



Moderate-intensity continuous training or high-intensity interval training with or without resistance training for altering body composition in postmenopausal women

Marine Dupuit, Melanie Rance, Claire Morel, Patrice Bouillon, Bruno Pereira, Alban Bonnet, Florie Maillard, Martine M. Duclos, Nathalie Boisseau

► To cite this version:

Marine Dupuit, Melanie Rance, Claire Morel, Patrice Bouillon, Bruno Pereira, et al.. Moderate-intensity continuous training or high-intensity interval training with or without resistance training for altering body composition in postmenopausal women. *Medicine and Science in Sports and Exercise*, 2020, 52 (3), pp.736-745. 10.1249/MSS.0000000000002162 . hal-02421652

HAL Id: hal-02421652

<https://uca.hal.science/hal-02421652>

Submitted on 15 Nov 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

MICT or HIIT ± RT programs for altering body composition in postmenopausal women

Marine Dupuit¹, Mélanie Rance², Claire Morel², Patrice Bouillon³, Bruno Pereira⁴, Alban Bonnet¹, Florie Maillard¹, Martine Duclos^{5,6,7,8}, Nathalie Boisseau^{1,6}

¹: Laboratory of metabolic adaptations during exercise in pathologic and physiologic conditions (AME2P), Université Clermont Auvergne, EA 3533, 63171 Clermont-Ferrand, France

marine.dupuit@uca.fr; albanbonnet9@gmail.com; florie.maillard@uca.fr;
nathalie.boisseau@uca.fr

²: Center of Resources, Expertise and Performance in Sports (CREPS), 03321 Bellerive-sur-Allier, France.

melanie.rance@creps-vichy.sports.gouv.fr; claire.morel@creps-vichy.sports.gouv.fr

³: Department of Cardiology, Vichy Hospital, 03300 Vichy, France.

patrice.bouillon@ch-vichy.fr

⁴: Clermont-Ferrand University Hospital, Biostatistics Unit (DRCI), 63000 Clermont-Ferrand, France.

bpereira@chu-clermontferrand.fr

⁵: Department of Sport Medicine and Functional Explorations, Clermont-Ferrand University Hospital, G. Montpied Hospital, 63000 Clermont-Ferrand, France

mduclos@chu-clermontferrand.fr

⁶: CRNH –Auvergne – Rhône-Alpes (CNRH-AURA), 63000 Clermont-Ferrand, France

mduclos@chu-clermontferrand.fr; nathalie.boisseau@uca.fr

⁷: UFR Medicine, Université Clermont Auvergne, 63000 Clermont-Ferrand, France

mduclos@chu-clermontferrand.fr

⁸: INRA, Human Nutrition Unit UMR1019, Clermont-Ferrand, France

Corresponding author

Professor Nathalie Boisseau (PhD). Laboratoire des Adaptations Métaboliques à l'Exercice en conditions Physiologiques et Pathologiques (AME2P), 3 rue de la Chebarde, 63171, Aubière Cedex, France.
Phone number: 00 33 4 73 40 55 19; nathalie.boisseau@uca.fr

ABSTRACT

Purpose: To compare body composition changes induced by moderate-intensity continuous training (MICT), high-intensity interval training (HIIT), or HIIT + resistance training (RT) programs (3 days/week, 12 weeks) in postmenopausal women with overweight/obesity, and to determine whether fat mass reduction is related to greater fat oxidation (FatOx).

Methods: Participants (n=27) were randomized in three groups: MICT (40min at 55-60% of peak power output, PPO), HIIT (60 x 8s at 80-90% of peak heart rate, 12s active recovery), and HIIT + RT (HIIT + 8 whole-body exercises: 1 set of 8-12 repetitions). DXA was used to measure whole-body and abdominal/visceral fat mass (FM) and fat-free mass (FFM). FatOx was determined at rest, during a moderate-intensity exercise (40min at 50% of PPO), and for 20 minutes post-exercise, before and after training.

Results: Overall, energy intake and physical activity levels did not vary from the beginning to the end of the intervention. Body weight and total FM decreased in all groups over time, but significant abdominal/visceral FM losses were observed only in HIIT and HIIT + RT groups. When expressed in percentage, total FM, FFM, and muscle mass were significantly modified only by HIIT + RT training. FatOx did not change at rest, but increased similarly in the three groups during and after exercise. Therefore, the HIIT-induced greater FM loss was not related to higher FatOx during or after exercise.

Conclusions: MICT or HIIT \pm RT could be proposed to non-dieting postmenopausal women with overweight/obesity to decrease weight and whole-body FM. The HIIT programs were more effective than MICT in reducing abdominal/visceral FM. RT addition did not potentiate this effect, but increased the percentage of muscle mass.

Key words: Menopause, (intra)-abdominal fat mass, high intensity interval training, resistance training, fat oxidation rate.

INTRODUCTION

In women, the incidence of obesity, type 2 diabetes and cardiovascular diseases (CVD) significantly increases after menopause and is related to an increase of fat mass (FM) (1–3), loss of fat-free mass (FFM) (especially muscle mass) (3), and body fat distribution alterations (1, 4). The increase of subcutaneous and particularly intra-abdominal FM (*i.e.*, visceral FM) after menopause partly explains the higher CVD risk in postmenopausal women (5).

Menopause is associated with a decrease of the resting metabolic rate (RMR) (6) and fat oxidation (FatOx) during physical activity (7, 8) and a lower total energy expenditure (EE) (8, 9). Although literature data show that the diet and physical activity combination promotes longer-term weight and/or FM loss, exercise alone also might have positive effects, particularly on subcutaneous and intra-abdominal FM (10), if the training program is well supervised and if the EE leads to a negative energy balance (11).

