EFFECT OF HIGH-INTENSITY INTERVAL TRAINING PROTOCOL ON ABDOMINAL FAT REDUCTION IN OVERWEIGHT CHINESE WOMEN: A RANDOMIZED CONTROLLED TRIAL

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Original scientific paper
UDC: 796.015.542:613.25-055.2(510)

Abstract:

The objective of the study was to compare the whole-body and abdominal fat loss resulting from high-intensity interval training (HIIT) with that from moderate-intensity continuous training (MICT) with equivalent oxygen cost in overweight women. Forty-three overweight women with matched anthropometric characteristics were randomly assigned to participate in: (1) HIIT [4 x 4-minute running at 85–95% HR_{peak}, 10-minute recovery], (2) MICT [33-minute running at 60–70% HR_{peak}] with oxygen cost equivalent to HIIT, and (3) no training [control], for 12 weeks, 4 $d \cdot wk^{-1}$. Dietary energy intake and habitual energy expenditure were not altered during the intervention. After the intervention, whole-body fat reduction and serum lipid profile modification were similar in the HIIT and MICT groups. With regard to the abdominal visceral (AVFA) and subcutaneous (ASFA) fat areas revealed by computed tomography scans, a greater reduction in ASFA was found in the HIIT than in the MICT group (p=.038). Moreover, a significant reduction in AVFA was found only in the HIIT group. No variables were changed in the control group. Twelve-week HIIT and MICT programmes with equivalent oxygen cost resulted in similar whole-body fat loss in overweight women. Nonetheless, HIIT appears to be more effective than MICT for controlling abdominal visceral and subcutaneous fat.

Key words: *interval training, continuous training, visceral fat, subcutaneous fat, obesity*

Introduction

The incidence of obesity and its related diseases has dramatically increased worldwide in the last few decades, mainly as a result of a physically inactive lifestyle and inappropriate dietary habits. Currently, along with behavioural and nutritional counselling, involvement in regular physical activity serves as the first line of defence in preventing obesity (Donnelly, et al., 2009; McInnis, Franklin, & Rippe, 2003). Although there is robust evidence that long-term exercise at moderate intensity could improve body composition, cardiovascular fitness and other health-related parameters including insulin sensitivity and lipid profile in healthy and obese people (Donnelly, et al., 2009; McInnis, et al., 2003), populations generally choose not to participate in physical activity. Lack of time and the monotony of exercise were cited as major barriers (Godin, et al., 1994; Reichert, Barros, Domingues, & Hallal, 2007).

It is well recognized that fat accumulated on the surface of abdominal viscera or inside the intra-abdominal solid organs is strongly associated with obesity-related complications including type 2 diabetes and cardiovascular disease (Hamdy, Porramatikul, & Al-Ozairi, 2006; Nicklas, et al., 2004). A high-volume, moderate-intensity continuous training (MICT) protocol has been shown to be a powerful strategy for inducing loss of abdominal fat, including visceral fat (Irwin, et al., 2003; Ross, et al., 2000). Moreover, fat loss appears to be associated with training intensity, with a modest increase in the intensity of an MICT protocol tending to augment abdominal fat loss (Irving, et al., 2008; Slentz, et al., 2005). However, such MICT regimes require a huge commitment by participants in terms of time and effort, making body-fat control measures less practical. In recent years, a growing body of literature has shown that high-intensity interval training (HIIT) could induce similar favourable metabolic adaptations associated with MICT in normal populations (Nybo, et al., 2010) and in patients with chronic diseases including obesity (Little, et al., 2011; Sijie, Hainai, Fengying, & Jianxiong, 2012; Tjonna, et al., 2008). The amount of exercise in an HIIT regime, which consists of repeated high-intensity exercise bouts, is relatively lower than that of MICT, favouring the development of time-efficient lifestyle intervention strategies for improving obesity-related health risk factors (Nie, et al., 2012). However, in our opinion, the interval training effects reported in previous studies in relation to abdominal fat reduction are limited. Trapp, Chisholm, Freund, and Boutcher (2008) reported that a 15-week interval cycling programme (60 x 8-second sprint, 12-second active recovery) resulted in a reduction in central abdominal fat in non-obese young women. Similar results for abdominal fat reduction were also found in overweight women with short-term, low-volume HIIT (10 x 60-second cycling at 90%HRmax, 3d·wk^{-1}, 6 weeks) (Gillen, Percival, Ludzki, Tarnopolsky, & Gibala, 2013). However, the use of DEXA, rather than computed tomography, to measure abdominal fat content in these studies (Irving, et al., 2008; Gillen, et al., 2013) meant that it was impossible to identify the extent of the abdominal fat reduction that occurred independently in viscera and subcutaneous tissues.

