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Original article

High-intensity interval training reduces abdominal fat mass in postmenopausal women with type 2 diabetes

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Abstract

Aim. – This study compared the effect of high-intensity interval training (HIIT) and moderate-intensity continuous training (MICT) for 16 weeks on whole-body and abdominal fat mass (FM) in postmenopausal women with type 2 diabetes (T2D).

Methods. – Seventeen women (69 ± 1 years; BMI: 31 ± 1 kg.m^{-2}) were randomly assigned to either a HIIT [60 × (8 s at 77–85% HR$_{max}$, 12 s of active recovery)] or MICT (40 min at 55–60% of their individual HRR) cycling program for 16 weeks, 2 days/week. Dual-energy X-ray absorptiometry was used to measure whole-body and regional FM content, including abdominal adiposity and visceral adipose tissue. Plasma cholesterol, HDL, LDL, triglycerides, glucose and HbA$_{1c}$ levels were measured. Levels of nutritional intake and physical activity were evaluated by 7-day self-reports.

Results. – Dietary energy (caloric) intake, physical activity level and total body mass did not vary in either group from the beginning to the end of the training intervention. Overall, total FM decreased and total fat-free mass significantly increased over time (by around 2–3%). Total FM reduction at the end of the intervention was not significantly different between groups. However, significant loss of total abdominal (−8.3 ± 2.2%) and visceral (−24.2 ± 7.7%) FM was observed only with HIIT. Time effects were noted for HbA$_{1c}$ and total cholesterol/HDL ratio.

Conclusion. – With no concomitant caloric restriction, an HIIT program in postmenopausal women with T2D (twice a week for 16 weeks) appeared to be more effective for reducing central obesity than MICT, and could be proposed as an alternative exercise training program for this population.

Keywords: Body composition; Health; Menopause; Physical activity; Type 2 diabetes

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Abbreviations: HIIT, high-intensity interval training; MICT, moderate-intensity continuous training; DEXA, dual-energy X-ray absorptiometry; FM, fat mass; FFM, fat-free mass; T2D, type 2 diabetes; HR, heart rate; HRR, heart rate reserve; IPAQ, International Physical Activity Questionnaire.

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1. Introduction

According to the International Diabetes Federation, diabetes currently affects 382 million people worldwide. Type 2 diabetes (T2D) is the most prevalent form (comprising 85–95% of the diabetic population). Overweight and obesity are major risk factors for a number of chronic diseases, including T2D; however, T2D prevalence is also related to the current increase in sedentary lifestyles and physical inactivity [1]. Whole-body fat and visceral adipose tissue (VAT) accumulation are associated with an increased risk of cardiovascular disease (CVD) in patients with T2D [2]. Compared with men and postmenopausal women, premenopausal women are more prone to accumulate fat in the gluteal–femoral region [3], which is protective against the risks of CVD. On the other hand, the hormonal and metabolic changes induced by menopause are followed by fat redistribution towards the upper body, including the abdominal area [4]. Although the mechanisms by which menopause decreases protection against accumulation of abdominal subcutaneous and visceral fat have not been fully elucidated, oestrogen deficiency seems to play a crucial role, as demonstrated by the lower abdominal fat gain seen in women taking hormone-replacement therapy (HRT) [5].

Due to the combined effects of age, T2D and visceral obesity, postmenopausal diabetic women are more at risk of CVD [6]. In such a population, effective strategies to lose weight and reduce total fat mass (FM) and VAT are essential for limiting such complications. While caloric restriction is an efficient strategy for losing weight and adipose tissue, physical activity, either alone or combined with nutritional management, can also play an important role in reducing FM while simultaneously preserving fat-free mass (FFM) [7]. A dose-dependent relationship between the amount of exercise performed and the amount of fat lost has been reported in sedentary, overweight, 45- to 60-year-old men and women [8].

The current international guidelines suggest that endurance training [moderate-intensity continuous training (MICT)] is the best strategy for weight loss and FM reduction [9]. In its latest recommendations, the American College of Sports Medicine (ACSM) prescribed 150–250 min.week^{-1} of moderate-intensity physical activity for effective prevention of weight gain, and > 250 min.week^{-1} for clinically significant weight loss, in men and women [9]. Yet, despite the cardiovascular and metabolic benefits of such programs, effective body weight loss may be limited or even non-existent if exercise is not associated with calorie restriction [10]. A growing body of evidence suggests that, compared with MICT, high-intensity interval training (HIIT) - repeated bouts of high-intensity effort followed by less-intense recovery times - may result in similar or better improvement of fitness and cardiovascular health in men and women [11,12]. Moreover, HIIT might also more effectively reduce FM, particularly abdominal subcutaneous FM and VAT [13]. Such HIIT effects were observed in normal weight and overweight/obese women [14–17]. Conversely, nothing is known of the potential effects of HIIT in postmenopausal women with T2D, despite their greater risk of developing CVD.

Thus, the purpose of the present study was to examine and compare the effects of 16-week HIIT and MICT programs on whole-body and abdominal FM in postmenopausal women with T2D. Our hypothesis was that HIIT could more effectively reduce total and abdominal (visceral) FM compared with traditional endurance training.