The American College of Sports Medicine (ACSM) has recommended moderate intensity continuous training (MICT) in patients with obesity for losing weight and/or FM (11). This strategy is efficient in pre- and post-menopausal women with overweight or obesity (12, 13). Currently, high-intensity interval training (HIIT), which includes repeated bouts of high intensity effort followed by varied recovery times (14), is considered a time-efficient and safe strategy to reduce total FM and particularly subcutaneous and intra-abdominal FM in people with overweight/obesity (15). Our group demonstrated that in postmenopausal non-dieting women with type 2 diabetes, HIIT is more effective for reducing central obesity than MICT, and can be proposed as an alternative exercise program in this population (16). Resistance training (RT) does not enhance weight loss, but may increase FFM and decrease FM, and is associated with health risk reduction (11). Although several previous publications have focused on RT or MICT + RT effects on body composition (17, 18), only few randomized trials compared the impact of a combined HIIT + RT program in overweight/obese adults (19, 20),

and no study has been performed on postmenopausal women. The effects of HIIT \pm RT programs on fat mass losses may be partly due to the increase of RMR, total EE and FatOx (21). No study has thoroughly evaluated the impact of HIIT or HIIT + RT on these parameters in postmenopausal women, but limited post-training muscle mass gain in the female population could alter these adaptations (22).

Therefore, the aim of this study was to compare the effects of 12-week MICT, HIIT and HIIT + RT programs on body composition and FatOx in postmenopausal women with overweight/obesity. We hypothesized that compared with the traditional MICT, HIIT programs could be more efficient in reducing whole-body and abdominal/visceral FM and to favor FatOx, and that HIIT + RT, by also improving FFM and RMR, could offer the best benefits.

METHODS

The study was approved by the relevant ethics committee (Comité de Protection des Personnes Sud Est VI, CPPAU1303) and was registered on ClinicalTrials.gov via the Protocol Registration System (ClinicalTrials.Gov: NCT 03357016). After receiving detailed information on the study objectives and protocol, all participants signed a written informed consent.

Participants

Thirty-five women (mean age 62.4 ± 6.7 yr) were recruited according to the following inclusion criteria: postmenopausal women, body mass index (BMI) $>25 \text{ kg/m}^2$ and $\leq 40 \text{ kg/m}^2$, and stable eating habits and physical activity for at least 3 months. Non-inclusion criteria were: medical contraindications to intense physical activity, painful joints, and taking hormone replacement therapy. Finally, 30 postmenopausal women with overweight/obesity were selected for the

three 12-week interventional programs (Fig. 1). None of the participants had history of chronic arterial or respiratory disease, CVD, or endocrine disorders. All participants reported low levels of physical activity, based on the Global Physical Activity Questionnaire (GPAQ) results (23). Upon recruitment, participants were randomly assigned to an exercise modality [HIIT ($n = 10$), MICT ($n = 10$), HIIT + RT $n = 10$]. A familiarization period of at least 10 days allowed participants to get accustomed with the exercise equipment before training.

EXPERIMENTAL DESIGN

Anthropometric and body composition measurements. Body weight was measured to the nearest 0.1 kg on a Seca 709 scale (Balance Seca 709, France) in fasting conditions, with the subjects wearing only underwear. Height was measured to the nearest 0.5 cm with a wall-mounted stadiometer. Body mass index (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, Pembrokeshire, 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 15 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 (16). The same experienced investigator took all anthropometric measurements at baseline and after 12 weeks of training.

Adipose and fat-free mass tissue localization. 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 (DXA) 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 the total abdominal FM (kg), and the area from the iliac crest to the feet to calculate the lower-body FM (kg). The same operator performed all analyses. Total visceral FM (kg) was estimated from the total abdominal FM on DXA, mean subcutaneous abdominal skinfold thickness and abdominal height, as previously described (16).

Preliminary visit-maximal exercise testing. $\text{VO}_{2\text{max}}$ was measured during a graded exhaustive exercise test on a cycle ergometer (Ergoline, Bitz, Germany). After a 3min warm-up at 30 W, power output was increased by $10 \text{ W} \cdot \text{min}^{-1}$ until the participant's exhaustion (the test lasted between 10 and 15 minutes after warm-up). Participants were strongly encouraged by the experimenters throughout the test to perform a maximal effort. Respiratory gases (VO_2 and VCO_2) were measured breath-by-breath through a mask connected to O_2 and CO_2 analyzers (Oxycon pro-Delta, Jaeger, Hoechberg, Germany). $\text{VO}_{2\text{max}}$ was determined as the highest oxygen uptake during a 15s period. Ventilatory parameters were averaged every 30s. Heart activity was monitored by ECG throughout the test, and heart rate (HR) recorded continuously. The achievement of $\text{VO}_{2\text{max}}$ criteria were: 1) oxygen uptake reaching a plateau with increasing work rate; 2) RER values higher than 1.1; and 3) peak heart rate (PHR) within 10% of the age-predicted maximal values (24). The peak power output (PPO), expressed in watts or $\text{watts} \cdot \text{kg}^{-1}$, was considered the highest power measured at $\text{VO}_{2\text{max}}$.

Training programs.

We made the choice to have similar energy expenditure (EE) between MICT and HIIT sessions and to have the same session duration between MICT and HIIT + RT, because lack of time is a barrier to exercise for people with overweight/obesity. Thus, before the beginning of the training programs, the EE induced by a HIIT session (20 min duration) was measured in four subjects using a Metamax 3B apparatus (Matsport, France), and the time needed to spend the same energy was calculated during the MICT session. The mean EE spent for each HIIT or MICT session was 180 ± 22 kcal and the time required for a MICT session was established to 40 minutes. Therefore, each HIIT + RT session lasted 40 minutes (20 min of HIIT and 20 min of RT).

Participants performed three exercise sessions per week for 12 weeks (total = 36 sessions). Sessions were generally in the morning on Monday, Wednesday and Friday, to allow a sufficient recovery period, and were supervised by an experienced physical activity instructor. Each session included also 5 min warm-up and 2 min cool-down periods, in addition to the formal training.

