to those who did not complete this treatment phase (Table 1). Table 2 shows the comparable peak exercise test characteristics in the participants randomly assigned to the lifestyle intervention and control groups. No significant between-group differences were evident in peak exercise, HRR, or metabolic measurements ($P > 0.05$). Resting heart rate was not associated with baseline measures of body composition. At baseline, ΔHRR60 was the only post-exercise time point that was associated with body mass or BMI. Both post-exercise HRR variables (ΔHRR60 and ΔHRR120) were modestly but significantly correlated to both absolute and body mass-adjusted measures of $\dot{V}O_{2\text{peak}}$. The strongest associations between HRR and $\dot{V}O_{2\text{peak}}$ were observed for the ΔHRR60 data.

There was a modest but statistically significant reduction in body weight in the lifestyle group compared with the control during the 3-month intervention period (test for interaction, $P = 0.004$; Table 3). Forty-four participants completed a maximal exercise test at 3 months. The lifestyle intervention group showed a significantly improved $\dot{V}O_{2\text{peak}}$ normalized for body weight (21.6 to 23.6 mL/kg/min) compared with a reduction (22.6 to 21.6 mL/kg/min) in the control group (test for interaction, $P = 0.001$). ΔHRR60 increased from 21.3 ± 6.2 to 27.8 ± 10.2 bpm in the intervention group compared with a small reduction (26.8 ± 12.3 to 24.5 ± 9.9 bpm) observed in the controls (test for interaction $P = 0.0001$). In contrast, significant improvements in both groups for HRR were evident at 120 s post-maximal exercise (main effect of time, $P = 0.002$) with no significant interaction with treatment. In the lifestyle group, ΔHRR120 increased compared to controls. Changes in the relative (%) decline in heart rate at 60 and 120 s after cessation of exercise (%HRR60 and %HRR120) showed consistent findings to changes in HRR expressed in absolute units. There were no significant correlations between ΔHRR60 ($r = -0.45$; $P = 0.79$) and ΔHRR120 ($r = -0.31$; $P = 0.86$) and ΔBMI during the intervention.

Discussion

The present study has demonstrated significant improvements in both $\dot{V}O_{2\text{peak}}$ and post-exercise HRR measures following lifestyle intervention in a group of previously sedentary, clinically obese premenopausal participants. Few studies have previously examined the effect of lifestyle intervention, including exercise training, on measures of HRR among clinically obese women. Indeed, to the best of our knowledge, this is the first RCT of lifestyle intervention to evaluate measures of HRR following maximal exercise testing in apparently healthy clinically obese women.

In recent years, several complimentary indices of HRR have been reported. Following exercise, typically heart rate reductions of 15–20 bpm in the first minute of recovery (ΔHRR60) have been reported (Rossy & Thayer, 1998). At baseline, the reduction in heart rate following maximal exertion (approximately 24 bpm) exceeded threshold values (during active recovery or passive recovery in the supine position) indicating increased relative risk of cardiovascular mortality in asymptomatic individuals.

Several studies have validated the seminal observation by Imai et al. (1994) that early HRR after dynamic exercise is mainly a function of vagal reactivation, with the sympathetic withdrawal becoming more prominent later in recovery (Arena et al., 2010). A more rapid HRR within a 120-s recovery period may therefore be a function of an increase in vagal activity or reduction in sympathetic activity. The results of the present investigation show significant intervention-based improvements in

Table 3. Pre- and post-intervention anthropometric, CRF, and metabolic measurements from the graded treadmill walking test in the participants completing the intervention phase

	Lifestyle (n = 22)		Control (n = 22)		Main effect Time	Interaction effect
	Preintervention	Post-intervention	Preintervention	Post-intervention	P-value	P-value
Anthropometry						
Weight	106.6 ± 17.8	104.6 ± 19.2	99.5 ± 19.6	101.3 ± 18.7	0.878	0.004
BMI, kg/m ²	39.0 ± 6.4	38.3 ± 7.0	36.9 ± 7.0	37.7 ± 6.6	0.780	0.003
VO ₂ , mL/min	2276 ± 360	2454 ± 382	2227 ± 332	2155 ± 319	0.144	0.001
VO ₂ , mL/kg/min	21.6 ± 3.3	23.6 ± 4.5	22.7 ± 3.1	21.6 ± 3.1	0.211	0.0005
RER	1.09 ± 0.05	1.09 ± 0.05	1.08 ± 0.06	1.08 ± 0.05	0.632	0.676
Peak heart rate, bpm	170 ± 11	172 ± 12	173 ± 14	171 ± 14	0.713	0.102
Resting heart rate	98.0 ± 12.9	96.0 ± 14.3	90.5 ± 14.2	89.0 ± 15.8	0.0001	0.873
HRR60	21.3 ± 6.2	27.8 ± 10.2	26.8 ± 12.3	24.5 ± 9.9	0.204	0.001
HRR120	44.8 ± 10.8	52.5 ± 13.4	45.7 ± 8.5	50.8 ± 10.8	0.0002	0.403
Cardiac autonomic index	5.4 ± 3.4	3.9 ± 1.9	5.0 ± 4.0	5.2 ± 4.6	0.226	0.138
%HRR60	12.6 ± 3.6	16.3 ± 6.3	15.3 ± 6.6	14.2 ± 5.8	0.165	0.013
HRR120	26.4 ± 5.5	30.7 ± 8.0	26.2 ± 4.5	29.3 ± 6.2	0.0001	0.496

