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ORIGINAL RESEARCH ARTICLE

Long-term Lifestyle Intervention with Optimized High-Intensity Interval Training Improves Body Composition, Cardiometabolic Risk, and Exercise Parameters in Patients with Abdominal Obesity

ABSTRACT

Gremeaux V, Drigny J, Nigam A, Juneau M, Guilbeault V, Latour E, Gayda M: Long-term lifestyle intervention with optimized high-intensity interval training improves body composition, cardiometabolic risk, and exercise parameters in patients with abdominal obesity. Am J Phys Med Rehabil 2012;91:941–950.

Objective: The aim of this study was to study the impact of a combined long-term lifestyle and high-intensity interval training intervention on body composition, cardiometabolic risk, and exercise tolerance in overweight and obese subjects.

Design: Sixty-two overweight and obese subjects (53.3 ± 9.7 yrs; mean body mass index, 35.8 ± 5 kg/m^2) were retrospectively identified at their entry into a 9-mo program consisting of individualized nutritional counselling, optimized high-intensity interval exercise, and resistance training two to three times a week. Anthropometric measurements, cardiometabolic risk factors, and exercise tolerance were measured at baseline and program completion.

Results: Adherence rate was 97%, and no adverse events occurred with high-intensity interval exercise training. Exercise training was associated with a weekly energy expenditure of 1582 ± 284 kcal. Clinically and statistically significant improvements were observed for body mass (−5.3 ± 5.2 kg), body mass index (−1.9 ± 1.9 kg/m^2), waist circumference (−5.8 ± 5.4 cm), and maximal exercise capacity (+1.26 ± 0.84 metabolic equivalents) ($P < 0.0001$ for all parameters). Total fat mass and trunk fat mass, lipid profile, and triglyceride/high-density lipoprotein ratio were also significantly improved ($P < 0.0001$). At program completion, the prevalence of metabolic syndrome was reduced by 32.5% ($P < 0.05$). Independent predictors of being a responder to body mass and waist circumference loss were baseline body mass index and resting metabolic rate; those for body mass index decrease were baseline waist circumference and triglyceride/high-density lipoprotein cholesterol ratio.

Conclusions: A long-term lifestyle intervention with optimized high-intensity interval exercise improves body composition, cardiometabolic risk, and exercise tolerance in obese subjects. This intervention seems safe, efficient, and well tolerated and could improve adherence to exercise training in this population.

Key Words: Lifestyle Intervention, High-intensity Interval Exercise Training, Abdominal Obesity, Body Composition, Cardiometabolic Risk, Prevention

Obesity is still increasing dramatically and is associated with a wide variety of comorbidities, such as cardiovascular (CV) diseases, type 2 diabetes, stroke, hypertension, and certain types of cancer. In addition, visceral adiposity, which is strongly correlated to waist circumference (WC), is more pathogenic than subcutaneous adiposity and is one of the key features of metabolic syndrome (MS) and is associated with an increased risk of CV and all-cause mortality.[1]

Body mass loss can improve or prevent many of the obesity-related risk factors for CV disease. Dietary modification and exercise training remain the cornerstone of body mass loss programs and the prevention of body mass regain. Moreover, a higher cardiorespiratory fitness provides a strong protective effect against all-cause and CV mortality in men with MS[2] and in obese subjects.[3] Moderate-intensity physical activity between 150 and 250 mins/week provides modest body mass loss, whereas greater amount of physical activity (>250 mins/wk) is associated with a clinically significant higher body mass loss.[4] Thus, most lifestyle intervention and exercise programs designed for body mass loss have focused on moderate-intensity continuous exercise training (MICET). However, these programs lead to modest results,[5] often because of poor adherence to exercise training. Other exercise modalities may be more appropriate to increase adherence to exercise training programs.

Compared with isoenergetic continuous exercise, high-intensity interval exercise (HIIE) was perceived to be less difficult (lower rate of perceived exhaustion) in obese women.[6] HIIE refers to repeated periods of intensive exercise interspersed with periods of passive or active "moderate-intensity" recovery. Previous studies in healthy subjects showed that short exercise phase protocols (15–30 secs) with passive recovery intervals of equal length elicit a longer total exercise time with a similar time spent near oxygen consumption per unit time ($\dot{V}O_2$) peak compared with continuous training,[7] thus providing a more important stimulus for $\dot{V}O_2$ peak improvement relative to continuous exercise. Similar results were demonstrated in several medical conditions. Indeed, we previously showed that an optimized HIIE protocol consisting of 15- to 30-sec training intervals with passive recovery periods leads to a longer total exercise time and a lower rating of perceived exertion relative to an isoenergetic continuous exercise in overweight CAD and obese CHF patients.[8–10]

No data are available regarding the effects of a combined lifestyle intervention and optimized HIIE on body composition, cardiometabolic risk, and exercise capacity in subjects with abdominal obesity. On the basis of our previous research in patients with CV disease[8–10] and in patients with MS,[11] we hypothesized that introducing optimized HIIE in a long-term (9 mos) lifestyle intervention (CV risk factors and nutritional counselling) would be efficient and well tolerated and have positive effects on the above-mentioned parameters in overweight or obese adults with a high WC, who are at particular risk of developing CV disease. The data present herein describe the results of the first year of implementation of this protocol in our center.