Moderate-intensity continuous training (MICT). The MICT session consisted of 40min at 55-60% of the participant's PPO performed continuously on a C-Max Club Fitness bike. During the first 6 weeks, the intensity was set at 55% of the PPO and was increased to 60% for the last 6 weeks to take into account the participants' aerobic fitness improvement. Each participant's resistance, pedal cadence (50-70 rpm), and power (watts) were controlled to reach the expected intensity.

High-intensity interval training (HIIT). The HIIT training program was based on the protocol by Maillard et al. (2016) (16), an attractive and feasible cycling program for postmenopausal women with overweight/obesity. The HIIT protocol consisted of repeated

cycles of sprinting/speeding for 8s followed by slow pedaling (20–30 rpm) for 12s on a WattBike pro Concept2 (with a freewheel and a double air and magnetic braking system). Resistance was very low to facilitate acceleration and limit bicycle-wheel inertia. Resistance was controlled to reach ~ 80% of each participant's PHR during the 20min session. All participants could complete the full 20min exercise program at this intensity after two or three sessions. HR was continuously monitored (A300, Polar, Finland) to control the intensity. Overall, the mean intensity during a HIIT session corresponded to $85 \pm 4\%$ of PHR.

High-intensity interval training and resistance training (HIIT + RT). HIIT was always performed before RT to normalize the concurrent training effects (25). The HIIT session was the same as for the HIIT alone group. The upper and lower body muscular strength was measured using the one-repetition maximum (1 RM) method with bench press and leg press exercises on UniversalTM weight machines, as previously described (26). Briefly, a warm-up of 5–10 repetitions at 40–60% of the perceived maximum was performed, followed by 3–5 repetitions at 60–80% of the perceived maximum. Three to four subsequent attempts were then made to determine the 1 RM for each exercise. Rest periods (3-5min) were introduced between lifts to ensure optimal recovery.

The RT program included two different training circuits with ten exercises/each and was based on the program by Marx et al. (27). Circuit 1 included leg press, bench press, knee extension, cable row, dumbbell calf raise, elbow flexion, abdominal muscle, triceps exercises with upper pulley, plank and bum exercises. Circuit 2 included knees extension, pullover, leg press, side raise with dumbbells, dumbbell calf raise, triceps exercises with upper pulley, hip thrust, chin rowing, and plank to upright row. Participants performed a single-set circuit, with a load of 8–12 repetitions at around 80% of 1RM, with 1- to 1.5min rest period between exercises. The workouts were individually supervised by the same certified personal trainer. When

participants achieved more than 12RM, the load was adjusted to remain in the planned intensity zone. Participant alternated between circuits every 3 weeks to minimize boredom and to create some variation in the exercise choice.

Resting metabolic rate (RMR) and substrate oxidation. Subjects arrived at the laboratory at 7.30 am after overnight fast (12h). Participants were asked to eat a similar dinner for the pre- and post-training session the evening before, and to avoid any kind of strenuous exercise the day before. The experiment was conducted in a ventilated room at a temperature of 19–20°C. RMR and substrate oxidation were determined from respiratory gases using a Metamax 3B apparatus (Matsport, France). Carbohydrate oxidation and FatOx were measured at rest, during moderate-intensity prolonged exercise, and during the recovery period. Exercise consisted in 40min of cycling at 55% of their PPO determined before and after training on a cycle ergometer (Ergoline, Bitz, Germany). Cadence was maintained between 60 and 70 rpm. HR was continuously monitored (A300, Polar, Finland). Resting gas exchange data were recorded for 10 minutes, with the subject sitting on the bicycle. The last 2min of gas exchange data from each stage were averaged to calculate VO_2 and VCO_2 that were then used to determine the RER ($\text{RER} = \text{VCO}_2/\text{VO}_2$). Recording was continued during the recovery period for 20 minutes. RMR assessment was considered valid in the presence of a minimum of 10min of steady state with less than 10% of fluctuations in oxygen consumption (VO_2). RMR ($\text{kcal}\cdot\text{day}^{-1}$) was calculated using the Weir equation (28), and substrate oxidation ($\text{g}\cdot\text{min}^{-1}$) was calculated using the Frayn's equations (29), as follows:

$$\text{RMR} = [(3.941 \times \text{VO}_2) + (1.1106 \times \text{VCO}_2)] \times 1440$$

$$\text{Carbohydrate (CHO) oxidation} = [(4.55 \times \text{VCO}_2) - (3.21 \times \text{VO}_2)]$$

$$\text{FatOx} = [(1.67 \times \text{VO}_2) - (1.67 \times \text{VCO}_2)]$$

Physical activity and dietary assessments. Participants were asked to maintain their normal levels of physical activity during the 12-week study period. Their usual weekly level of physical activity was determined at baseline and after 12 weeks using the French version of the GPAQ (23). They were also asked to maintain their normal eating habits for the study period. At baseline and at week 12 of training, each participant filled in a 7-day food-intake diary that was evaluated by a dietician using a nutrition analysis software program (Nutrilog®, Marans, France).

Biochemical Assays. Blood samples were taken the week before starting the training (pre-intervention) and then 2–4 days after the last exercise session (post-intervention), depending on the participants' availability and to avoid any potential effect of the last exercise session on the results. After overnight fasting, a cannula was inserted in the antecubital vein, and whole blood was collected in EDTA- and fluoride-containing vacutainers tubes. The plasma concentration of total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), and triglycerides (TG) was immediately measured, using a Synchron Clinical System UniCel DxC analyzer (Beckman Coulter, Brea, CA, USA) and a cholesterol oxidase method for TC (CHOL reagent), a direct homogeneous method for HDL-C (HDL-D reagent), and a lipase/glycerol kinase method for TG (GPO reagent). The low-density lipoprotein cholesterol (LDL-C) fraction was indirectly quantified using the equation described by Friedewald et al. (30). Plasma glucose concentration was immediately determined using the hexokinase method (UniCel DxC analyzer, Synchron). Plasma insulin concentration was measured by enzyme-linked immunosorbent assay from Sigma-Aldrich Insulin Elisa kit (Paris, France). HbA1c values were evaluated with a high-performance liquid chromatography (HPLC) Variant II analyzer equipped with the new 270-2101 NU Kit (Bio-Rad Laboratories, Hercules, CA, USA).