2. Methods

2.1. Subjects

Twenty 61- to 80-year-old women were recruited from the French Diabetes Association in Auvergne (AFD 63). The mean time elapsed since T2D diagnosis was 14.5 ± 2.1 years. The main inclusion criteria were:

- postmenopausal women;
- T2D;
- body mass index (BMI) > 25 kg/m^2 and ≤ 40 kg/m^2;
- stable eating habits and physical activity for at least 3 months.

Exclusion criteria were:

- medical contraindications for intense physical activity;
- painful joints;
- taking HRT.

A total of 17 postmenopausal women with T2D were finally selected for the two 16-week interventional programs (Fig. 1). None of the participants had a history of chronic arterial or respiratory disease, CVD or any endocrine disorder except T2D. All of the women were being medically treated: nine with biguanides; four with biguanides and glinides or dipeptidyl peptidase (DPP)-4 inhibitors; two with biguanides and DPP-4 inhibitors and sulphonamides; and two with biguanides and insulin injections (insulin detemir or aspart). Although all participants reported low levels of physical activity [as per their International Physical Activity Questionnaire (IPAQ) results], all had been going to a fitness centre for at least 1 year (for 1 h twice a week) before beginning the study intervention. This activity had been suggested by AFD 63 and included 10 min of cycling, and around 20 min of resistance training and 10 min of stretching.

As age, physical fitness and FM distribution can alter lipid oxidation [18,19], participants were first subdivided in two groups matched for age, their theoretical maximum aerobic power ($MAPth = 3$ W/kg FFM) [20] and abdominal-to-lower-body FM ratio. The two groups were then randomly allocated to either HIIT ($n = 8$) or MICT ($n = 9$).

The study had approval from the relevant ethics committee (Comité de Protection des Personnes Sud Est VI, CPPAU814) and was registered on ClinicalTrails.gov via the Protocol Registration System (ClinicalTrials.Gov: NCT02352246). After receiving detailed information on study objectives and protocol, each participant gave their written informed consent.

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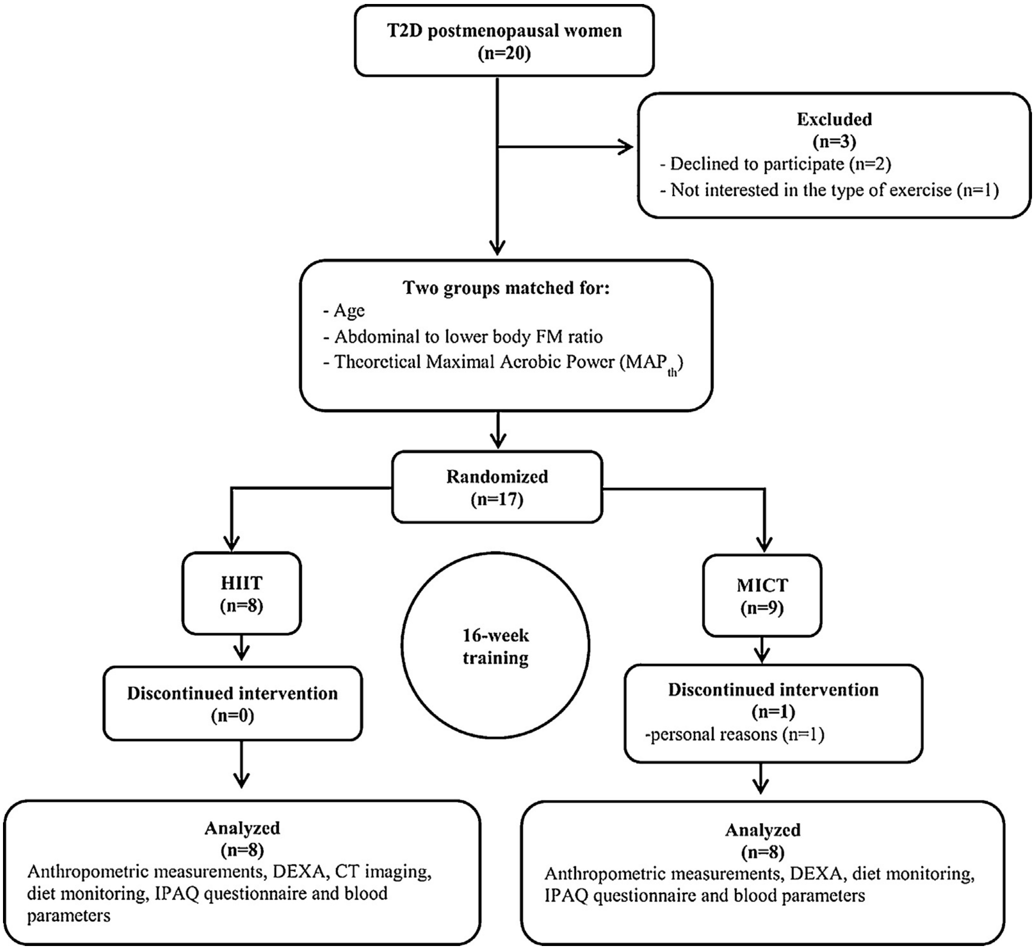

Fig. 1. Flow diagram of study participant recruitment. T2D: type 2 diabetes; FM: fat mass; HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; DEXA: dual-energy X-ray absorptiometry; CT: computed tomography; IPAQ: International Physical Activity Questionnaire.