MATERIAL AND METHODS

Patients

This was a retrospective study conducted at the cardiovascular prevention and rehabilitation center (ÉPIC) of the Montreal Heart Institute in the context of a multidisciplinary primary prevention body mass loss program (KILO-ACTIF), including lifestyle modification (education on risk factor control and nutrition counselling) and supervised exercise training. Data were examined from a cohort of obese subjects consecutively enrolled in this 9-mo program from 2008 to 2010 for whom complete data were available. All subjects included were overweight or obese (body mass index [BMI] >27 kg/m^2) at program entry and were over abdominal obesity thresholds. Subjects receiving pharmacologic therapy for either diabetes or hypertension were not excluded. Subjects with a history of coronary heart disease (documented previous myocardial infarction, previous coronary revascularization, or documented myocardial ischemia on myocardial scintigraphy) were excluded. Among the 69 subjects initially enrolled, 62 completed the program. Reasons for noncompletion included family problems (n = 3), pulmonary infection (n = 1), rheumatoid arthritis diagnosis (n = 1), and worsening of pain in subjects with preexisting knee pain that could not be related to training (n = 2).

Measurements

At baseline and after program completion, all subjects underwent a complete clinical evaluation including measurement of height, body mass, and WC. WC was measured with the patient standing, bare midriff, after a full expiration, with both feet touching and arms hanging freely. The measuring tool was placed perpendicular to the long axis of the body and horizontal to the floor, at the midpoint between the lowest rib and the iliac crest.[12] Segmental body composition was assessed by bioimpedance analysis (Tanita, model 418 C, Japan)[13] to measure total fat mass, trunk fat mass, total fat-free mass, and resting metabolic rate (RMR)[14] according to the constructor's instruction manual. A resting electrocardiogram, symptom-limited maximal exercise treadmill test using the ramp protocol,[15] and fasting blood test (glucose, lipid profile) were also performed. Treadmill exercise testing was performed using a symptom-limited ramp protocol[15] (Series 2000, Marquette Treadmill and Marquette ECG Case 12; GE Healthcare). The treadmill slope and speed were progressively increased at fixed intervals (i.e., 10–60 secs) starting at 0% slope, with the increase in slope and speed calculated on the patient's estimated functional capacity such that the protocol was completed in 8 to 12 mins. During the tests, the subject's electrocardiogram was monitored continuously, as well as blood pressure, using a standard cuff mercury sphygmomanometer (Welch Allyn-Tycos). Maximal exercise tolerance was defined as the highest level of metabolic equivalents estimated from maximal treadmill speed and slope.[16] All subjects were instructed to take their usual medications before exercise testing. Subjects also performed a 6-min walk test, in addition to abdominal and thigh muscle endurance tests (Shirado test and squat wall test). The 6-min walk test was performed on a 50-m unobstructed path, after a familiarization trial, according to the American Thoracic Society recommendations.[17] For the Shirado test, the subject was lying on the ground, facing the ceiling, with the hip and knee flexed at a 90-degree angle (0 degrees representing full extension), arms crossed on the chest, and hands applied on the contralateral shoulder. The subject was then instructed to lift both scapula off the ground and keep this position as long as possible. Time to exhaustion was noted in seconds.[18] For the leg extensors test, the subject was standing, with the back facing the wall, leaned backwards, and let the hip slide on the wall until hip and knees were flexed at a 90-degree angle. The subject was then instructed to keep this position as long as possible, without pushing hands on the thighs. The result was also measured in seconds.[19]

Exercise training program attendance was obtained from medical charts and from an electronic system that automatically records each subject's entry into our center. A 100% adherence was defined as the achievement of at least two supervised sessions per week. Weekly unsupervised exercise training sessions and physical activity performed in and/or out the center were reported in a diary.

Cardiometabolic risk factors and the presence of MS were assessed. Hypertension was defined as systolic blood pressure of 130 mm Hg or greater and/or diastolic blood pressure of 85 mm Hg or greater or use of antihypertensive therapy. Dyslipidemia was defined as a medical history of dyslipidemia, use of lipid-lowering therapy, or a low-density lipoprotein cholesterol level greater than 2.5 mmol/L and total/high-density lipoprotein (HDL) cholesterol ratio greater than 4 mmol/L in patients not receiving statins. Medication was reported from each subject's medical chart. MS was defined according most recent criteria[20]: presence of three or more of the following five criteria: abdominal obesity (WC ≥94 cm in men and ≥80 cm in women), a triglyceride level of 1.70 mmol/L or greater, an HDL-cholesterol level of less than 1.0 mmol/L in men and less than 1.3 mmol/L in women, systolic blood pressure of 130 mm Hg or greater or diastolic blood pressure of 85 mm Hg or greater, and a fasting plasma glucose level of 5.6 mmol/L or greater.

Lifestyle Intervention and Optimized HIIE Program

Supervised exercise training sessions (HIIE and resistance exercise) consisted of two to three weekly supervised 54-min sessions. Subjects were encouraged to perform one or two additional unsupervised continuous moderate-intensity sessions per week, such as walking and/or cycling (45-min duration, Borg scale level 12–14) outside or inside the center.[11]

Optimized HIIE Program

HIIE prescription was based on the results of the baseline maximal exercise test.[8–10] Maximal aerobic power was estimated from the maximal metabolic equivalent treadmill value according to the following method: (1) treadmill metabolic equivalent value was converted to oxygen uptake expressed in mL/min; (2) treadmill $\dot{V}O_2$ peak in mL/min was then converted into cycling $\dot{V}O_2$ peak value in mL/min by subtracting 16%[21]; and (3) cycling $\dot{V}O_2$ peak value was then converted to Watts using a sex-specific conversion chart.[22] An individualized HIIE prescription of 80% of maximal aerobic power was then calculated for each subject. Optimized HIIE sessions were performed on an ergocycle (model 846i; Precor, Woodinville, WA) under the supervision of a kinesiologist and consisted of a 5-min warm-up at 50 W, followed by two sets of 10 mins of repeated bouts of 15 to 30 secs at 80% of maximal aerobic power interspersed by a 15- to 30-sec period of passive recovery and a 5-min cool down at 50 W.