The HOMA-IR index was calculated using the formula: $\text{HOMA-IR} = [\text{Fasting glucose (mmol.L}^{-1}) \times \text{Fasting insulin (}\mu\text{U.mL}^{-1})] / 22.5$.

Statistical analyses. Before the study start, the sample size required for a statistical power of 80% was calculated based on previous results on FM loss after HIIT training in women (31). 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. (32), for FM loss could be detected with seven women per group. Our sample was increased to ten women per group at the beginning of the intervention to take into account participants lost to follow-up.

All statistical analyses were carried out with the STATISTICA version 12.00 software (StatSoft Inc., Tulsa, OK, USA). Data are presented as the mean \pm standard deviation (SD). The data normal distribution was tested 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 \times time interactions. When a significant effect was found, post-hoc multiple comparisons were performed using the Newman-Keuls test. The effect size was reported when significant main or interaction effects were detected. The effect size was assessed using the partial eta-squared (η^2) and ranked as follows: ~ 0.01 = small effect, ~ 0.06 = moderate effect, ≥ 0.14 = large effect (33). Baseline values and changes between baseline and the study end [delta change: $(12 \text{ weeks} - \text{baseline} / \text{baseline}) \times 100$] were also compared among groups, using one-way ANOVA. Differences with a P-value ≤ 0.05 were considered statistically significant.

RESULTS

Participants' Characteristics. Of the 30 postmenopausal females randomized in the three training groups (n=10/group), 27 were retained for the analysis (n=3 left the study for different reasons listed in Fig. 1). At baseline, the mean age was not significantly different among groups (MICT: 67.1 ± 7.2 y; HIIT: 59.9 ± 5.9 y; HIIT + RT: 61.1 ± 5.4 y) as well as total body weight (MICT: 80.4 ± 7.1 kg; HIIT: 81.6 ± 12.7 kg; HIIT + RT: 75.6 ± 8.9 kg) and total FM (MICT: 30.6 ± 5.3 kg; HIIT: 27.6 ± 10.7 kg; HIIT + RT: 28.1 ± 5.8 kg) (Table 1). The participants' compliance with the training program was $97\% \pm 1\%$. No adverse event was reported during testing or training in any group.

Habitual Energy Intake and Energy Expenditure. Physical activity levels (GPAQ scores) were comparable between pre- and post-training in all groups. For all participants, the daily energy intake and the percentage of energy contribution from macronutrients did not significantly change during the intervention period. No significant dietary intake difference was observed in the three groups at baseline and after 3 months (mean values: $1563 \text{ kcal} \pm 276$ pre-intervention vs $1557 \text{ kcal} \pm 255$ post-intervention).

Aerobic Fitness. $\text{VO}_{2\text{max}}$ ($\text{ml} \cdot \text{min} \cdot \text{kg}^{-1}$) and PPO (watts or $\text{watts} \cdot \text{kg}^{-1}$) were not different in the three groups at baseline (Table 1). Overall, aerobic fitness ($\text{VO}_{2\text{max}}$ and PPO) significantly increased after the 12-week intervention (time effect, $p < 0.0001$, $\eta^2 = 0.71$). A group effect was noted concerning $\text{VO}_{2\text{max}}$ ($\text{ml} \cdot \text{min} \cdot \text{kg}^{-1}$) and PPO (when expressed in watts, but not in $\text{watts} \cdot \text{kg}^{-1}$) with lower values in the MICT group than in the HIIT and HIIT + RT groups ($p = 0.042$, $\eta^2 = 0.24$).

Anthropometric Measurements and Whole Body Composition. Overall, body weight (kg), total FM (kg) and waist and hip circumferences (cm) were significantly decreased after the 12-

week intervention (time effect, $p=0.02$, $\eta^2 = 0.21$; $p=0.002$, $\eta^2 = 0.34$; $p=0.01$, $\eta^2 = 0.44$; $p = 0.001$, $\eta^2 = 0.37$, respectively) (Table 1). When the absolute values were expressed in percentage (%), total FM decreased and FFM and muscle mass increased only in the HIIT + RT group ($p = 0.02$, $\eta^2 = 0.20$). The percentage of total FM loss (kg) was higher (but not significant, $p=0.07$) in the HIIT and HIIT + RT groups than in the MICT group ($-3.06 \% \pm 4.2$, $-4.43 \% \pm 3.1$ and $-0.05 \% \pm 3.9$ respectively), but with a large size effect ($\eta^2 = 0.19$) (Fig. 2).

Abdominal and Visceral Fat Mass. Baseline total abdominal (kg) and visceral FM (kg) were similar in the three groups. At the end of the training period, total abdominal FM (kg) was significantly reduced only in the HIIT and HIIT+RT groups (group \times time interaction; $p < 0.008$, $\eta^2 = 0.48$) (Table 1). When expressed as delta change values, abdominal and visceral FM changes were reduced only in the HIIT and HIIT + RT groups and were significantly different from MICT (Fig. 2). No significant difference was noted after training between the HIIT and HIIT + RT groups.

Resting Metabolic Rate, Substrate Oxidation and Energy Expenditure. None of the training modes altered RMR ($\text{kcal}\cdot\text{day}^{-1}$) and substrate oxidation at rest (Table 2). Overall, all training programs increased FatOx during moderate intensity exercise (expressed as percentage of EE or $\text{g}\cdot\text{min}^{-1}$) and during the recovery period (time effect, $p < 10^{-4}$, $\eta^2 = 0.47$) (Fig. 3). Concomitantly, carbohydrate oxidation decreased. No group effect was noted. EE (kcal) during exercise and during recovery did not change between pre- and post-intervention in any group.

Metabolic Profile. The lipid profile and glycemic parameters at baseline and after the 12-week intervention are listed in Table 3. Overall, plasma TG levels decreased after the intervention (time effect, $p=0.02$, $\eta^2 = 0.22$), without any group effect or group \times time interaction. Whatever

the training mode, TC, HDL-C, and LDL-C levels did not change. Glycemia, insulinemia, HbA1c, and HOMA-IR were not modified by the intervention.