The purpose of this study was to examine the effect of a specific 12-week HIIT programme on the whole-body and abdominal fat reduction in overweight/pre-obese Chinese women. A randomized controlled trial was applied to compare the HIIT protocol-induced reductions in the whole-body fat percentage (%BF), fat mass (FM), abdominal visceral and subcutaneous fat measured by computed tomography scans, and changes in the profiles of serum lipids and glucose, with those resulting from a traditional MICT programme with equivalent oxygen cost, and with those of untrained counterparts.

Methods

Subjects

Based on the overweight/pre-obese criteria in the Asian-Pacific region recommended by the World Health Organization (WHO, 2000), inclusion criteria for the subjects were as follows: (a) body mass index (BMI)≥25 kg/m^2; (b) %BF≥28; (c) body mass constant (±2 kg) in the past 3 months; (d) no regular physical training except participation in physical education classes twice per week; (e) no history of metabolic, hormonal, orthopaedic and cardiovascular disease or assumed related medication. Accordingly, 43 female undergraduate students were recruited. Experiments in the present study were performed in accordance with the Helsinki Declaration. Following an explanation of the purpose and constraints of the study, the subjects gave written informed consent for their participation in the study. The Ethical Committee of Hebei Normal University for the Use of Human & Animal Subjects in Research gave ethical approval of the study.

Study design

As shown in Figure 1, subjects with matched anthropometric characteristics were randomly assigned to three groups, namely: the high-intensity

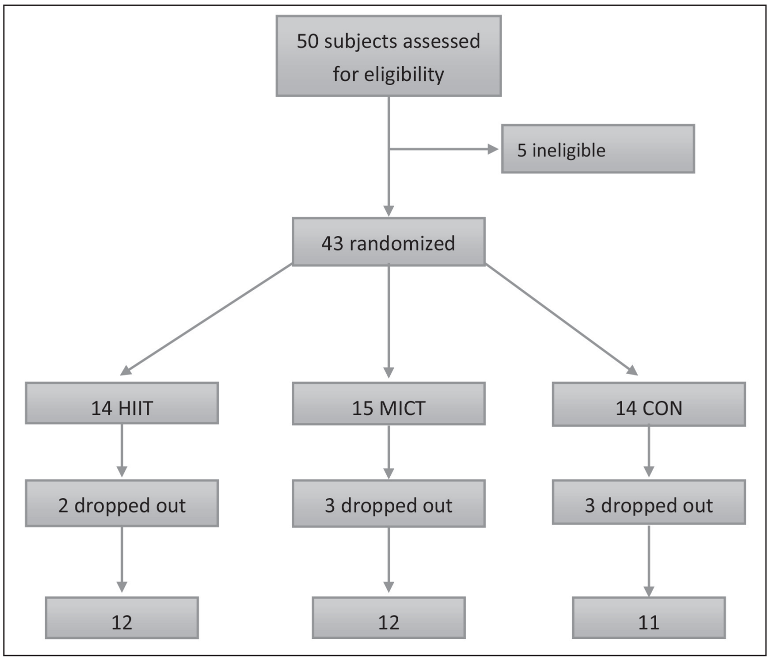

Figure 1. Distribution of study subjects. HIIT, high-intensity interval training group; MICT, moderate-intensity continuous training group; CON, control group.

interval training group (HIIT, n=14), the moderate-intensity continuous training group (MICT, n=15) and the control group (CON, n=14). Prior to the intervention, the anthropometry, aerobic capacity, %BF, abdominal visceral and subcutaneous fat areas, and serum lipids and glucose of the subjects were measured. The HIIT and MICT groups then commenced with exercise training 4 $d \cdot wk^{-1}$ for 12 weeks. The CON group received no training. During the experimental period, all subjects were asked to maintain their daily activity, and avoid altering their eating habits. After the intervention period, identical measurements of anthropometry, aerobic capacity, body fat and serum profile were repeated.

Training protocol

The HIIT protocol, which had been safely applied in patients with coronary artery disease, was described previously (Rognmo, Hetland, Helgerud, Hoff, & Slordahl, 2004). Briefly, subjects performed four bouts of 4-minute interval treadmill running at 85–95% of the measured peak heart rate (HR_{peak}), interspersed by 3-minute walking at 50–60% HR_{peak} and a 7-minute rest. For the first two weeks of training, the 4-minute run was performed at the lower limit (85% HR_{peak}) of the intensity range. Running speed was increased afterwards to achieve the intensity of 90% HR_{peak} in the third and fourth week, and was increased further to 95% HR_{peak} in the fifth week. The final running speed remained unchanged in the subsequent weeks of training.