2.2. Study design

2.2.1. Anthropometric measurements

Body weight was measured to the nearest 0.1 kg on a seca 709 scale (Hamburg, Germany) under fasting conditions, with subjects wearing only underwear. Height was measured to the nearest 0.5 cm with a wall-mounted stadiometer. BMI was calculated as body weight (kg) divided by the square of height (m^2). Waist circumference (cm) was measured midway between the last rib and upper iliac crest, and hip circumference at the level of the femoral trochanters. Both measures were taken in standing position with a measuring tape. Sagittal abdominal diameter (supine abdominal height) was measured with a Holtain–Kahn abdominal caliper (Holtain Limited, Crymych, Pembs, UK) to the nearest mm in the sagittal plane at the level of the iliac crests (L4–L5) during normal expiration, with the subject lying supine on a firm bench with knees bent. Abdominal skinfold thickness was measured at four different sites (at 12 cm and 7 cm to the right and left of the navel) with a Harpenden Skinfold Caliper (Mediflex Corp., Long Island, NY, USA), and the mean subcutaneous abdominal skinfold thickness was then calculated [21]. The same experienced investigator took all anthropometric measurements at baseline and after 16 weeks of training.

2.2.2. Body composition

Total body and regional FM as well as FFM (expressed as kg and % of body mass) were measured with a dual-energy X-ray absorptiometry (DEXA) scanner (QDR-4500A, Hologic, Inc., Marlborough, MA, USA). Two regions of interest were manually isolated and analyzed by an experienced technician:

- the area from L1–L2 to the pubic rami to determine total abdominal FM (kg);
- the area from the iliac crest to the feet to calculate lower-body FM (kg).

All analyses were performed by the same operator. Total visceral FM (kg) was estimated from the total abdominal FM on DEXA, mean subcutaneous abdominal skinfold thickness and abdominal height, as previously described [21]. For the HIIT group only, visceral FM (g) was also assessed at the L4–L5 level by computed tomography (CT; Somatom AS64 scanner, Siemens AG, Erlangen, Germany), using the semi-automatic segmentation MIPAV (Medical Image Processing, Analysis, and Visualization) plug-in software. CT images were analyzed by an experienced technician.

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2.2.3. *Training protocol*

Participants performed two exercise sessions per week for 16 weeks. To allow for a sufficient recovery period, the two sessions were done on Tuesdays and Thursdays (between 2.30 pm and 4.00 pm). Exercise training was performed on C-MAX Club fitness bikes, and supervised by an experienced physical activity instructor. In both intervention groups, training sessions included 5-min warm-up and 5-min cool-down sessions on the bike at a workload chosen by the participant herself. Blood pressure and blood glucose (Accu-Chek Performa Blood Glucose Meter, Roche Diagnostics, Risch-Rotkreuz, Switzerland) were monitored before and after each exercise session. Energy expenditures (EEs) per exercise session were measured 1 week before the program started, using a SenseWear® MF Armband (BodyMedia, Pittsburgh, PA, USA), which calculates EEs from accelerometry, body temperature, heat flux, impedance and individual characteristics, in four subjects who performed one MICT session and one HIIT session. EEs per session did not differ between the two modalities (262 ± 58 kcal with HIIT and 240 ± 58 kcal with MICT).

2.2.4. *High-intensity interval training (HIIT)*

The HIIT training program was based on the protocol by Trapp et al. [17], which appears to be an attractive and feasible cycling program for sedentary middle-aged women. In fact, this HIIT modality is more like the square-wave endurance exercise test (SWEET) [22] than sprint interval training (SIT), which involves 'supramaximal' levels of intensity [12]. The HIIT protocol consisted of repeated cycles of sprinting for 8 s [at around 80% maximum heart rate (HR_{max})] followed by pedalling slowly (20–30 rpm) for 12 s (maximum of 60 cycles per 20-min session). The selected resistance was the same for each participant and was very low (almost zero) to facilitate acceleration and limit bicycle-wheel inertia.

All of the participating women were able to complete the full 20-min exercise program after three or four sessions. Mean HR was monitored at the beginning, middle and end of the study (weeks 2, 8 and 15, respectively). HIIT-induced a mean HR that was 77–85% of the estimated maximum HR ($EstHR_{max} = 208–0.7 \times \text{age}$) [23] at each evaluation. After the 20-min exercise session, subjects reduced their workload and pedalled for another 5 min before getting off the bicycle.