DISCUSSION

The aim of this study was to compare the body composition and FatOx changes induced by a 12-week MICT, HIIT or HIIT + RT intervention in postmenopausal women with overweight or obesity. All three modalities improved body composition (body weight, FM loss), but HIIT (alone and with RT) led to a greater percentage of FM loss. Moreover, abdominal and visceral FM (%) were only reduced in the HIIT and HIIT + RT groups, and were significantly different from MICT. Our results also indicate that HIIT-induced total or (intra)-abdominal FM losses were not related to higher FatOx during moderate intensity exercise or during the 20min post-exercise period.

Physical activity is recommended in the framework of weight management programs to prevent weight gain, to induce weight loss, and to avoid weight regain after weight loss. Indeed, exercise on its own may generate significant weight and FM loss (10) with beneficial effects on health (11). Furthermore, (intra)-abdominal FM reduction is of interest due to FM association with CVD risks (34). The current international guidelines generally suggest endurance training as the best strategy for weight loss and FM reduction in both sexes. In the last position stand by the American College of Sports Medicine (ACSM) (11), moderate intensity physical activity (between 150 and 250 min.week⁻¹) is recommended for preventing weight gain, and more exercise for providing significant weight loss. Recent evidence suggests that HIIT can be a time-efficient strategy to decrease whole-body and (intra)-abdominal FM in sedentary individuals with overweight/obesity (15, 35). In their meta-analysis, Wewege et al.

evaluated the effect of HIIT and MICT on weight and FM changes in individuals with overweight and obesity (35). They found that both HIIT and MICT programs improved FM and waist circumference, even in the absence of body weight changes. They also showed that HIIT and MICT were similarly efficient, but that HIIT training required ~40% less time commitment. The meta-analysis by Maillard et al. (2018) focused on HIIT effects on whole-body and (intra)-abdominal FM loss in individuals with normal weight and with overweight/obesity. The authors confirmed that HIIT is a time-efficient strategy to decrease not only whole-body FM, but also abdominal and visceral FM (15). On the other hand, results were less convincing in postmenopausal women. Indeed, only three studies have evaluated the effects of HIIT on body composition in this population (16, 36, 37), and only one showed a positive effect of HIIT on total and (intra)-abdominal FM loss (16). To our knowledge, no study is available on the effects of HIIT + RT on body composition in postmenopausal women.

Our results indicate that MICT, HIIT and HIIT + RT programs (3 sessions.week⁻¹, 12 weeks) decrease body weight, waist and hip circumferences and whole-body FM in postmenopausal women with overweight/obesity. This confirms the conclusions of the two previously mentioned meta-analyses. However, when expressed as delta change values (post-pre/pre × 100), our study showed that in post-menopausal women, FM losses were significantly higher in the HIIT and HIIT + RT (-3.1 kg and -4.4 kg, respectively) than in the MICT group (-0.1 kg). ~~Conversely, the meta-analysis by Wewege et al. found that HIIT and MICT were similarly effective (35).~~ Compared with the three studies on postmenopausal women and HIIT-induced body composition changes, our results are similar to those of the ~~meta-analysis~~ study performed by Maillard et al. (16), but in contradiction with those reported by Mandrup et al. (36) and Steckling et al. (37) who did not detect any HIIT effect on total FM. These discrepancies could be explained by the different exercise modalities (14). Indeed, we used the same HIIT protocol

as Maillard et al. (16) (*i.e.*, 60 x 8s at 80-90% of PHR, 12s active recovery), whereas Mandrup et al. and Steckling et al. used three blocks of varying intervals with multiple periods of maximum performance for 1h (36), and 4x 4 min 90%HRmax + 3 min active recovery 70 HRmax (37), respectively. Furthermore, in the study by Mandrup et al. (36), women did not have obesity, and it is well known that HIIT-induced FM loss is more effective in individuals with obesity (15). Finally, Mandrup et al. and Steckling et al. did not evaluate dietary intakes and/or physical activity levels during their interventions. A spontaneous increase of energy intake or a decrease in total energy expenditure could explain the absence of effect on FM in these works. In our study, the levels of physical activity and total energy intake remained unchanged, strengthening our conclusion that HIIT is an efficient strategy to lose body weight and FM in postmenopausal women with overweight/obesity.

At baseline the plasma values were within the normal ranges, and this may explain why training did not modify the lipid profile and glucose homeostasis. Although our participants did not have hypertriglyceridemia (defined as a TG concentration higher than 150 mg.dL⁻¹ or 1.7 mmol.L⁻¹) and higher risk of cardiovascular disease (38), we observed a decrease of TG levels over time, but without difference between groups.

Our results also demonstrate that only HIIT and HIIT + RT significantly decreased (intra)-abdominal FM (*i.e.*, subcutaneous FM from the abdomen and visceral FM). It is worth noting that despite exercising almost half the time compared with the MICT group (20min *vs.* 40min), women in the HIIT group lost 7.4% of total abdominal FM and 3.2% of visceral FM. Conversely, no change was observed in the MICT group, and the total abdominal FM loss in the HIIT + RT group was not higher than in the HIIT group, despite the longer exercise time (40min). These results confirm the meta-analysis by Maillard et al. (15) showing that HIIT significantly reduces abdominal ($p = 0.007$) and visceral ($p = 0.018$) FM, with no difference between men and women.