In the MICT group, the training consisted of continuous moderate running at 60–70% of HR_{peak}. Similarly to the HIIT protocol, subjects exercised at a lower intensity limit (60% HR_{peak}) during the first two weeks. The running speed was then increased corresponding to that in the HIIT group, achieved the upper limit (70% HR_{peak}) of the intensity range in the fifth week, and remained unchanged afterwards. To define the duration of continuous running in the MICT group with an oxygen cost equivalent to that of the HIIT group, the calculation reported by Rognmo et al. (2004) was employed. Briefly, the duration of the moderate run at 60–70% of HR_{peak} = (total $\dot{V}O_2$ of the four 4-minute running bouts at 85–95% of HR_{peak} + total $\dot{V}O_2$ of the three 3-minute walking at 50–60% HR_{peak})/total $\dot{V}O_2$ of the moderate run at 60–70% of HR_{peak}. The exercise duration of the moderate run at the upper intensity limit was rounded up to 33 minutes, representing the same oxygen cost as that of the HIIT group. For verification of the oxygen cost equivalence, the total O_2 consumption in litres (L) during the exercise in a single training session in the sixth week was assessed. It did not differ between the HIIT (49.8±4.7 L) and MICT (50.7±4.7 L) group.

All training sessions for the HIIT and MICT groups were conducted under direct supervision of researchers. Exercise HR was closely monitored. Training adherence was determined as the percentage of the actual duration of the exercise performed at a preset intensity relative to the total exercise duration prescribed. In each training session, the 10-minute warm-up and 5-minute cool down exercises at 50–60% of HR_{peak} were identical in both groups.

Physical activity and dietary assessment

A daily diary approach for self-reported physical activity was used for estimating habitual energy expenditure during the 3-week pre-intervention and 12-week intervention period. The total energy expenditure, expressed as $METs \cdot hr \cdot wk^{-1}$, was estimated on the basis of the metabolic equivalents (METs) reported in the Compendium of Physical Activities (Ainsworth, et al., 2011), the duration of recorded activities in a week, and body weight.

For the caloric intake, the diets of each subject were recorded on a daily basis during the 3-week pre-intervention and 12-week intervention period according to the guidelines of the NRISM Sports Nutrition Centre (National Research Institute of Sports Medicine, China) for monitoring dietary consumption. Dietary records and corresponding energy intake were analysed using the NRISM dietary and nutritional analysis system (version 3.1) designed for Chinese athletes and the general population. The advice of a dietician was sought each week to avoid deviation in caloric intake.

Measurements

All the measurements were carried out one week before the start of the training programme and three days after the last training session. Subjects reported to the laboratory in the morning (8:00 a.m.) after refraining overnight from drinking and physical activity.

Anthropometric measurements

Standing body height was measured to the nearest 0.5 cm with the participants barefoot and with their back against a wall-mounted stadiometer. Body weight was measured to the nearest 0.1 kg using a bioelectrical impedance analyser (X-SCAN PLUS, Jawon Medical, Seoul, Korea). Body mass index (BMI) was defined as weight in kilograms divided by height in metres squared ($kg \cdot m^{-2}$). The circumference of the waist and hips, and the waist--to-hip ratio were measured according to the guidelines recommended by Eston and Reilly (2009).

Body fat assessments

The whole-body %BF and fat mass (FM) of the subjects were measured using the X-SCAN PLUS body composition analyser (Jawon Medical, Seoul, Korea). During the measurement, the subjects were dressed in light attire and were barefooted. The analyser measured the bioelectrical impedance of the subjects with eight stand-on hand-to-foot electrodes and multi-frequency (1, 5, 50, 250, 550 and 1000 kHz). %BF and FM were estimated based on the measured impedance by using a built--in experimentally derived algorithm. During the measurement, subjects were required to stand barefoot on the foot electrode panel and hold the hand electrodes with the metallic plate in contact with the thumb and palm. The procedure took approximately 60 seconds. Prior to the measurement, subjects were asked to empty their bladders and remove all metal accoutrements from their bodies. The measurement was performed twice within five minutes and the average value was the result. The reliability of the repeated measurements, revealed by the intra-class correlation coefficient (ICC), was .93 and .94 pre- and post-intervention, respectively.

Abdominal visceral (AVFA) and subcutaneous (ASFA) fat cross-sectional areas were assessed using a computed tomography scanner (Somatom Definition Flash; Siemens, Forchheim, Germany) with a consistent acquisition protocol set at 120 kVp and 150 mA. During the assessment, subjects were scanned in the supine position with their arms stretched above the head, taking a 5-millimetre scan for 2 seconds at the level of the umbilicus (approximately the L4–L5 inter-vertebral space). The computation of AVFA and ASFA was achieved using the built-in volume calculation software of the computed tomography scanner. For each scan, the number of voxels in the entire data set with computed tomography numbers between -190 and -30 Hounsfield units was plotted for adipose tissue. By examining the areas under the curve, the total adipose tissue volume was determined. In this study, all scans and analyses were performed by the same technician, who was blinded to the participants and interventions. The ICCs for the AVFA and ASFA computations between two scans in the selected subjects were .94 and .95, respectively.

Identical body fat assessments were performed at the same time of the day post-intervention. Moreover, pre- and post-intervention assessments were carried out at the identical stage of the menstrual cycle of the subjects, and in avoidance of the phase of menses.