The length of the intervals was chosen by the kinesiologist. The two 10-min periods were separated by a 4-min passive recovery. Target Borg rating of perceived exertion was set at 15 during the exercise sessions. Total exercise time was 34 mins per HIIE session.

Resistance Training Session

Resistance training was prescribed and performed under the supervision of a kinesiologist and consisted of 20 mins of circuit weight training performed with free weights and elastic bands adapted to each patient's capacity. Individualized training load target was 50% of maximal weight lifted (1-RM). 1-RM estimation was performed for each muscle group at baseline and reperformed when rating of perceived exertion was less than 15 on the Borg scale during training sessions. Fifty percent of 1-RM estimation was performed using the method suggested by the American Heart Association for individuals with and without CV diseases, that is, load allowing patient to achieve 15 repetitions.[23] For each muscle group, patients performed one set of 15 to 20 repetitions, followed by a 30-sec rest period, at a target rating of perceived exertion of 15.

Total Weekly Energy Expenditure

This was estimated for supervised exercise training (HIIE and resistance training sessions) and for additional moderate aerobic exercise sessions. Briefly, for each patient, the weekly number of minutes of each type of exercise was multiplied by the specific activity energy expenditure values described by Clark[24] in obese subjects, that is, 13.4 kcal/min for MICET, 19.87 kcal/min for HIIE, and 19.97 kcal/min for circuit-interval resistance training. This allowed calculating total weekly active energy expenditure.

Lifestyle Intervention

All subjects underwent five individual meetings with a dietician in our center. The first visit was used to obtain data on eating habits and motivation and to provide the principles of the Mediterranean diet.[25] The macronutrient composition (percentage daily calories) of this diet was as follows: protein, 20%; carbohydrate, 45% (with a high intake of fibers); and total fat, 35% (saturated fatty acids, 7%; monounsaturated, 25%; polyunsaturated, 2.5%, ω6/ω3 ratio, 3–6). The total daily energy consumption was adapted to each patient, without severe

TABLE 1 Baseline characteristics of obese subjects

	Total (n = 62)	Metabolic Syndrome Subgroup (n = 37)
Age, yrs	53.3 ± 9.7	54 ± 9.9
Male/female, n	40/22	14/23
Height, cm	165 ± 9	165 ± 10
Body mass, kg	97.9 ± 18	98.8 ± 17.8
BMI, kg/m^2	35.8 ± 5	36 ± 5.1
WC, cm	112.6 ± 13.2	113.7 ± 13.6
Obesity[a]	55 (88.7)	34 (91.8)
Hypertension[b]	42 (67.7)	29 (78.3)
Rest SBP, mm Hg	134 ± 13	137 ± 13*
Rest DBP, mm Hg	81.3 ± 8.3	82.3 ± 8.1
Dyslipidemia	53 (85.4)	33 (89.2)
Abnormality of fasting glycemia[c]	20 (32.3)	20 (54.1)
Smoking	11 (17.7)	9 (24.3)
Medications		
Aspirin	10 (16.1)	8 (22)
Antiplatelets agents	1 (1.6)	0
β-Blockers	4 (6.5)	4 (10.8)
Calcium channel blockers	6 (9.7)	5 (13.5)
ACE inhibitors	4 (6.5)	4 (10.8)
Angiotensin receptor blockers	7 (11.3)	5 (13.5)
Statin	16 (25.8)	14 (37.8)
Oral hypoglycemic agents	3 (4.8)	2 (5.4)

Data are presented as mean ± SD or n (%).

[a]BMI ≥ 30 kg/m^2.

[b]Resting SBP ≥ 130 mm Hg or resting DBP ≥ 85 mm Hg or antihypertensive treatment.

[c]Fasting glycemia ≥ 5.6 mmo l/L.

BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; ACE, angiotensin converting enzyme.

restriction. The aim was to meet, as far as possible, the Canadian guidelines (2000–2400 kcal/day).[26] Subsequent visits at the 5th, 12th, 20th, and 36th weeks were performed to review the principles and adherence to the Mediterranean diet, to report dietary intake, and to answer patient's questions. In addition, participants received two group teaching sessions aimed at providing guidance regarding CV risk factor control, reading food labels, and tasting Mediterranean-style dishes.

Statistical Analysis

All data are expressed as mean ± SD and/or in number and percentage. All analyses were performed using SAS 9.2 (SAS Institute Inc, Cary, NY). Normal distribution of the data was verified by the Shapiro-Wilk test. Data were logarithmically transformed when this assumption was not met. For continuous variables, statistical differences in the total group and in the MS subgroup were evaluated by a one-way repeated-measures analysis of variance. For categorical variables, the proportion of subjects with cardiometabolic abnormalities and MS at baseline and program completion was compared using the McNemar test. Significance was set at $P < 0.05$. Univariate logistic regression analysis was used to identify which baseline variables were significantly associated with being a responder for body mass loss greater than 5% of body mass, decrease in WC of greater than 5 cm, and a decrease in BMI of greater than 1 kg/m^2 after the program. These threshold values were chosen given their clinical relevance.[27,28] When P value was <0.25, the parameter was included in a stepwise multivariate logistic regression model[29] to determine independent predictors of being a responder for body mass, WC, and BMI loss.