BMI, body mass index; CRF, cardiorespiratory fitness; HRR, heart rate recovery; RER, respiratory exchange ratio.

HRR only at the 60-s point (Δ HRR60) after maximal exertion. Δ HRR120 improved in both intervention and control groups with no significant interaction effect. This finding of improved HRR in both groups may represent familiarity with the exercise testing protocol or regression to the mean effects. Interestingly, a similar pattern of change was observed for resting heart rate in both the intervention and control participants. Accordingly, the Cardiac Autonomic Index proposed by Jae et al. (2009), a ratio integrating both resting heart rate and post-exercise HRR, improved more in the lifestyle intervention compared to controls, but this did not attain statistical significance. Given that a predominance of parasympathetic activity may exist more in women (Ross et al., 2004), the effect of increased physical activity on measures of cardiac autonomic function may be less evident (Nilsson et al., 2007).

HRR is traditionally expressed (and prognostically validated) in absolute values (Lind & Andr  n, 2002; Calling et al., 2006; Jae et al., 2009). However, it has been suggested that a relative value would probably be more physiologically meaningful. The absolute decrease in heart rate following exercise is not only a measure of the rapidity of heart rate reduction but also the peak heart rate attained. Imai et al. (1994) measured the beat-by-beat heart rate decay for the first 30 s after exercise to provide pathophysiological information on the underlying HRR. This can be assumed to be closer to %HRR60 than to Δ HRR60. However, the prognostic impact of the relative decline in heart rate after exercise has not been reported. In the present study, relative HRR values (%HRR60 and 120 s) were similarly significantly influenced by the lifestyle intervention.

We did not observe a positive association between the improvements in HRR and weight loss, suggesting that the modest weight loss achieved in the intervention group was not related to improvements in cardiac auto-

nomic (by modulating parasympathetic activity). Other studies have demonstrated that weight loss improves vagal tone in overweight populations. Laaksonen et al. (2003) showed that weight loss through dietary restriction in obese patients with metabolic syndrome reduced heart rate and cardiac spectral indices of heart rate variability, indicating enhanced parasympathetic tone. Similarly, following a 6-month weight reduction program in healthy obese women, cardiac parasympathetic tone was increased after a 9.5% reduction in body weight. Giallauria et al. (2008) reported impaired HRR in overweight women with polycystic ovary syndrome that correlated with BMI and insulin resistance. Lind and Andr  n (2002) showed that HRR was inversely associated with insulin resistance and other risk factors tending to cluster with insulin resistance, including BMI and abdominal obesity in healthy participants. Thus, it is possible that the improvements in HRR after substantive weight loss, as we observed, may reflect changes in autonomic function in response to improvements in insulin sensitivity.

The improvements observed in our intervention are clinically relevant in relation to the higher CVD risk in obese women. Within the Lipid Research Clinics investigation (Probstfield & Rifkind, 1991), the age-adjusted hazard ratio for cardiovascular death for every metabolic equivalent (MET) decrease in exercise capacity and each 10 bpm deterioration in HRR was 1.20 [95% confidence interval (CI), 1.18–1.30] and 1.36 (95% CI, 1.19–1.55) respectively. In a subsequent report using annual CVD mortality rates, Mora et al. (2005) estimated that half of the women with a Framingham Risk Score (FRS) of 10% to 19%, plus half of the women with FRS 6% to 9%, would be reclassified as high risk on the basis of having poor HRR and low exercise capacity. In the St James Women Take Heart program (Gulati et al., 2010), the FRS-adjusted mortality risk decreased by 17% for every 1-MET increase in exercise capacity. During

submaximal exercise testing, Cole et al. (2000) analyzed data on >5000 participants aged ≥ 30 years, and defined an abnormal HRR of < 42 bpm in the second minute of recovery. The first 2 min of HRR may be the most important in terms of predicting mortality and presence of coronary artery disease (CAD). HRR has been suggested to approximate parasympathetic tone and may be a better predictor of mortality after 1 min (HRR₆₀) post-exercise, whereas the second minute (HRR₁₂₀) may better predict presence of CAD (Lipinski et al., 2004).