Serum profiles

A 5-millilitre blood sample was obtained by venipuncture from an antecubital vein of subjects while they were at rest. The samples collected were placed on ice immediately, and then centrifuged for 15 minutes at 3,000 rpm within 60 minutes. Serum was then dispensed into 0.5-millilitre aliquots and stored at -80°C until analysis. Commercially available kits (Shanghai Kehua Bio-engineering, China) were used with an automatic chemistry analyser (7180, HITACHI, Japan) to determine glucose, triglycerides (TG) and total cholesterol (TC). The inter- and intra-coefficient of variance for the measures were as follows: glucose (7%, 4%), TG (5%, 6%), and TC (4%, 3%).

Graded exercise test

The linear relationships between running speed and steady-state HR as well as the aerobic capacity of subjects were assessed using a graded treadmill testing held prior to the intervention. The initial speed of the treadmill (h/p/cosmos, Pulsar, Germany) was set at 4.5 $km{\cdot}hr^{-1}$ and was increased by 0.8 $km{\cdot}hr^{-1}$ every three minutes until volitional exhaustion. Respiratory responses including $\dot{V}O_2$ during the exercise test were measured using a metabolic measuring instrument (MAX-II, Physiodyne, Quogue, NY, USA). HR was recorded at the end of each stage using an HR monitor (S810, Polar, Finland) at 5-second intervals. VO_{2max} was the highest average value of 30-second VO_2. The ICC of the VO_{2max} measurement in our laboratory was .92. Following the graded test, various running speeds, which would elicit selected percentages of steady-state HR, were defined from the linear relationship of steady-state HR versus speed. The defined speed was subsequently individually applied during exercise training in the MICT and HIIT programmes.

Statistical analysis

The Shapiro-Wilk normality test revealed that all the data on anthropometry, body composition and serum profile were normally distributed. A 3x2 [groups (HIIT, MICT, CON) x time (pre-, post-intervention)] two-way ANOVA with one--factor repeated measures was used to evaluate the main treatment effects and interactions between variables. *Post-hoc* analyses using the Newman--Keuls test were performed when the main effects of ANOVA were significant. The effect size for the ANOVA was determined by calculating the partial eta-squared. All results were expressed as Mean±SD. All tests for statistical significance were standardized at an alpha level of $p<.05$.

Results

Withdrawal and training adherence

During the intervention period, three subjects in the MICT group withdrew from training due to intolerance of continuous running and associated leg discomfort. Two subjects withdrew from the HIIT group for personal reasons that were not exercise-related. In the CON group, the dietary and physical activity records of three subjects were not valid for analysis due to lack of completion. In terms of training adherence, mean values of 94±3% and 90±2% were noted in the HIIT and MICT groups, respectively. Accordingly, the data from 12 subjects in the HIIT and MICT groups, and 11 subjects in the CON group, were valid for subsequent analyses.

Measurements of anthropometry, aerobic capacity, and habitual energy intake and output

Pre- and post-intervention data and the results of ANOVA are shown in Table 1. With regard to the pre-intervention assessments of anthropometry and aerobic capacity, there was no difference in variables among the HIIT, MICT and CON groups (p>.05). After the 12-week intervention, a significant increase in $\dot{V}O_{2max}$ and reductions in body mass, BMI and the circumference of the waist and hips in relation to the corresponding pre-intervention values were noted in both the HIIT and MICT groups (p<.05). A significant reduction in the waist-to-hip ratio was observed only in the HIIT group (p<.05). For the CON group, a tiny but significant decrease in $\dot{V}O_{2max}$ was found post-intervention (p<.05). Other variables did not change significantly (p>.05).

In terms of the estimated habitual energy intake (HIIT: 1943±92 vs 1922±89, MICT: 1860±135 vs 1835±131, CON: 1786±200 vs 1783±183 kcal·d^{-1}) and output (HIIT: 82.2±14.0 vs 84.4±14.6, MICT: 73.4±6.4 vs 71.6±9.7, CON: 80.5±13.7 vs 83.1±11.9 METs·hr·wk^{-1}), there was no significant difference (p>.05) between the pre-intervention and intervention period in each group.

Body fat assessments

Table 2 shows the pre- and post-intervention %BF, FM, AVFA and ASFA of the three groups, and associated ANOVA results. In the pre-intervention assessment, there was no significant difference (p>.05) in any of the variables among the three groups. After the intervention, significant reductions in %BF, FM and ASFA in relation to the corresponding pre-intervention levels were observed in both the HIIT and MICT groups (p<.05). The change in %BF and FM was similar in the two groups, while the reduction in ASFA in the HIIT group was significantly greater than that in the MICT group (p=.038, Figure 2). For the AVFA, a significant reduction was found only in the HIIT group (p=.001, Figure 3). None of the variables in the CON group differed significantly post-intervention.