RESULTS

The main characteristics of the subjects at baseline are described in Table 1. There were no changes in medications related to CV risk factors during the program. All patients were able to complete HIIE sessions at the targeted intensity (80% of maximal aerobic power for peaks). No adverse events were noted during HIIE or resistance training. Exercise training adherence (including supervised and unsupervised sessions) was 2.9 ± 0.8 sessions per week, and all patients performed at least the two HIIE sessions per week, except for two of them (adherence rate, 97%). This corresponded to a weekly time of 174 ± 66 mins/week and an energy expenditure of 1582 ± 274 kcal. All the subjects completed the five visits with the dietician and the two group sessions. After program completion, all anthropometric characteristics significantly decreased (P < 0.0001), except for muscle mass and basal metabolic rate, which did not differ from baseline values (Table 2). Fasting lipid parameters and systolic blood pressure also improved significantly ($P < 0.05$; Table 3). Furthermore, the prevalence of MS was significantly reduced by 32.5% after program completion (pre, n = 37 *vs.* post, n = 25; $P < 0.05$). Maximal exercise capacity, resting heart rate (HR), 6-min walk test distance, Shirado test, and static wall squat endurance time all significantly improved (Table 4).

We identified 28 responders for body mass loss, 32 for WC loss, and 30 for BMI loss. Baseline higher BMI and greater RMR were significant independent

TABLE 2 Subjects' physical characteristics at baseline and after 9 mos of program, for all patients and the metabolic syndrome group

	Total (n = 62)		Metabolic Syndrome Subgroup (n = 37)	
	Baseline	9 mos	Baseline	9 mos
Age, yrs	53.3 ± 9.7		54 ± 9.9	
Body mass, kg	97.9 ± 18.0	2.5 ± 16.9[a]	98.8 ± 17.8	93.5 ± 16.3[a]
BMI, kg/m^2	35.8 ± 5.0	33.3 ± 6.4[a]	36 ± 5.1	34.1 ± 4.7[a]
Total fat mass, kg	40.5 ± 10.0	36.1 ± 9.6[a]	40.8 ± 10.1	36.1 ± 9.1[b]
Total fat mass, %	41.7 ± 6.6	39.4 ± 7.4[a]	41.7 ± 6.3	39.3 ± 6.6[b]
Total fat-free mass, kg	56.5 ± 12.8	55.3 ± 12.1	58.6 ± 13.5	55.9 ± 12.3
Total fat-free mass, %	58.4 ± 7.4	60.5 ± 7.3[a]	58.3 ± 6.3	60.8 ± 6.7[b]
Trunk fat mass, kg	21.1 ± 4.8	19.1 ± 4.8[b]	21 ± 4.6	18.9 ± 4.5[b]
Trunk fat mass, %	40.7 ± 4.9	38.6 ± 5.8[a]	40.3 ± 4.5	38.3 ± 4.8[b]
Resting metabolic rate, kcal	1747 ± 451	1700 ± 362	1747 ± 395	1701 ± 361

Data are presented as mean ± SD.

Difference between baseline and 9 mos: [a]$P < 0.0001$; [b]$P < 0.001$.

BMI, body mass index.

TABLE 3 Cardiometabolic risk factors at baseline and after 9 mos of program, for all patients and the metabolic syndrome group

	Total (n = 62)		Metabolic Syndrome Subgroup (n = 37)	
	Baseline	9 mos	Baseline	9 mos
Waist circumference, cm	112.6 ± 13.2	106.8 ± 12.2[a]	113.7 ± 13.6	107.8 ± 12.2[a]
Resting SBP, mm Hg	134 ± 13.6	129.2 ± 11.0[b]	137.5 ± 13.9	132.3 ± 9.7[b]
Resting DBP, mm Hg	81.3 ± 8.3	78.9 ± 6.7	82.3 ± 8.1	79.8 ± 6.1
Fasting glycemia, mmol/L	5.28 ± 0.71	5.35 ± 0.62	5.35 ± 8.1	5.47 ± 0.71
Total cholesterol, mmol//L	5.01 ± 0.99	4.85 ± 0.90	5.2 ± 1.04	4.86 ± 0.92[b]
HDL-cholesterol, mmol//L	1.19 ± 0.25	1.29 ± 0.29 [a]	1.21 ± 0.28	1.27 ± 0.31[b]
LDL-cholesterol, mmol//L	3.18 ± 0.88	2.98 ± 0.79[b]	3.35 ± 0.93	3.03 ± 0.8[b]
Total cholesterol/HDL-cholesterol	4.31 ± 0.93	3.86 ± 0.83[b]	4.42 ± 0.9	3.95 ± 0.87[c]
Triglycerides, mmol//L	1.43 ± 0.60	1.29 ± 0.69[c]	1.44 ± 0.58	1.29 ± 0.73[b]
Triglycerides/HDL	1.32 ± 0.87	1.1 ± 0.77[a]	1.3 ± 0.82	1.12 ± 0.83[c]

Data are presented as mean ± SD.

Difference between baseline and 9 mos: $^aP < 0.0001$; $^bP < 0.05$; $^cP < 0.001$.

SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL, high-density lipoprotein; LDL, low-density lipoprotein.

predictors of successful body mass loss. Baseline higher BMI and RMR were also independent predictors of successful WC loss. Finally, baseline WC, RMR, and triglyceride/HDL ratio were independent predictors of successful BMI loss (Table 5).

DISCUSSION

This comprehensive long-term lifestyle modification program in patients with abdominal obesity including nutritional counselling and an optimized HIIE program was effective at improving body mass, WC, BMI, total and trunk fat mass, cardiometabolic risk, and functional capacity. The prevalence of MS was reduced by 32.5% in this sample. Independent predictors of being a responder to body mass, WC, and BMI loss were identified and included baseline BMI, RMR, and triglyceride/ HDL index.

To our knowledge, this is the first study to document the effects of a long-term lifestyle intervention and optimized HIIE on those parameters in subjects with abdominal obesity. Previous studies have examined the effects of short-term (2–16 wks) HIIE in cardiac or obese patients,[6,30–33] but they focused on exercise capacity or body mass, and data on body composition are scarce. Our results regarding body mass (−5.4 kg, or −5.5%), WC (−5.8 cm, or −5.15%), and BMI (−2.2 kg/m^2) decrease are consistent with those generally reported in studies in obese subjects using nutritional counselling and MICET, either alone or combined.[5] However, some MICET procedure still has to be investigated in large samples, such as exercises performed at the maximal oxidation rate of lipids, for instance.[34] Our resuts are also in line with those of previous studies in obese patients using HIIE

TABLE 4 Exercise parameters at baseline and after 9 mos of program for all obese subjects and the metabolic syndrome subgroup

	Total (n = 62)		Metabolic Syndrome (n = 37)	
	Baseline	9 mos	Baseline	9 mos
Exercise capacity, METs	8.29 ± 1.48	9.54 ± 1.74[a]	8.01 ± 1.5	9.26 ± 1.8[a]
Resting HR, beats/min	75.1 ± 14.5	69 ± 11[a]	75 ± 18	68.3 ± 11.1[b]
Maximal HR, beats/min	159.3 ± 16.6	161 ± 16	155.6 ± 18.6	158.8 ± 17.4
Delta HRR at 1 min, beats/min	−15.2 ± 5.3	−15.5 ± 6.1	−15.5 ± 5.9	−16.1 ± 5.6
6MWT, m	593 ± 61	702 ± 111[a]	590 ± 65	703 ± 134[a]
Shirado test, secs	54 ± 42	107 ± 63[a]	50 ± 43	106 ± 57[a]
Static wall squat test, secs	40 ± 23	114 ± 71[a]	35 ± 20	116 ± 79[a]

Data are presented as mean ± SD.

Difference between baseline and 9 mos: $^aP < 0.0001$; $^bP < 0.05$.

METs, metabolic equivalents; HR, heart rate; HRR, heart rate recovery; 6MWT, 6-min walk test.

TABLE 5 Independent predictors (threshold models) of being a responder to body mass decrease (>5 % of baseline body mass), WC decrease (>5 cm of baseline WC), and BMI decrease (>1kg/m^2 of baseline BMI)

Variables	Odds Ratio	95% CI	*P*
Body mass decrease			
Smoking	7.9	1.34–46.65	0.002
BMI	1.18	1.03–1.35	0.01
RMR	1.2	1–1.3	0.04
WC decrease			
RMR	1.2	1–1.4	0.005
BMI	1.22	1.06–1.41	0.018
BMI decrease			
WC	1.09	1.02–1.16	0.005
RMR	1.2	1–1.3	0.04
TG/HDL-cholesterol	2.19	0.98–4.91	0.05

WC, waist circumference; BMI, body mass index; CI, confidence interval; RMR, resting metabolic rate; TG, triglyceride; HDL, high-density lipoprotein.

alone[6,32] or HIIE and strength training.[35] The mean training frequency (2.9 sessions per week) was just under the minimum amount recommended by the American College of Sports Medicine,[4] but weekly mean training time was in line with MICET recommendations (174 ± 66 mins and 1582 ± 274