408

409 The mechanisms underlying HIIT-induced total and (intra)-abdominal FM loss are still not
410 completely elucidated, but might partly be explained by significant higher lipolysis during
411 exercise and greater post-exercise total and abdominal fat oxidation (15). These adaptations are
412 probably facilitated by the higher excess post-exercise oxygen consumption observed after
413 exercises performed above 75% $\text{VO}_{2\text{max}}$ (39). Indeed, lipid oxidation decreases above 40–
414 50% $\text{VO}_{2\text{max}}$, but higher intensities still induce significant lipolysis from β -adrenergic receptors
415 stimulation. Thus, HIIT can increase plasma FFA levels during exercise and then promote
416 greater fat oxidation during the recovery period. This adaptation could explain why people who
417 are engaged in regular vigorous physical activities are less fat than those who never take part
418 in such activities (32). After an acute session of HIIT, MICT or High-Intensity Resistance
419 Training (HIRT) performed by recreationally active women, Wingfield et al. (40) demonstrated
420 lower RER in the HIIT than the MICT and HIRT groups (30min and 60min of recovery),
421 confirming the higher post-exercise fat oxidation in HIIT.

422 It is now recognized that higher amount of visceral/abdominal fat is lost in HIIT compared with
423 MICT programs (15). As the content of β -adrenergic receptors is higher in intra-abdominal
424 than in subcutaneous adipose tissue (41), the higher HIIT-induced sympathetic nervous system
425 stimulation could explain the larger reliance on visceral FM. Moreover, visceral adipose tissue
426 is characterized by smaller adipocytes, greater lipolytic activity, and lower responses to the
427 antilipolytic effects of insulin compared with subcutaneous depots (42). Lastly, subcutaneous
428 or (intra)-abdominal FM losses may also be facilitated by HIIT-induced PGC1- α transcription
429 stimulation. Shirvany and Arabzadeh (43) recently proposed that the increase of PGC1- α
430 expression in muscle tissue may induce endocrine effects on adipose tissue and adipokines,
431 leading to higher fat oxidation. Altogether, this may explain why HIIT promotes greater
432 abdominal and visceral FM losses compared with the traditional MICT.

433

434 We also made the hypothesis that HIIT, compared with MICT, might increase fat oxidation at
435 rest and during free-living physical activities (walking, cycling, gardening...) by altering
436 metabolic flexibility. To test this hypothesis, we determined fat oxidation before and after the
437 training period at rest and during a moderate-intensity exercise (40min at 50% of PPO) and
438 during the 20min recovery time. None of the training modes altered RMR (kcal.day⁻¹) and
439 substrate oxidation at rest. As expected, FatOx levels were significantly increased, but without
440 any difference among the three groups. The mean FatOx change measured after training (~
441 +32%) was similar to what reported by other studies using the same amount of activity (12
442 weeks/3 times per week). For example, Talanian et al. (44) showed an increase of 36% in
443 whole-body fat oxidation during a 1 hour-cycling performed at 60% VO₂peak after a HIIT
444 program (two weeks, 7 sessions including 10 x 4min at 90%VO₂peak with 2min recovery) in
445 young sedentary women with overweight or obesity. Our study, which was the first to compare
446 FatOx in postmenopausal women with overweight/obesity at rest, during moderate intensity
447 physical activity and during the recovery period after three different training programs, did not
448 find a greater impact of HIIT on metabolic flexibility and no correlation appeared between
449 FatOx and total or (intra)-abdominal FM loss. Thus, the hypothesis of a greater FatOx after
450 HIIT programs was not verified in postmenopausal women and cannot explain the larger
451 adipose tissue reduction.

452 Our study also examined the effects of HIIT combined with RT on body composition
453 in postmenopausal women. An increase of muscle mass after HIIT + RT program might
454 enhance RMR and therefore, the 24h EE. The 24h EE increase could favor in turn body FM
455 loss because a part of the EE is provided through lipid oxidation. The recent meta-analysis by
456 Sabag et al. (45) shows that HIIT + RT leads to similar muscle mass gain (hypertrophy) as RT
457 alone. Furthermore, concurrent HIIT and RT does not negatively affect muscle mass gain.

However, these results should be considered with caution because this meta-analysis concerned 263 young participants (18-34 years) among whom only 33 were inactive or untrained. Thus, these conclusions are probably more adapted to young athletes than to individuals with overweight/obesity.

In our study, loss of total and of (intra)-abdominal FM was not significantly different in the HIIT and HIIT + RT groups. In fact the lack of muscle mass gain (kg) in the HIIT + RT group could explain this finding. Indeed, the duration or volume and/or intensity of the RT protocols in our study could have been insufficient to induce a significant increase of muscle mass. It is not possible to compare our results with the literature because this is the first study dealing with HIIT + RT effects on body composition in postmenopausal women. However, three studies on endurance training + RT have been performed. For example, Martin et al. (46) did not find any effect of HIIT or combined training (aerobic + resistance exercises) on total body fat (%) and muscle mass index ($\text{kg}\cdot\text{m}^{-2}$) in postmenopausal women after a 12-week intervention. Davidson et al. found greater total, abdominal and visceral FM losses following a 6-month MICT + RT program (30min walking at 65-70% $\text{VO}_{2\text{max}}$ + 9 resistance exercises, 3 d·wk⁻¹) compared with MICT or RT alone in older adults with obesity (42). These adaptations were associated with significant skeletal muscle gain, which may confirm the potential link between muscle mass gain and FM loss after RT. Finally, Nunes et al. (47) demonstrated a decrease of whole-body FM (-0.3%) after a 12-week MICT + RT program (60 min of walking at 70% of PHR and resistance exercises at 70% of one repetition maximum; 3 d·wk⁻¹) in postmenopausal women. However, they did give any information on FFM and muscle mass changes. Additional studies using different RT modalities (duration, volume, intensity) are probably needed to determine whether RT alone or together with HIIT might promote muscle mass gain in postmenopausal women, leading to significant FM loss.

One of the limitations of this study concerns the groups tested. Indeed, it is difficult to conclude about a potential effect of HIIT + RT without knowing whether the RT intervention alone could induce positive adaptations. Thus, to determine whether the RT intervention can favor muscle adaptations, it would have been interesting to add also a RT group. We decided to have the same session duration for the MICT and HIIT + RT programs since a lack of time has been cited as a barrier for overweight/obese people. This limited the amount of RT work and this might not have been enough to induce muscle mass gain, especially in women. Furthermore, we can also hypothesize that the HIIT + RT combination may alter muscle adaptations by inducing molecular pathway interferences between training modalities. Indeed, it has been suggested that endurance training performed before RT negatively affects RT adaptations through inhibition of the AKT-mTOR pathway activation by AMPK (25). Finally, a last group, MICT+ RT, might induce different adaptations but appeared to us less attractive due to the duration of the session (≥ 1 hour).