Serum profile

The pre- and post-intervention serum profile and ANOVA results are shown in Table 3. The pre-intervention levels of serum TG, TC and glucose did not differ (p>.05) among the three groups. After the intervention, a similar reduction in serum TC was found in the HIIT and MICT group (p<.05). With regard to other serum variables, no significant changes were found. There were no significant differences in any serum variables between pre- and post-intervention in the CON group (p>.05).

Table 1. Pre- and post-intervention anthropometry and aerobic capacity of HIIT, MICT and CON groups

	HIIT (n=12)		MICT (n=12)		CON (n=11)		2-way ANOVA		
	Pre	Post	Pre	Post	Pre	Post	Time F (1,32); p; ES	Group F (2,32); p; ES	Interaction F (2,32); p; ES
Age (yr)	21.0±1.0		20.6±1.2		20.9±1.0				
Body height (cm)	160.0 ±5.1		157.7±7.1		158.6±6.7				
Body mass (kg)	66.4±9.3	61.2±8.4*	64.8±6.1	60.3±5.8*	64.0±6.1	64.0±6.5	66.91; .00; .68	.15; .87; .01	16.45; .00; .51
	[-5.2 (-6.3, -3.9)]		[-4.5 (-6.2, -2.9)]		[0.0 (-1.7,1.7)]				
BMI (kg·m^{-2})	25.8±2.7	23.8 ±2.4*	26.0±1.6	24.2 ±1.3*	25.4±1.5	25.4±1.7	64.52; .00; .67	.26; .78; .02	15.66; .00; .50
	[-2.0 (-7.4, -1.5)]		[-1.8 (-2.5, -1.1)]		[0.0 (-0.7, 0.7)]				
WC (cm)	80.5±7.0	75.8±6.2*	78.2±4.6	74.5±4.3*	80.9±4.1	80.0±5.5	53.46; .00; .63	1.75; .19; .10	7.09; .00; .31
	[-4.7 (-5.7, -3.6)]		[-3.7 (-5.5, -2.0)]		[-0.9 (-2.8, 1.1)]				
HC (cm)	100.8±6.4	96.3 ±5.1*	100.9±4.5	97.0 ±5.1*	101.2±6.1	101.5±6.2	61.99; .00; .66	.91; .42; .05	17.88; .00; .53
	[-4.5 (-5.8, -3.3)]		[-3.9 (-5.8, -2.1)]		[0.3 (-0.2, 0.6)]				
WHR	0.80 ±0.03	0.79 ±0.04*	0.78 ±0.03	0.77 ±0.04	0.79±0.05	0.78±0.05	5.13; .03; .14	.94; .40; .06	.72; .50; .04
	[-0.01 (-0.02, 0.0)]		[-0.01 (-0.02, 0.01)]		[-0.01 (-0.03,0.01)]				
VO_{2max} (mL·min^{-1}·kg^{-1})	33.1±3.0	37.7±3.0*	33.0±3.3	37.6±3.7*	30.3±3.6	28.6±3.6*	20.42; .00; .39	15.29; .00; .49	13.49; .00; .46
	[4.6 (1.9, 7.1)]		[4.6 (2.5, 6.9)]		[-1.7 (-2.9,-0.3)]				

Values are Means±SD [Mean change (95%CI)]; F: f-ratio, P: p-value; ES: effect size
BMI: body mass index; WC: waist circumference; HC: hip circumference; WHR: waist-hip ratio;
VO_{2max}: maximum volume of oxygen uptake
* Significantly different from corresponding pre-intervention value, p<.05

Table 2. Pre- and post-intervention whole-body and abdominal fat of HIIT, MICT and CON groups

	HIIT (n=12)		MICT (n=12)		CON (n=11)		2-way ANOVA		
	Pre	Post	Pre	Post	Pre	Post	Time F (1,32); p; ES	Group F (2,32); p; ES	Interaction F (2,32); p; ES
% BF (%)	31.3±3.6	28.2±3.9*	32.0±2.4	29.2±2.4*	32.8±1.8	32.6±2.2	101.69; .00; .76	3.38; .05; .17	22.10; .00; .58
	[-3.1 (-3.8, -2.4)]		[-2.8 (-3.6, -2.0)]		[-0.2 (-0.8,0.6)]				
FM (kg)	19.4±5.0	17.5±4.8*	19.3±2.8	17.7±2.8*	21.0±2.5	20.9±2.8	65.92; .00; .67	1.77; .19; .10	14.37; .00; .47
	[-1.9 (-2.4, -1.5)]		[-1.7(-2.2, -1.2)]		[-0.1 (-0.9, 0.7)]				
AVFA (cm^2)	64.9±17.5	53.1±14.5*	60.4±15.5	55.6±14.9	64.5±18.7	61.8±20.8	22.90;.00; .42	.31; .74; .02	4.11; .03; .20
	[-11.8 (-17.5, -6.0)]		[-4.8 (-10.5, 0.7)]		[-2.7 (-6.3, 0.9)]				
ASFA (cm^2)	255.3±77.4	205.6±68.3*	229.4±57.4	204.0±55.7*	253.9±47.9	248.7±48.0	31.08; .00; .49	1.01; .38; .06	7.10; .00; .31
	[-49.7 (-65.7, -33.7)] [a]		[-25.4 (-43.5, -7.3)]		[-5.2 (-26.3, 15.9)]				