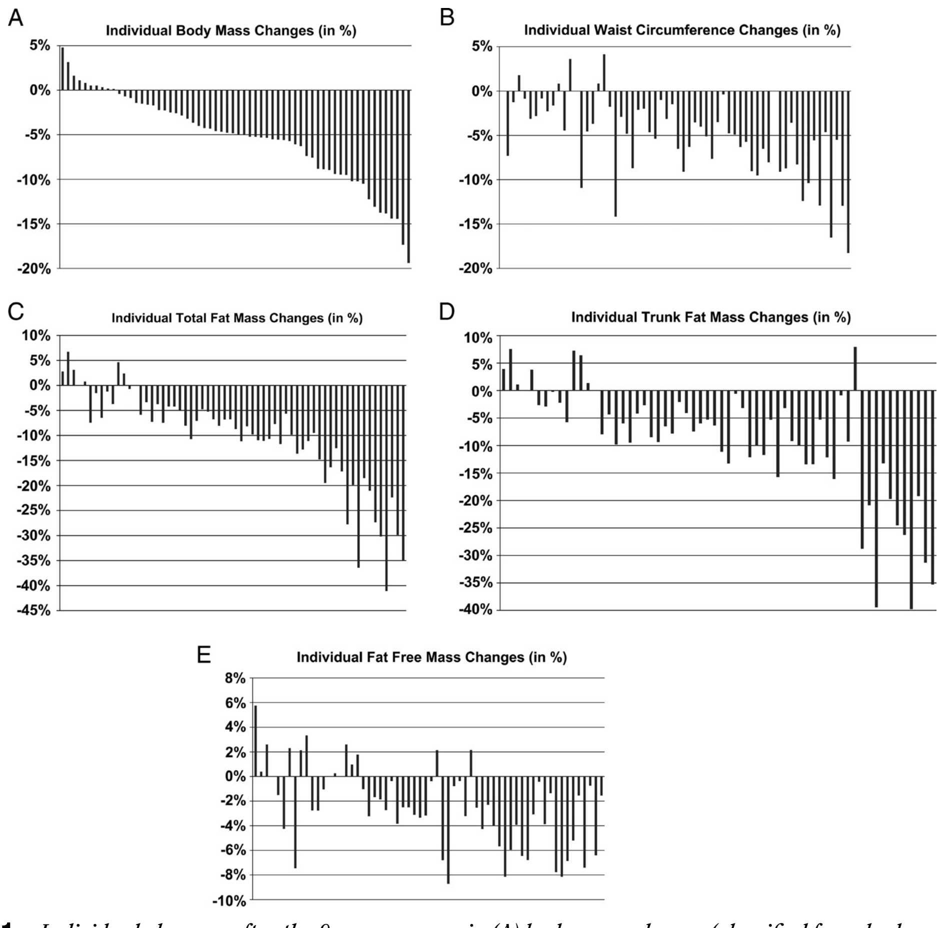

FIGURE 1 *Individual changes after the 9-mo program in (A) body mass change (classified from body mass gain on the left to body mass loss on the right) and corresponding (B) waist circumference change, (C) total fat mass change, (D) trunk fat mass change, and (E) fat-free mass change.*

kcal/week).[4] In contrast, the 5.4-kg body mass loss achieved in our program would require the equivalent of 225 mins per week of MICET.[4]

A mean 5.8-cm reduction in WC was achieved by our subjects. This is slightly better the 5-cm threshold reported to reduce the relative risk for total mortality by 9%.[27] In contrast, previous studies in obese subjects showed no change in waist-to-hip ratio after short-term HIIE or MICET.[6,32] In our MS subgroup, WC decrease (−5.9 cm) was similar to that reported by Tjonna et al.[33] (−5 cm) but greater than that reported by Stensvold et al.[35] after HIIE. This could be partly caused by the different training protocols and different definitions used for abdominal obesity. We chose the 94- and 80-cm cutoff in men and women, respectively, because our sample exclusively contained Europids. Indeed, the International Diabetes Federation stated in 2005 that "in future studies of populations of Europid origin (white people of European origin, regardless of where they live in the world), prevalence should be given, with both European and North American cut-offs to allow better comparisons."[20] Finally, the difference obtained using either Adult Treatment Panel III[36] values or International Diabetes Federation definitions was minimal, as only two men had a WC less than 102 cm and one woman had a WC less than 88 cm.

We found that baseline BMI and RMR were independent predictors of being a responder for body mass loss (>5% of baseline value) and for WC decrease (>5 cm of baseline value). As noted by others,[37] we also observed a discrepancy at the individual level between body mass, WC, trunk fat mass, and fat-free mass changes among our cohort, illustrating a high interindividual variation of body composition after the intervention (Fig. 1*A–E*). Muscle mass is positively correlated with RMR,[38] and a lower RMR has been shown to be a risk factor for body mass gain.[39] In our study, percentage total fat-free mass increased during the program (Table 2) and is consistent with the results of Stensvold et al.[35] Combining HIIE and resistance training with a dietary intervention could represent an optimal method for preserving muscle mass while promoting loss of adiposity. We also found that a higher baseline triglyceride/HDL ratio, a marker of insulin resistance and atherogenic lipid profile,[40] was an independent predictor for BMI decrease. Although exercise training has clearly been shown to improve insulin resistance in obese subjects, individuals with a greater degree of insulin resistance state seemed to be particularly responsive to an exercise program combining both HIIE and resistance training, as previously demonstrated.[41] Finally, higher baseline BMI was logically associated with higher body mass loss, WC, and BMI decrease, as previously reported.[42]

Higher cardiorespiratory fitness has been shown to be protective against CV and total mortality in obese subjects or subjects with MS.[2,43] Maximal exercise capacity improved by 15% or 1.25 metabolic equivalents in both groups, which is slightly higher than in our previous study in MS patients with MICET (+11.6%).[11] This was, however, lower compared with that reported by Schjerve et al.[32] and Tjonna et al.[33] but higher than that reported by Stensvold et al.[35] (10% peak $\dot{V}O_2$ increase). Importantly, the aforementioned three studies used a different HIIE protocol compared with ours: four blocks of 4-min intervals at 85%–95% of maximum HR, with 3 mins of active recovery at 50%–60% of maximum HR between each block. A higher HIIE training frequency and/or intensity may explain the greater increment in peak $\dot{V}O_2$ in those studies.[32,33] In addition, 6-min walk test distance and skeletal muscle endurance were increased after our program, which are more reflective of functional capacity and the ability to carry out activities of daily living. Moreover, greater abdominal muscle endurance could prevent the apparition of other disabling symptoms, such as low back pain. We also demonstrated a decrease in resting HR after the program. A higher HR has been shown to be independently associated with CV morbidity and mortality across the spectrum of CV disease.[44]