A potential limitation of the current study is the steady-state 3-min increments in the maximal exercise test protocol and subsequent 3-min standing recovery period. Some investigators (e.g. Shetler et al., 2001) have recommended that following ramp-based maximal exercise testing, a rapid postural change to a supine position should be considered for assessing HRR. However, transition from treadmill standing to a supine position may require a relatively large proportion of immediate post-exercise recovery time. Accordingly, HRR results in this study are difficult to compare with previous work due to methodological differences. Higher peak $\dot{V}O_2$ attained with upright treadmill exercise may be associated with a higher cardiac output and heart rates during the early recovery period, resulting in slower ΔHRR_{60} (despite comparable heart rates at peak exercise). A previous study (Takahashi et al., 2000), using an upright cycling protocol, has shown that HRR with an upright body position may be slower than during supine recovery. It has also been reported that vagal activity is higher in the supine than in the upright position in healthy people (Robinson et al., 1966). Other studies, including the Lipid Research Clinic (Probstfield & Rifkind, 1991) using either submaximal treadmill tests with passive recovery in the sitting position (Janssen et al., 2002) or maximal tests with passive recovery in the supine position (Takahashi et al., 2000) only report data on ΔHRR_{120} (Mora et al., 2005) or found that HRR₁₂₀ was a stronger prognostic predictor than ΔHRR_{60} (Shetler et al., 2001). A further limitation of the study is that it constitutes a relatively small cohort of sedentary, obese premenopausal participants analyzed on a *per protocol* basis. However, our findings are suggestive that intensive lifestyle modification, incorporating moderate-intensity supervised exercise training, and lifestyle physical activity can favorably improve $\dot{V}O_{2peak}$ and measures of HRR. These variables may provide complimentary measures for directly quantifying overall improvements in cardiorespiratory status related to CVD risk.

We recommend that larger RCTs of lifestyle activity and structured exercise are now required to confirm the effectiveness of such interventions on HRR in premenopausal obese women. In conclusion, obese premenopausal women achieved significant improvements in ΔHRR_{60} and $\dot{V}O_{2peak}$ following a 3-month intensive lifestyle intervention. Improvements in these measures

may be protective against the excess cardiovascular mortality observed among sedentary obese women.

There is now a more consistent pattern of findings from randomized controlled trials that long-term exercise training, without weight reduction, modestly decreases abdominal adipose tissue and improves insulin action among overweight/obese adults. Exercise effects on glucose tolerance may also be evident within normoglycemic overweight/obese individuals, although improvements are more probable with concurrent weight loss. Most randomized studies have been performed within middle-aged and older males, and evidence for improvements in abdominal fat, insulin action, and glucose tolerance within overweight or obese women is more limited. Exercise alone and combined with dietary intervention is effective in improving impaired glucose regulation and delaying or preventing type 2 diabetes among both sexes. HRR has been previously associated with obesity and related metabolic disorders in overweight/obese females (Giallauria et al., 2008), and our study extends these findings.

Perspectives

Epidemiological reports indicate that physical activity and CRF may be strongly independently predictive of CVD outcomes, especially among women. Indeed, low levels of two non-invasive cardiorespiratory measures derived from exercise testing, peak oxygen consumption ($\dot{V}O_{2peak}$), and post-exercise HRR have consistently been linked to CVD risk in women even after accounting for other CVD risk factors. Post-exercise HRR has been proposed as a measure of cardiac autonomic function. Randomized studies evaluating changes in CRF and cardiac autonomic function in clinical obesity are sparse, especially in the setting of non-requisite calorie restriction. This study found that short-term physical activity and exercise improved CRF and HRR with only modest weight loss in clinically obese premenopausal females. Given the great difficulties of losing weight and maintaining a reduced weight over the long term, this study underscores the benefits of lifestyle physical activity and exercise in improving fitness to reduce CVD risk. To date, extensive attention has been given to weight-loss interventions. However, the long-term effect of CRF change, primarily resulting from increasing physical activity, increasingly appears likely to be as important as weight loss for reducing premature CVD mortality.

Key words: exercise training, obesity, autonomic function, vagal reactivity, primary prevention.

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