2.2.5. *Moderate-intensity continuous training (MICT)*

Women in the MICT group exercised at 55–60% of the target HR (THR) for their individual HR reserve (HRR) for 40 min. THR ranges were determined from $EstHR_{max}$ (see above) and HR at rest (HR_{rest}), using the following formulas: $THR_{55\%HRR} = (EstHR_{max} - HR_{rest}) \times 0.55 + HR_{rest}$; and $THR_{60\%HRR} = (EstHR_{max} - HR_{rest}) \times 0.60 + HR_{rest}$. Exercise duration was gradually increased over the first 2 weeks to reach 40 min/session of cycling. THR was calculated again after 2 months because of the subjects' potential improvements in fitness. At the end of each exercise session, there was a 5-min cool-down.

2.2.6. *Diet monitoring*

Women were asked to maintain their normal eating habits during the 16-week study period. At baseline and at week 16 of training, each participant provided a 7-day food-intake diary, which was evaluated by a dietitian using nutrition analysis software (Nutrilog®, Marans, France).

2.2.7. *Physical activity levels*

Participants were asked to maintain their normal levels of physical activity during the study period. Their usual weekly level of physical activity was determined at baseline and after 16 weeks by the French version of the IPAQ [24].

2.2.8. *Blood parameters*

Blood samples were taken the week before beginning the protocol (T0: baseline values) and then 3–5 days after the last exercise session (T4), depending on the subjects' availability and to avoid any potential effect of the last exercise session on results. After an overnight fast, a cannula was inserted into the antecubital vein, and whole blood was collected in EDTA and fluoride Vacutainers. Plasma concentrations of total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C) and triglycerides (TG) were immediately measured, using a Synchron Clinical System UniCel DxC analyzer (Beckman Coulter, Brea, CA, USA), with a cholesterol oxidase method for TC (CHOL reagent), a direct homogeneous method for HDL-C (HDLD reagent) and a lipase/glycerol kinase method for TG (GPO reagent). The low-density lipoprotein (LDL) fraction was indirectly quantified using the equation described by Friedewald et al. [25]. Plasma glucose concentration was immediately determined by a hexokinase method (UniCel DxC analyzer, Synchron). Finally, HbA_{1c} values were evaluated by a high-performance liquid chromatography (HPLC) Variant II analyzer equipped with the new 270-2101 NU Kit (Bio-Rad Laboratories, Hercules, CA, USA).

2.3. *Statistical analysis*

All statistical analyses were carried out with STATISTICA version 8.00 software (StatSoft Inc., Tulsa, OK, USA). Results are expressed as means ± standard error of the mean (SEM). Before the study began, the sample size required for a statistical power of 80% was calculated based on previous results for FM loss after HIIT training in young women [17]. Based on a two-sided type I error of 5%, a minimum difference of 1.5 ± 0.88 kg, as described by Tremblay et al. [35], for FM loss could be detected with seven women per group. However, our sample size was increased to eight and nine women per group, respectively, at the beginning of the intervention to take into account participants lost to follow-up.

The data were tested for normal distribution using the Kolmogorov–Smirnov test, and the homogeneity of variance was tested with the F-test. Data were log-transformed, when appropriate, prior to statistical analyses. Two-way analysis of variance (ANOVA) with repeated measures was used to determine group and time effects, and group × time interactions. When a significant effect was found, post-hoc multiple

Table 1
Anthropometric and body composition values based on dual-energy X-ray absorptiometry (DEXA) at baseline and after 16 weeks of moderate-intensity continuous training (MICT; $n = 8$) and high-intensity interval training (HIIT; $n = 8$).