Values are Means±SD [Mean change (95%CI)]; F: f-ratio, P: p-value; ES: effect size
%BF: percentage of body fat; FM: fat mass; AVFA: abdominal visceral fat area; ASFA: abdominal subcutaneous fat area
* Significantly different from corresponding pre-intervention value, p<.05
[a] Change in variable post-intervention is significantly greater than that in the MICT group, p<.05

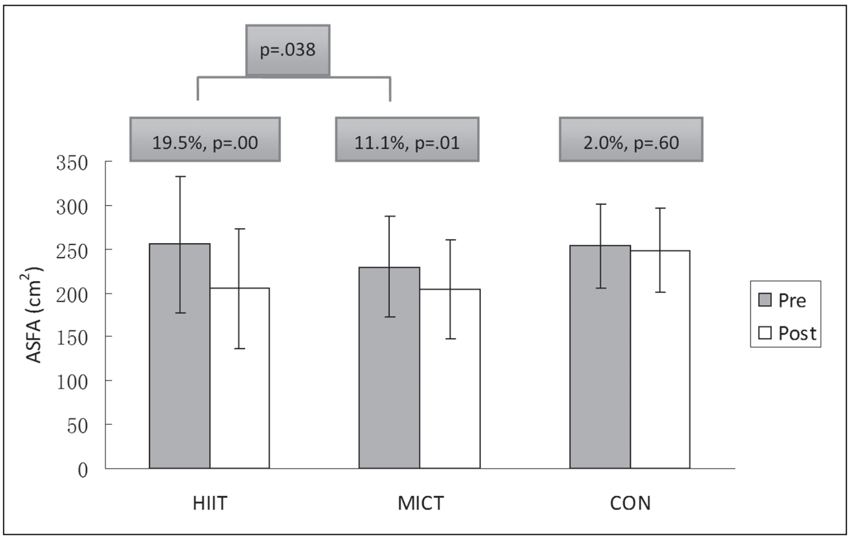

Figure 2. Pre- and post-intervention abdominal subcutaneous fat area (ASFA) of HIIT, MICT and CON groups. Values in each box are percentage change in post-intervention ASFA relative to the pre-intervention value and p-value.

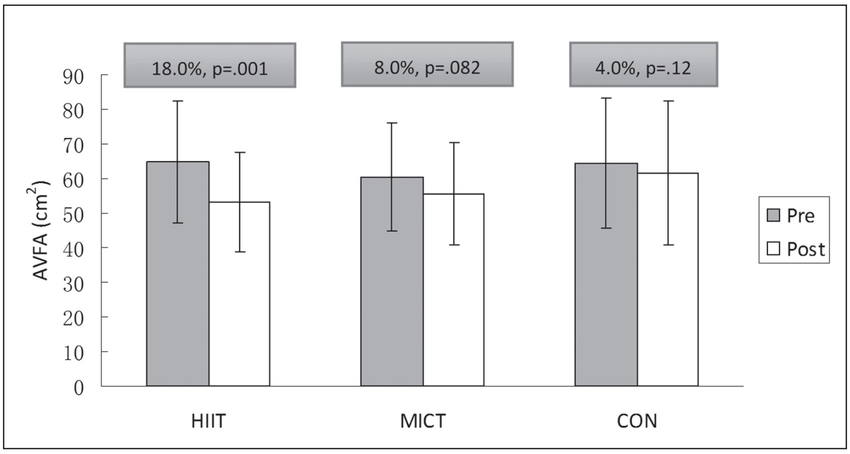

Figure 3. Pre- and post-intervention abdominal visceral fat area (AVFA) of HIIT, MICT and CON groups. Values in each box are percentage change in post-intervention AVFA relative to the pre-intervention value and p-value.