There are several limitations in our study. First, this was a nonrandomized retrospective study that did not include a control group. However, previous studies evaluating the effectiveness of exercise training programs in obese patients with MS did not show significant improvements in exercise and metabolic parameters in the control groups (i.e., receiving no diet or exercise intervention).[45] Moreover, the relative contribution of HIIE, resistance training, and diet could not be assessed because a combined lifestyle and HIIE intervention was performed. Second, we did not objectively control the dietary intakes. However, all patients were followed by the same dietician, who provided nutritional counselling tailored to each patient and could check every month the self-reported modifications in eating habits. Third, our sample was too small to perform subgroup analysis investigating the potential effects of sex and menopausal status. However, the proportion of women in our sample (65%) is within the usual reported range of previous controlled studies investigating the effects of different modalities of exercise in obese or MS patients (60%–75%).[32,33,35] Moreover, even if menopausal status might influence response to exercise training, it seems difficult to differentiate between physiologic changes that are solely caused by age and lifestyle as opposed to those related with menopause,[46] and exercise recommendations for this population do not seem to differ from those for the general population.[47] Finally, our results represent the experience of one single institution and thus could be affected by recruitment bias and may not be generalized to all obese subjects. However, our results are based on a "real-life" clinical program performed in a tertiary care center that better reflects results observed in routine clinical settings compared with randomized studies with highly selected patients. We do believe that our program is feasible and less monotonous and has the real potential to improve adherence to exercise training while being time-efficient to improve body composition, CV risk, and exercise capacity.

In conclusion, our results show that a long-term lifestyle intervention combining optimized HIIE and resistance training improved body composition, abdominal obesity, cardiometabolic profile, CV risk, MS prevalence, maximal exercise capacity, and muscular endurance in obese subjects. Supervised optimized HIIE performed twice a week seemed feasible, safe, and time-efficient in this overweight and obese population, even though a higher training frequency would probably have provided incremental benefits. Our results suggest that although a short HIIE program is beneficial for improving exercise capacity and certain cardiometabolic risk factors, a longer program could provide further improvements in other parameters, such as body composition, WC, insulin sensitivity, and lipid profile. Further long-term randomized studies comparing HIIE with MICET are now needed to confirm these results both for body mass and abdominal adiposity loss and the prevention of their regain and to better define the optimal association of diet and exercise (MICET *vs.* HIIE).

REFERENCES

1. Lakka HM, Laaksonen DE, Lakka TA, et al: The metabolic syndrome and total and cardiovascular disease mortality in middle-aged men. *JAMA* 2002; 288:2709–16
2. Katzmarzyk PT, Church TS, Blair SN: Cardiorespiratory fitness attenuates the effects of the metabolic syndrome on all-cause and cardiovascular disease mortality in men. *Arch Intern Med* 2004;164:1092–7
3. Wei M, Kampert JB, Barlow CE, et al: Relationship between low cardiorespiratory fitness and mortality in normal-weight, overweight, and obese men. *JAMA* 1999;282:1547–53
4. Donnelly JE, Blair SN, Jakicic JM, et al: American College of Sports Medicine position stand. Appropriate physical activity intervention strategies for weight loss and prevention of weight regain for adults. *Med Sci Sports Exerc* 2009;41:459–71
5. Wu T, Gao X, Chen M, et al: Long-term effectiveness of diet-plus-exercise interventions vs. diet-only interventions for weight loss: A meta-analysis. *Obes Rev* 2009;10:313–23
6. Coquart JB, Lemaire C, Dubart AE, et al: Intermittent versus continuous exercise: Effects of perceptually lower exercise in obese women. *Med Sci Sports Exerc* 2008;40:1546–53
7. Thevenet D, Tardieu-Berger M, Berthoin S, et al: Influence of recovery mode (passive vs. active) on time spent at maximal oxygen uptake during an intermittent session in young and endurance-trained athletes. *Eur J Appl Physiol* 2007;99:133–42
8. Guiraud T, Juneau M, Nigam A, et al: Optimization of high intensity interval exercise in coronary heart disease. *Eur J Appl Physiol* 2010;108:733–40
9. Guiraud T, Nigam A, Juneau M, et al: Acute responses to high-intensity intermittent exercise in CHD patients. *Med Sci Sports Exerc* 2011;43:211–7
10. Meyer P, Normandin E, Gayda M, et al: High-intensity interval exercise in chronic heart failure: Protocol optimization. *J Card Fail* 2012;18:126–33
11. Gayda M, Brun C, Juneau M, et al: Long-term cardiac rehabilitation and exercise training programs improve metabolic parameters in metabolic syndrome patients with and without coronary heart disease. *Nutr Metab Cardiovasc Dis* 2008;18:142–51
12. Ness-Abramof R, Apovian CM: Waist circumference measurement in clinical practice. *Nutr Clin Pract* 2008;23:397–404
13. Pietrobelli A, Rubiano F, St-Onge MP, et al: New bioimpedance analysis system: Improved phenotyping with whole-body analysis. *Eur J Clin Nutr* 2004; 58:1479–84
14. Sakamoto Y, Nishizawa M, Sato H, et al: International comparison: resting energy expenditure prediction models. *Am J Clin Nutr* 2002;75(suppl: P65): 358S–9
15. Fletcher GF, Balady GJ, Amsterdam EA, et al: Exercise standards for testing and training: A statement for healthcare professionals from the American Heart Association. *Circulation* 2001;104:1694–740
16. ACSM's Guidelines for Exercise Testing and Prescription (7th ed). *Metabolic Calculation (Appendix D).* Philadelphia, PA, Lippincott Williams & Wilkins, 2006, p. 289–99
17. ATS statement: Guidelines for the six-minute walk test. *Am J Respir Crit Care Med* 2002;166:111–7
18. Ito T, Shirado O, Suzuki H, et al: Lumbar trunk muscle endurance testing: An inexpensive alternative to a