	MICT		HIIT		Anova (*P*)			MICT	HIIT	*P*
	Baseline	16 weeks	Baseline	16 weeks	G	T	G × T	Δ Change (%)	Δ Change (%)	
Body weight (kg)	73.9 ± 3.4	74.5 ± 3.5	79.5 ± 5.2	79.4 ± 5.2	0.41	0.63	0.39	0.8 ± 0.6	−0.2 ± 0.9	0.43
BMI (kg/m^2)	29.7 ± 1.2	29.9 ± 1.3	32.6 ± 1.7	32.4 ± 1.6	0.21	0.93	0.26	0.7 ± 0.6	−0.6 ± 0.9	0.27
Waist circumference (cm)	108.5 ± 2.1	107.9 ± 2.3	109.8 ± 4.3	109.6 ± 4.6	0.77	0.67	0.82	−0.6 ± 1.2	−0.2 ± 1.1	0.96
Hip circumference (cm)	107.0 ± 2.9	108.8 ± 2.3	111.0 ± 4.3	107.5 ± 3.7*	0.77	0.38	**0.02**	1.8 ± 1.4	−3.0 ± 1.1***	**0.03**
Total FM (kg)	28.2 ± 2.1	27.6 ± 2.1	29.1 ± 2.9	28.3 ± 2.9	0.83	**0.02**	0.74	−2.4 ± 1.5	−2.9 ± 1.3	0.63
Total FM (%)	37.9 ± 1.3	36.7 ± 1.3	36.2 ± 1.7	35.2 ± 1.5	0.44	**0.01**	0.70	−3.2 ± 1.2	−2.5 ± 1.3	0.79
Total FFM (kg)	45.6 ± 1.5	46.9 ± 1.7	50.4 ± 2.6	50.9 ± 2.6	0.17	**0.03**	0.35	2.8 ± 1.0	1.1 ± 1.2	0.32
Arm FM (kg)	3.4 ± 0.3	3.3 ± 0.2	3.6 ± 0.2	3.4 ± 0.2	0.63	**0.02**	0.60	−2.9 ± 2.6	−5.0 ± 2.1	0.64
Arm LBM (kg)	3.6 ± 0.2	3.6 ± 0.2	4.2 ± 0.2	4.1 ± 0.2	0.09	0.25	0.19	0.3 ± 1.0	−2.2 ± 1.7	0.19
Leg FM (kg)	8.5 ± 0.8	8.6 ± 0.9	9.6 ± 1.4	8.9 ± 1.1*	0.68	0.11	**0.05**	0.7 ± 1.5	−5.5 ± 2.7***	**0.05**
Leg LBM (kg)	12.2 ± 0.4	12.8 ± 0.4**	14.4 ± 1.0	14.1 ± 0.8	0.09	0.25	**0.003**	5.3 ± 1.2	−1.8 ± 1.3***	**0.001**
Lower-body FM (kg)	13.9 ± 0.9	13.8 ± 0.9	14.2 ± 1.8	13.6 ± 1.6	0.98	0.10	0.23	−0.9 ± 1.4	−3.3 ± 1.9	0.37
Total abdominal FM (kg)	8.7 ± 1.0	8.6 ± 0.9	8.7 ± 1.1	7.8 ± 0.9*	0.79	**0.02**	**0.03**	−0.3 ± 2.1	−8.3 ± 2.2***	**0.03**
Visceral FM (kg)	4.8 ± 0.9	5.0 ± 0.8	4.1 ± 0.6	3.1 ± 0.6**	0.24	0.07	**0.01**	10.5 ± 9.7	−24.2 ± 7.7***	**0.02**

In bold: significant differences ($P \leq 0.05$). Data are means ± SEM; Δ Change (%) = [(16 weeks − baseline/baseline) × 100]; G: group effect; T: time effect; G × T: group × time interaction; BMI: body mass index; FM: fat mass; FFM: fat-free mass; LBM: lean body mass (FFM excluding bone mineral content).

[*] $P \leq 0.05$ (vs. same-group baseline).

[**] $P \leq 0.01$ (vs. same-group baseline).

[***] $P \leq 0.05$ (between group differences in Δ change values).

comparisons were performed using the Newman–Keuls test. Values at baseline and changes from baseline to the end of the study [delta change: (16 weeks–baseline/baseline) × 100] were also compared between groups, using the non-parametric Mann–Whitney U test. Wilcoxon's signed-rank test was used to analyze CT data from the HIIT group, and Pearson's correlations were used to test relationships between variables. Differences with a *P*-value ≤ 0.05 were considered statistically significant.

3. Results

3.1. Subjects

Of the 20 postmenopausal women contacted for this study, 17 were ultimately enrolled (see flow chart on Fig. 1). Medical treatments did not differ between groups. One subject withdrew from the MICT group for personal reasons after 1 month. Nevertheless, at baseline, both groups remained comparable in terms of age (MICT: 70.1 ± 2.4 years; HIIT: 68.2 ± 1.9 years), abdominal-to-lower-body FM ratio (MICT: 0.22 ± 0.03; HIIT: 0.25 ± 0.02; $P = 0.67$) and MAP*th* (MICT: 138 ± 4 W; HIIT: 151 ± 8 W; $P = 0.20$).

3.2. Anthropometric measurements and total body mass and composition

Compared with baseline, body weight and waist circumference did not change in either group after the 16-week intervention (Table 1). However, a group × time interaction was noted for hip circumference values, with a significant decrease only in the HIIT group ($P \leq 0.05$). A time effect was observed for total FM and FFM changes ($P \leq 0.05$; Table 1, Fig. 2). Overall, arm FM was decreased (time effect without group × time interaction; $P \leq 0.05$), whereas leg FM was reduced only in the HIIT group ($P \leq 0.05$). After the training program, leg lean body mass (LBM, defined as FFM minus bone mineral content) was increased in the MICT group ($P \leq 0.05$), whereas arm LBM did not change significantly over time.

3.3. Total abdominal and visceral FM assessed by DEXA

Total abdominal and visceral FM did not differ at baseline between groups. Compared with baseline, the total (subcutaneous plus visceral) abdominal FM was significantly reduced (group × time interaction; $P \leq 0.05$) only with HIIT. Visceral FM (from L1–L2 to pubic rami) was also reduced only in the HIIT group ($P \leq 0.01$; Table 1, Fig. 2).