Table 3. Pre- and post-intervention serum profiles of HIIT, MICT and CON groups

	HIIT (n=12)		MICT (n=12)		CON (n=11)		2-way ANOVA		
	Pre	Post	Pre	Post	Pre	Post	Time F (1,32); p; ES	Group F (2,32); p; ES	Interaction F (2,32); p; ES
TG (mmol·L^{-1})	0.98±0.43	0.91±0.28	0.87±0.24	0.98±0.34	0.79±0.22	0.94±0.38	.76; .39; .02	.30; .74; .02	.98; .39; .06
	[-0.07 (-0.27, 0.12)]		[0.11 (-0.16, 0.39)]		[0.14(-0.14, 0.45)]				
TC (mmol·L^{-1})	4.25±0.58	3.75±0.44*	4.34±0.82	3.81 ±0.75*	3.36 ±0.42	3.45 ±1.0	6.38; .02; .17	4.39; .02; .22	2.52; .10; .14
	[-0.50 (-0.91, -0.08)]		[-0.53 (-0.82, -0.24)]		[0.09 (-0.59, 0.76)]				
Glucose (mmol·L^{-1})	4.71±0.37	4.97±1.46	4.62±0.31	4.64±1.30	4.41±0.50	3.87±0.67	.20; .66; .01	3.16; .06; .17	1.37; .27; .08
	[0.26 (-0.66, 1.18)]		[0.02 (-0.73, -0.76)]		[-0.54 (-1.10, 0.01)]				

Values are Means±SD [Mean change (95%CI)]; F: f-ratio, P: p-value; ES: effect size
TG: triglyceride; TC: total cholesterol
* Significantly different from corresponding pre-intervention value, p<.05

Discussion and conclusions

This study was designed to compare the changes in abdominal fat as well as the whole-body fat between two homogenous groups of overweight/pre-obese females who had participated in either a specific HIIT programme or an MICT programme with equivalent oxygen cost for 12 weeks. After the intervention, there was a reduction of approximately 2 kg FM, equivalent to 9.9 and 8.7 whole-body %BF, in the HIIT and MICT groups, respectively. Moreover, the declines in total cholesterol, waist and hip circumference were similar in both groups. No changes in any of these variables were found in the control subjects. Such changes in the whole-body fat and related variables in the HIIT and MICT groups, but not in the CON group, should not be attributed to diet or daily activity as the recorded dietary energy intake, as well as habitual energy expenditure did not vary among the three groups during the intervention period. The similar declines in the total cholesterol, resulting from the two training protocols with equivalent oxygen cost, are a further supporting evidence for the previous notion that training-induced adaptations in lipoproteins are dose-responsive depending on the total amount of calories expended during the training (Paoli, et al., 2013).

With regard to the HIIT programme, which comprised repeated high-intensity exercise bouts interspersed with short-term recovery intervals, CHO, rather than fat, was likely to be utilized most during the exercise (Achten & Jeukendrup, 2004; Romijn, et al., 1993). The similar degree of fat loss resulting from the HIIT, relative to that in the MICT, may be associated with the elevated post-exercise energy expenditure elicited by the repeated high-intensity exercise bouts. It is known that post-exercise $\dot{V}O_2$ and energy expenditure are greater and remain elevated longer after high-intensity exercise when compared with light-to-moderate-intensity exercise (Knab, et al., 2011; LaForgia, Withers, & Gore, 2006). Whyte, Ferguson, Wilson, Scott, and Gill (2013) further found that the respiratory quotient 18–22 hours after a brief exercise protocol of repeated cycling sprints was lower than that of the control, indicating that the rate of fat oxidation was increased post-exercise. These are in line with previous findings that the performance of mild continuous exercise (50% $\dot{V}O_{2max}$) and high-intensity interval exercise (100% $\dot{V}O_{2max}$) with identical work output resulted in a similar 24-hour fat oxidation of ~79 g (Treuth, Hunter, & Williams, 1996). It has been postulated that the differences in substrate oxidation between mild- and high-intensity exercise were compensated for post-exercise, leading to similar substrate oxidation patterns over 24 hours, regardless of the level of exercise intensity (Saris & Schrauwen, 2004). In this study, although we did not assess post-exercise substrate oxidation in subjects during the intervention period, it is reasonable to postulate that the similar whole-body fat loss measured in the HIIT and MICT groups was, at least in part, due to the potential equivalent post-exercise fat metabolism elicited by the two training protocols.

Regional fat recorded from a single computed tomography scan at the level of the umbilicus (approximately the level of L4 and L5) is generally accepted to accurately reflect the total visceral fat volume (Kobayashi, Tadokoro, Watanabe, & Shinomiya, 2002; Seidell, et al., 1987; Yoshizumi, et al., 1999), and is therefore widely used for the evaluation of visceral fat accumulation in the abdomen (Irving, et al., 2008; Kim, et al., 2009). In the present study, the ASFA reduction in the HIIT group was significantly greater than that in the MICT group (19.5 vs. 11.1%). Similar results were also found for the change in AVFA with a significant reduction only observed in the HIIT group (18 vs. 8%). The discrepancy in the effect of training on abdominal fat reduction between the HIIT and MICT groups was further supported by the changes in anthropometry in the subjects, with a significant reduction in the waist-to-hip ratio only being found in the HIIT group. In contrast, a corresponding discrepancy was not observed in the whole-body FM reduction. The decline in the FM in both groups was of a similar magnitude after the intervention. The lack of corresponding discrepancy in the change in the whole-body FM could not be explained clearly. Nonetheless, in association with the changes in whole-body %BF and total body mass post-intervention (Table 1), that were similar between HIIT and MICT, the findings suggested that the two different training protocols might have also caused a dissimilar fat reduction in parts of the body other than the abdomen. The actual changes in local-area body fat content induced by the two distinct training protocols await further investigation.