machine for evaluation. *Arch Phys Med Rehabil* 1996; 77:75–9

19. Arnot R, Gaines C: Wall squat, sport selection. New York, NY, *The Viking Press*, 1984, p. 149
20. Alberti KG, Zimmet P, Shaw J: The metabolic syndrome—A new worldwide definition. *Lancet* 2005;366:1059–62
21. Myers J, Buchanan N, Walsh D, et al: Comparison of the ramp versus standard exercise protocols. *J Am Coll Cardiol* 1991;17:1334–42
22. Robergs R: Simplified method and program for incremental exercise protocol development. *JEPonline* 2007;10:1–23
23. Williams MA, Haskell WL, Ades PA, et al: Resistance exercise in individuals with and without cardiovascular disease: 2007 update: A scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation* 2007;116: 572–84
24. Clark JE: Examining matched acute physiological responses to various modes of exercise in individuals who are overweight. *J Strength Cond Res* 2010;24: 2239–48
25. Trichopoulou A, Costacou T, Bamia C, et al: Adherence to a Mediterranean diet and survival in a Greek population. *N Engl J Med* 2003;348:2599–608
26. Academies IoM: *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Washington, DC, The National Academy Press, 2005
27. Berentzen TL, Jakobsen MU, Halkjaer J, et al: Changes in waist circumference and mortality in middle-aged men and women. *PLoS One* 2010;5:pii: e13097
28. Stevens J, Truesdale KP, McClain JE, et al: The definition of weight maintenance. *Int J Obes (Lond)* 2006;30:391–9
29. Hosmer D, Lemeshow S: *Applied logistic regression*. New York, NY, John Wiley & Sons, 1989
30. Rognmo O, Hetland E, Helgerud J, et al: High intensity aerobic interval exercise is superior to moderate intensity exercise for increasing aerobic capacity in patients with coronary artery disease. *Eur J Cardiovasc Prev Rehabil* 2004;11:216–22
31. Wisloff U, Stoylen A, Loennechen JP, et al: Superior cardiovascular effect of aerobic interval training versus moderate continuous training in heart failure patients: A randomized study. *Circulation* 2007;115: 3086–94
32. Schjerve IE, Tyldum GA, Tjonna AE, et al: Both aerobic endurance and strength training programmes improve cardiovascular health in obese adults. *Clin Sci (Lond)* 2008;115:283–93
33. Tjonna AE, Lee SJ, Rognmo O, et al: Aerobic interval training versus continuous moderate exercise as a treatment for the metabolic syndrome: A pilot study. *Circulation* 2008;118:346–54
34. Brun JF, Jean E, Ghanassia E, et al: Metabolic training: New paradigms of exercise training for metabolic diseases with exercise calorimetry targeting individuals. *Ann Readapt Med Phys* 2007;50: 528–34
35. Stensvold D, Tjonna AE, Skaug EA, et al: Strength training versus aerobic interval training to modify risk factors of metabolic syndrome. *J Appl Physiol* 2010;108:804–10
36. Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults. Executive summary of the third report of the National Cholesterol Education Progra (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). *JAMA* 2001;285:2486e97
37. Ross R, Bradshaw AJ: The future of obesity reduction: Beyond weight loss. *Nat Rev Endocrinol* 2009;5:319–25
38. Stiegler P, Cunliffe A: The role of diet and exercise for the maintenance of fat-free mass and resting metabolic rate during weight loss. *Sports Med* 2006;36: 239–62
39. Zurlo F, Lillioja S, Esposito-Del Puente A, et al: Low ratio of fat to carbohydrate oxidation as predictor of weight gain: Study of 24-h RQ. *Am J Physiol* 1990; 259:E650–7
40. Hawley JA: Exercise as a therapeutic intervention for the prevention and treatment of insulin resistance. *Diabetes Metab Res Rev* 2004;20:383–93
41. Tsekouras YE, Magkos F, Kellas Y, et al: High-intensity interval aerobic training reduces hepatic very low-density lipoprotein-triglyceride secretion rate in men. *Am J Physiol Endocrinol Metab* 2008;295:E851–8
42. Forbes GB: Body fat content influences the body composition response to nutrition and exercise. *Ann N Y Acad Sci* 2000;904:359–65
43. Blair SN, Church TS: The fitness, obesity, and health equation: Is physical activity the common denominator? *JAMA* 2004;292:1232–4
44. Diaz A, Bourassa MG, Guertin MC, et al: Long-term prognostic value of resting heart rate in patients with suspected or proven coronary artery disease. *Eur Heart J* 2005;26:967–74
45. Christ M, Iannello C, Iannello PG, et al: Effects of a weight reduction program with and without aerobic exercise in the metabolic syndrome. *Int J Cardiol* 2004;97:115–22
46. Maltais M, Desroches J, Dionne I: Changes in muscle mass and strength after menopause. *J Musculoskelet Neuronal Interact* 2009;9:186–97
47. Asikainen T, Kukkonen-Harjula K, Miilunpalo S: Exercise for health for early postmenopausal women: A systematic review of randomised controlled trials. *Sports Med* 2004;34:753–78