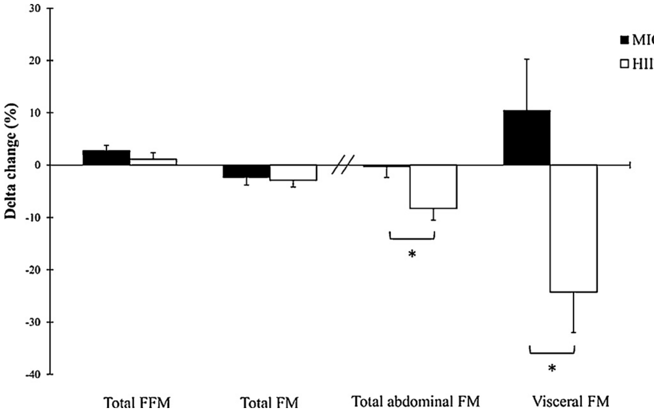

Fig. 2. Body composition changes [based on dual-energy X-ray absorptiometry (DEXA) imaging] between baseline and end of the 16-week exercise program with MICT ($n = 8$) and HIIT ($n = 8$). Data are means ± SEM. MICT: moderate-intensity continuous training; HIIT: high-intensity interval training; FFM: fat-free mass; FM: fat mass; delta change (%) = [(16 weeks − baseline/baseline) × 100]. $^{*}P \leq 0.05$ (MICT vs. HIIT groups).

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Table 2
L4–L5 computed tomography data at baseline and after 16 weeks of high-intensity interval training (HIIT; $n = 8$).

	Baseline	16 weeks	P	Δ Change (%)
L4–L5 abdominal FM (g)	81.4 ± 5.9	77.1 ± 5.1*	**0.01**	−4.8 ± 1.4
Subcutaneous adipose tissue	38.6 ± 3.1	36.6 ± 2.7	0.34	−3.5 ± 3.7
Visceral adipose tissue	42.8 ± 3.7	40.6 ± 3.9*	**0.04**	−5.7 ± 2.2

In bold: significant differences ($P \leq 0.05$). Data are means ± SEM; Δ Change (%) = [(16 weeks − baseline/baseline) × 100]; FM: fat mass.
* $P \leq 0.05$ (vs. baseline).

Table 3
Lipid, fasting glucose and HbA$_{1c}$ changes from baseline to week 16 with moderate-intensity continuous training (MICT; $n = 8$) and high-intensity interval training (HIIT; $n = 8$).

	MICT		HIIT		Anova (P)			MICT	HIIT	P
	Baseline	16 weeks	Baseline	16 weeks	G	T	G × T	Δ Change (%)	Δ Change (%)	
HbA$_{1c}$ (%)	7.6 ± 0.3	7.4 ± 0.3	7.4 ± 0.3	7.3 ± 0.3	0.75	**0.01**	0.50	−3.5 ± 1.1	−2.3 ± 1.3	0.80
Fasting glucose (mmol.L^{-1})	8.4 ± 0.7	8.8 ± 1.1	9.7 ± 0.7	10 ± 0.8	0.25	0.74	0.90	6.8 ± 14.4	3.1 ± 6.5	1.00
TG (mmol.L^{-1})	1.1 ± 0.1	1.0 ± 0.1	1.9 ± 0.3	1.9 ± 0.5	**0.03**	0.59	0.98	−1.7 ± 8.9	−6.1 ± 7.9	0.86
Total cholesterol (mmol.L^{-1})	4.5 ± 0.3	4.3 ± 0.3	4.8 ± 0.3	4.7 ± 0.5	0.37	0.11	0.87	−5.0 ± 3.1	−7.2 ± 6.9	0.95
HDL (mmol.L^{-1})	1.6 ± 0.1	1.7 ± 0.2	1.3 ± 0.1	1.4 ± 0.1	0.16	0.26	0.99	1.5 ± 2.7	2.5 ± 1.6	0.77
LDL (mmol.L^{-1})	2.4 ± 0.3	2.2 ± 0.2	2.6 ± 0.3	2.7 ± 0.3	0.28	0.09	0.37	−8.3 ± 5.6	−4.1 ± 7.3	0.45
Total cholesterol/HDL	2.9 ± 0.3	2.7 ± 0.2	3.9 ± 0.3	3.5 ± 0.4	0.11	**0.03**	0.74	−6.3 ± 3.0	−9.6 ± 6.2	0.69

In bold: significant T (time) or G (group) and significant differences ($P \leq 0.05$). Data are means ± SEM; Δ Change (%) = [(16 weeks − baseline/baseline) × 100]; G: group effect; T: time effect; G × T: group × time interaction; TG: triglycerides; HDL/LDL: high-density/low-density lipoprotein.

3.4. Abdominal subcutaneous and visceral FM at L4–L5 on CT

As DEXA revealed that visceral FM decreased only in the HIIT group, CT was performed only in this group after the intervention. The scans revealed that, at the end of the 16-week period, L4–L5 abdominal FM and visceral FM were significantly reduced by HIIT compared with baseline (−4.8% and −5.7%, respectively; Table 2). However, the amount of L4–L5 subcutaneous abdominal FM had not changed at the end of the training period.

3.5. Blood parameters

Plasma triglyceride levels were higher with HIIT (group effect, $P \leq 0.05$). Overall, HbA$_{1c}$ and TC-to-HDL ratio both decreased after the intervention (time effect, $P \leq 0.05$). No change was observed for the other parameters between pre- and postexercise (Table 3). TC reduction was positively correlated with total visceral FM loss ($r = 0.39$; $P \leq 0.05$) and HbA$_{1c}$ change was positively associated with the decrease in abdominal FM ($r = 0.29$; $P \leq 0.05$).