In conclusion a 12-week cycling MICT or HIIT \pm RT program (3 sessions.week⁻¹) can be proposed to non-dieting postmenopausal women with overweight/obesity to decrease weight and whole-body FM. HIIT programs seems more successful in reducing (intra)-abdominal FM than the traditional moderate continuous training. As the level of subcutaneous abdominal and visceral FM is correlated with the CVD risk, this study confirms that HIIT is an effective and time-efficient modality to reduce such risk in this population. HIIT + RT did not potentiate this effect, but improved body composition by increasing the percentage of FFM, including muscle mass. HIIT-induced greater total and (intra)-abdominal FM loss is not related to changes in metabolic flexibility at rest, during moderate intensity exercise, or during the recovery period. Additional studies are needed to better understand the underlying mechanisms

of HIIT-induced FM loss and to determine whether the concomitant muscle mass gain induced by RT potentiates these adaptations.

Acknowledgements

The authors want to thank all the study participants for their kind collaboration, the nurse, Anne Misson and Cyril Chomarot and Renaud Laurent for their kind assistance during the training sessions and their help in data collection.

Conflict of interest

The results of this study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MD was the PhD student on the MATISSE study and designed and supervised the different training modalities. She met all participants, collected and analyzed all heart rate monitoring data during training, supervised training sessions, collected and analyzed the data obtained for RMR and during the prolonged exercise (FAT oxidation measurements), carried out the anthropometric measurements and wrote the first and subsequent drafts of the paper. MR was a co-investigator, and assisted with the study design. CM, PB and MD, physicians, assisted with the study design, and oversaw the medical aspects of the study. AB and FM were sport instructors, supervised training sessions with MD, and helped collecting data for RMR and

during the prolonged exercise (FAT oxidation measurements). NB conceived the study idea, was responsible for the overall study design, and for monitoring data collection. BP was responsible for all statistical analyses. All authors read and approved the final manuscript.

Funding

The MATISSE Study was funded by the University of Clermont Auvergne (AME2P laboratory). The funders had no role in the study design, the collection, analysis, and interpretation of data, the writing of the manuscript, and the decision to submit the article for publication.

BIBLIOGRAPHY

1. Kanaley JA, Sames C, Swisher L, et al. Abdominal fat distribution in pre- and postmenopausal women: The impact of physical activity, age, and menopausal status. *Metab Clin Exp*. 2001;50(8):976–82.
2. Ley CJ, Lees B, Stevenson JC. Sex- and menopause-associated changes in body-fat distribution. *Am J Clin Nutr*. 1992;55(5):950–4.
3. Svendsen OL, Hassager C, Christiansen C. Age- and menopause-associated variations in body composition and fat distribution in healthy women as measured by dual-energy X-ray absorptiometry. *Metab Clin Exp*. 1995;44(3):369–73.
4. Trémollières FA, Pouilles JM, Ribot CA. Relative influence of age and menopause on total and regional body composition changes in postmenopausal women. *Am J Obstet Gynecol*. 1996;175(6):1594–600.
5. Palmer BF, Clegg DJ. The sexual dimorphism of obesity. *Molecular and Cellular Endocrinology*. 2015;402:113–9.
6. Hodson L, Harnden K, Banerjee R, et al. Lower resting and total energy expenditure in postmenopausal compared with premenopausal women matched for abdominal obesity. *J Nutr Sci*. 2014;3:e3.
7. Abildgaard J, Pedersen AT, Green CJ, et al. Menopause is associated with decreased whole body fat oxidation during exercise. *Am J Physiol Endocrinol Metab*. 2013;304(11):E1227–1236.
8. Lovejoy JC, Champagne CM, Jonge L de, Xie H, Smith SR. Increased visceral fat and decreased energy expenditure during the menopausal transition. *International Journal of Obesity*. 2008;32(6):949–58.
9. Gavin KM, Kohrt WM, Klemm DJ, Melanson EL. Modulation of Energy Expenditure by Estrogens and Exercise in Women. *Exerc Sport Sci Rev*. 2018;46(4):232–9.
10. Verheggen RJHM, Maessen MFH, Green DJ, Hermus ARMM, Hopman MTE, Thijssen DHT. A systematic review and meta-analysis on the effects of exercise training versus hypocaloric diet: distinct effects on body weight and visceral adipose tissue. *Obesity Reviews*. 2016;17(8):664–90.
11. 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(2):459–71.
12. Zhang H, Tong TK, Qiu W, et al. Comparable Effects of High-Intensity Interval Training and Prolonged Continuous Exercise Training on Abdominal Visceral Fat Reduction in Obese Young Women. *J Diabetes Res*. 2017;2017:5071740.
13. Frank LL, Sorensen BE, Yasui Y, et al. Effects of exercise on metabolic risk variables in overweight postmenopausal women: a randomized clinical trial. *Obes Res*. 2005;13(3):615–25.