Further, our present data were unable to elucidate the discrepancies in the reductions of visceral and subcutaneous fat and related underlying mechanisms between the two training modalities. Nevertheless, the current results are in line with previous findings, in which a significant reduction in AVFA in obese women was only observed subsequent to a high--intensity endurance training protocol, and not to a low-intensity protocol with equivalent training volume (Irving, et al., 2008). Recently, it was reported that a 6-week high-intensity interval training programme did not induce an increase in mitochondrial content and fat oxidation in the abdominal subcutaneous adipose tissue of healthy overweight men (Larsen, et al., 2014). However, the adaptations resulting from the relatively short training period restrict its implications for the dose-response relationship between training intensity and abdominal fat loss. At present, it is still not clear whether exercise intensity is a critical training variable for inducing different adaptations in abdominal visceral fat storage (Vissers, et al., 2013). In terms of the acute physiological responses to exercise, higher-intensity exercise appears to be more effective than low-to-moderate-intensity exercise for inducing the secretion of lipolytic hormones, which may facilitate greater post-exercise energy expenditure and fat oxidation (Irving, et al., 2008). Indeed, post-exercise fat metabolism in individuals has been shown to be correlated with the intensity of the preceding exercise, and the greater post-exercise fat utilization in response to higher exercise intensity may be partly related to the release of growth hormone, which plays various roles in regulating metabolism and body composition (Enevoldsen, et al., 2007; Pritzlaff, et al., 2000). In clinical cases of acromegaly, patients whose growth hormone and insulin-like growth factor I are higher than normal have less visceral and subcutaneous fat, most markedly visceral fat, than their healthy counterparts (Freda, et al., 2008). Whether the greater reductions in AVFA and ASFA subsequent to an HIIT programme are due to the higher release of lipolytic hormones in response to the high-intensity exercise sessions awaits further investigation.

In the use of aerobic exercise as a means of controlling body fat in individuals, high-volume continuous-exercise training protocols are usually adopted based on a dose-response relationship (Ohkawara, Tanaka, Miyachi, Ishikawa-Takata, & Tabata, 2007). However, the high training volume (700 kcal·d^{-1}) (Ross, et al., 2000) and prolonged training period (≥12 months) (Irwin, et al., 2003) of endurance training regimes hinder the practicality of this means of body-fat control in the general population. In the present study, the more favourable abdominal fat reduction in the HIIT group than in the MICT group, and the lack of contrast in the whole-body fat reduction and serum lipid profile modification between the two groups, indicated that the low-volume, high-intensity interval training modality could at least induce effective fat loss in overweight/pre-obese persons in the same way as that associated with the traditional high-volume endurance training. Further, we noted that the prolonged monotonous exercise mode applied in the MICT group led to complaints of boredom and leg discomfort that were seldom reported in the HIIT group. The inconsistent responses in subjects to these two training modalities are consistent with a previous suggestion that exercise performed intermittently tends to enhance training adherence and reduce attrition compared with the single-bout continuous exercise (Jacobsen, Donnelly, Snyder-Heelan, & Livingston, 2003; Jakicic, Wing, Butler, & Robertson, 1995). In light of the current findings, low-volume, high-intensity interval training may be more beneficial in terms of a practical approach to weight control or weight loss in overweight/pre--obese persons. Given the nature of the exercise, this study did raise questions as to the feasibility of high-intensity interval training as a realistic alternative to the traditional endurance training for fat loss in obese people. Nevertheless, the present study may stimulate follow-up research on interval-based approaches for identifying the optimal combination of exercise mode, intensity and volume necessary to safely induce fat loss in this special population in a practical, time-efficient manner.

In conclusion, the 12-week HIIT and MICT programmes with equivalent oxygen cost conducted in two groups of homogenous young overweight/pre-obese women resulted in similar fat loss as indicated by the similar reductions in body weight, FM, %BF, serum total cholesterol, and waist and hip circumferences. Nevertheless, the reductions in the ASFA and AVFA were greater in the HIIT group. These findings suggest that an HIIT protocol comprising repeated high-intensity exercise bouts could induce effective fat loss in overweight/pre--obese persons in the same way as that associated with the traditional high-volume MICT. Further, with regard to the control of abdominal adiposity, HIIT appears to be more effective than the MICT modality for inducing a reduction in abdominal subcutaneous and visceral fat in this special population.

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Submitted: January 18, 2014
Accepted: March 31, 2015

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Acknowledgements

This work was supported by grants from the Natural Science Foundation of Hebei Province (No. C2013205151) and the Natural Fund of Hebei Normal University (No. L2012Z09), China.

Competing interests: the authors declare no competing interests.