3.6. Physical activity and diet

After 16 weeks, levels of physical activity (IPAQ score) were unchanged compared with baseline. Similarly, total energy (kcal) intake and macronutrient consumption (distribution and total amount) also did not change significantly (data not shown).

4. Discussion

The present study was designed to compare whole-body and abdominal FM changes induced by a 16-week HIIT or MICT intervention in postmenopausal women with T2D. The two training modalities resulted in similar whole-body FM loss; however, HIIT was significantly more effective than traditional endurance training in reducing total abdominal and visceral FM in this population.

The current guidelines of both the American Diabetes Association (ADA) and European Association for the Study of Diabetes (EASD) acknowledge the therapeutic effects of exercise interventions in patients with T2D. In terms of physiological adaptations, there are differences between the long-term adaptive responses to low-/moderate-intensity and intermittent high-intensity training programs. HIIT and MICT are different exercise modalities with different effects [22,26,27], but they both improve glycaemic control, insulin sensitivity, body composition, blood pressure, muscle strength and aerobic capacity [28,29]. Thus, both modalities are of value in the management of T2D and/or obesity.

Recent evidence suggests that HIIT can be a time-efficient strategy to decrease whole-body FM in sedentary overweight/obese individuals [13]. This goes against the belief that high-intensity training programs are not appropriate for optimal fat oxidation and weight loss in such populations. To our knowledge, only Mitranun et al. [30] have previously investigated HIIT-induced FM loss in postmenopausal women. They studied the effects of 12-week MICT (20 min at 60% VO$_{2peak}$) and HIIT (4 × 1 min at 80% VO$_{2peak}$ interspersed with 4 min at 50% VO$_{2peak}$) programs (three times a week) on glycaemic

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control, microvascular reactivity and body composition in 43 volunteers aged 50–70 years with T2D (14 men and 29 postmenopausal women; BMI > 29 kg.m^{-2}). They reported that, at the end of the training period, body mass was reduced only in the HIIT group, although the same fat loss percentage was observed in both groups (around 2%). Unfortunately, the authors did not focus on HIIT-induced gender-specific responses, and their use of bioelectrical impedance rather than DEXA or CT imaging to measure body composition did not allow assessment of the extent of abdominal FM reduction. Thus, our present study is the first to determine the impact of HIIT on whole-body and abdominal FM in postmenopausal women using precision technologies.

Our results indicate that there was no significant loss of body mass after the 16-week MICT and HIIT programs. This accords with previous studies showing that physical activity alone (without concomitant calorie restriction) does not lead to significant weight loss [10]. Nevertheless, our study found that training reduced total FM and increased FFM, but with no group effect or group × time interaction. This means that the two interventions both provided stimuli with similar effects on whole-body composition in postmenopausal women with T2D.

The total amount of FM lost in our two groups (about 2 kg) was comparable to previous data in the literature. Zhang et al. [15] reported an FM loss of 1.9 kg (range: −2.4, −1.5) after HIIT and of 1.7 kg (range: −2.2, −1.2) after MICT in young overweight Chinese women (12-week training program). As in our study, the authors emphasized that the recorded dietary energy intakes and habitual EEs did not change during the intervention. HIIT may sometimes be more effective for reducing total body fat than other types of exercise [13]; however, our study is not the first to find no differences between MICT and HIIT [15]. This discrepancy in the literature might be explained by differences in the intervention modalities, the number of sessions per week and the studied populations. Another reason could be the hormone status of the population. In fact, it is well known that oestrogen deficiency decreases fat oxidation at rest, but also during exercise [31]. Thus, the reduced fat oxidation rate observed in postmenopausal women in our study could have blunted the potential differences between MICT and HIIT in reducing FM.

Although the two training programs did not differ in terms of total FM loss, only HIIT led to reductions in leg and abdominal FM after 16 weeks. Despite exercising almost half the time as in the MICT group, women in the HIIT group lost 5% of leg FM and 8% of total abdominal FM, whereas no change was observed in the MICT group. Similarly, DEXA analysis of total VAT indicated that FM was reduced only in the HIIT group. Furthermore, the significant decrease in abdominal and visceral FM with HIIT was confirmed by L4–L5 CT imaging (−4.8% and −5.7%, respectively). Our results are consistent with the study by Gillen et al. [14], in which 16 young overweight women (27 ± 8 years, BMI: 29 ± 6 kg.m^{-2}) completed, under fast and fed conditions, 18 HIIT sessions (10 × 60-s cycling exercises at around 90% HR$_{\text{max}}$, 60-s recovery) for 6 weeks. Under both conditions, whole-body mass was unchanged at the end of training, whereas DEXA analysis revealed a decrease in whole-body and abdominal fat percentages compared with baseline. Similarly, Heydari et al. [32] showed significant decreases in abdominal (7%) and visceral FM (10%) at the level of L4–L5 in young overweight men (24.7 ± 4.8 years, BMI: 28.4 ± 0.5 kg.m^{-2}) after 12 weeks of HIIT (60 × 8-s cycling exercises, 12-s recovery). More recently, Zhang et al. [15] demonstrated, with CT scans, that HIIT (4 × 4-min running bouts at 85–95% HR$_{\text{peak}}$) was more effective than MICT (33-min running bouts at 60–70% HR$_{\text{peak}}$) at inducing significant reductions in visceral and subcutaneous abdominal FM in young overweight Chinese women (20.9 ± 0.3 years, BMI ≥ 25 kg.m^{-2}).

Overall, our results in T2D (overweight) postmenopausal women are in agreement with previous studies reporting that HIIT is more effective than MICT for decreasing abdominal FM in young men and in young normal weight/obese women. As abdominal and visceral FM is more strongly associated with the risk of CVD compared with overall obesity [2,33], such HIIT-induced reduction of central adiposity is of interest for the management of overweight and T2D in postmenopausal women. This result is further strengthened by the correlation between TC reduction and visceral FM loss, and between HbA$_{1c}$ reduction and abdominal FM loss. Importantly, changes in body composition and blood parameters cannot be attributed to either diet or daily activity because the recorded dietary energy intakes and physical activity levels did not vary in either group during the interventions.

The MICT program had no significant effect on abdominal fat loss compared with HIIT; however, it significantly reduced HbA$_{1c}$ ($P = 0.01$). This is consistent with other studies suggesting metabolic effects with low-/moderate-intensity endurance training [27,34]. Interestingly, MICT also induced a significant increase in leg LBM (FFM excluding bone mineral content; $P = 0.003$), which was not observed with HIIT. The greater time spent on the bike with MICT (40 min twice a week for 12 weeks) might have favoured FFM increase compared with HIIT (8 s × 60 twice a week for 12 weeks), despite its greater exercise intensity.

The mechanisms underlying HIIT-induced total and abdominal FM loss are unclear, but may include greater exercise and postexercise total and abdominal fat oxidation. As a demonstration, people who indulge in vigorous physical activity on a regular basis are leaner than those who never take part in such activities [35]. It is also well known that HIIT is more effective than MICT for stimulating secretion of lipolytic hormones such as catecholamines [36], and noradrenaline (NA) increases fat oxidation, while adrenaline (A) enhances both carbohydrate oxidation and lipolysis. The greater fat oxidation following a HIIT session could be indirectly related to higher sympathetic nervous system (SNS) activation (by NA release), thereby ultimately producing increased levels of circulating free fatty acids (FFA) postexercise. Recently, Wingfield et al. [37] confirmed that HIIT favours fat mobilization during exercise and enhances fat oxidation during the recovery period. These authors found that, in recreationally active women, their respiratory exchange ratios were lower at 30 min and 60 min after HIIT than after MICT or high-intensity resistance training (HIRT). This could be facilitated by higher excess postexercise oxygen consumption (EPOC) when exercise is performed at > 75% VO$_{2\text{max}}$ [38].

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It is well known that lipid oxidation decreases above 40–50% VO_{2max}, a level at which lipolysis is still active.

Thus, HIIT is a well-adapted exercise modality that increases levels of circulating FFA during exercise and then promotes greater fat oxidation during recovery. As the content of β-adrenergic receptors is higher in visceral than in subcutaneous adipose tissue [39], the greater SNS activation during HIIT might explain the greater reliance on visceral FM during this type of exercise. In addition, it has been shown that VAT exhibits smaller adipocytes [40], greater lipolytic activity [41] and lower responses to the antilipolytic effects of insulin [42] than do subcutaneous depots. Altogether, this may contribute to an explanation of why HIIT induces greater abdominal and visceral FM loss than MICT.

One of the limitations of our present study is the small number of subjects. However, seven of the eight postmenopausal women in the HIIT group showed decreases in abdominal and visceral FM. This strengthens the significant role of HIIT on abdominal FM loss in only 16 weeks. On the other hand, it cannot be ruled out that a longer training period might have induced similar effects on abdominal and visceral FM in the MICT group as well. For example, the RESOLVE study showed that high-intensity, high-volume activity induces more rapid loss of visceral FM than endurance training, yet similar results were also observed with endurance training when the intervention was prolonged [43].

In conclusion, our study has demonstrated that, even in the absence of concomitant energy restriction, HIIT twice a week for 16 weeks reduces total abdominal and visceral FM in postmenopausal women with T2D more effectively than a traditional endurance cycling program. HIIT is a time-efficient, feasible, attractive and effective intervention for decreasing visceral obesity in postmenopausal women with T2D, and may be proposed as an alternative strategy to limit CVD risk in this population.

Authors contribution

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Data analysis and interpretation: Florie Maillard, Amidou Traore, Philippe de Pradel Del Amaze, Nathalie Boisseau.

Statistical expertise: Bruno Perreira, Florie Maillard, Nathalie Boisseau.

Disclosure of interest

The authors declare that they have no competing interest.

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