- 581 14. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with
582 lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *Br J*
583 *Sports Med.* 2014;48(16):1227–34.
- 584 15. Maillard F, Pereira B, Boisseau N. Effect of High-Intensity Interval Training on Total,
585 Abdominal and Visceral Fat Mass: A Meta-Analysis. *Sports Med.* 2018;48(2):269–88.
- 586 16. Maillard F, Rousset S, Pereira B, et al. High-intensity interval training reduces abdominal
587 fat mass in postmenopausal women with type 2 diabetes. *Diabetes Metab.* 2016;42(6):433–
588 41.
- 589 17. Romero-Arenas S, Martínez-Pascual M, Alcaraz PE. Impact of resistance circuit training
590 on neuromuscular, cardiorespiratory and body composition adaptations in the elderly.
591 *Aging Dis.* 2013;4(5):256–63.
- 592 18. Willis LH, Slentz CA, Bateman LA, et al. Effects of aerobic and/or resistance training on
593 body mass and fat mass in overweight or obese adults. *J Appl Physiol.* 2012;113(12):1831–
594 7.
- 595 19. Robinson MM, Dasari S, Konopka AR, et al. Enhanced Protein Translation Underlies
596 Improved Metabolic and Physical Adaptations to Different Exercise Training Modes in
597 Young and Old Humans. *Cell Metab.* 2017;25(3):581–92.
- 598 20. Picó-Sirvent I, Aracil-Marco A, Pastor D, Moya-Ramón M. Effects of a Combined High-
599 Intensity Interval Training and Resistance Training Program in Patients Awaiting Bariatric
600 Surgery: A Pilot Study [Internet]. *Sports (Basel).* 2019;7(3) doi:10.3390/sports7030072.
- 601 21. Astorino TA, Schubert MM, Palumbo E, Stirling D, McMillan DW. Effect of two doses of
602 interval training on maximal fat oxidation in sedentary women. *Med Sci Sports Exerc.*
603 2013;45(10):1878–86.
- 604 22. Lemmer L, Fm I, As R, et al. Effect of strength training on resting metabolic rate and
605 physical activity: age and gender comparisons. *Med Sci Sports Exerc.* 2001;33(4):532–41.
- 606 23. Hallal PC, Andersen LB, Bull FC, Guthold R, Haskell W, Ekelund U. Global physical
607 activity levels: surveillance progress, pitfalls, and prospects. *The Lancet.*
608 2012;380(9838):247–57.
- 609 24. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. *Journal*
610 *of the American College of Cardiology.* 2001;37(1):153–6.
- 611 25. Methenitis S. A Brief Review on Concurrent Training: From Laboratory to the Field
612 [Internet]. *Sports (Basel).* 2018;6(4) doi:10.3390/sports6040127.
- 613 26. Knutzen K, Brilla L, Caine D. Validity of 1RM Prediction Equations for Older Adults. *The*
614 *Journal of Strength & Conditioning Research.* 1999;13(3):242.
- 615 27. Marx JO, Ratamess NA, Nindl BC, et al. Low-volume circuit versus high-volume
616 periodized resistance training in women. *Med Sci Sports Exerc.* 2001;33(4):635–43.
- 617 28. Weir JB. New methods for calculating metabolic rate with special reference to protein
618 metabolism. 1949. *Nutrition.* 1990;6(3):213–21.

- 619 29. Frayn KN. Calculation of substrate oxidation rates in vivo from gaseous exchange. *J Appl*
620 *Physiol Respir Environ Exerc Physiol*. 1983;55(2):628–34.
- 621 30. Friedewald WT, Levy RI, Fredrickson DS. Estimation of the concentration of low-density
622 lipoprotein cholesterol in plasma, without use of the preparative ultracentrifuge. *Clin*
623 *Chem*. 1972;18(6):499–502.
- 624 31. Trapp EG, Chisholm DJ, Freund J, Boutcher SH. The effects of high-intensity intermittent
625 exercise training on fat loss and fasting insulin levels of young women. *Int J Obes (Lond)*.
626 2008;32(4):684–91.
- 627 32. Tremblay A, Simoneau J-A, Bouchard C. Impact of exercise intensity on body fatness and
628 skeletal muscle metabolism. *Metabolism*. 1994;43(7):814–8.
- 629 33. Cohen J. A power primer. *Psychol Bull*. 1992;112(1):155–9.
- 630 34. Sam S. Differential effect of subcutaneous abdominal and visceral adipose tissue on
631 cardiometabolic risk [Internet]. *Horm Mol Biol Clin Investig*. 2018;33(1)
632 doi:doi:10.1515/hmbci-2018-0014.
- 633 35. Wewege M, Berg R van den, Ward RE, Keech A. The effects of high-intensity interval
634 training vs. moderate-intensity continuous training on body composition in overweight and
635 obese adults: a systematic review and meta-analysis. *Obesity Reviews*. [date
636 unknown];18(6):635–46.
- 637 36. Mandrup CM, Egelund J, Nyberg M, et al. Effects of high-intensity training on
638 cardiovascular risk factors in premenopausal and postmenopausal women. *Am J Obstet*
639 *Gynecol*. 2017;216(4):384.e1-384.e11.
- 640 37. Steckling FM, Farinha JB, Figueiredo F da C, et al. High-intensity interval training
641 improves inflammatory and adipokine profiles in postmenopausal women with metabolic
642 syndrome. *Arch Physiol Biochem*. 2019;125(1):85–91.
- 643 38. Christian JB, Arondekar B, Buysman EK, Jacobson TA, Snipes RG, Horwitz RI.
644 Determining Triglyceride Reductions Needed for Clinical Impact in Severe
645 Hypertriglyceridemia. *The American Journal of Medicine*. 2014;127(1):36-44.e1.
- 646 39. Bahr R, Sejersted OM. Effect of intensity of exercise on excess postexercise O₂
647 consumption. *Metab Clin Exp*. 1991;40(8):836–41.
- 648 40. Wingfield HL, Smith-Ryan AE, Melvin MN, et al. The acute effect of exercise modality
649 and nutrition manipulations on post-exercise resting energy expenditure and respiratory
650 exchange ratio in women: a randomized trial. *Sports Med Open*. 2015;1(1):11.
- 651 41. Rebuffé-Scrive M, Anderson B, Olbe L, Björntorp P. Metabolism of adipose tissue in
652 intraabdominal depots in severely obese men and women. *Metab Clin Exp*.
653 1990;39(10):1021–5.
- 654 42. Davidson LE, Hudson R, Kilpatrick K, et al. Effects of Exercise Modality on Insulin
655 Resistance and Functional Limitation in Older Adults: A Randomized Controlled Trial.
656 *Arch Intern Med*. 2009;169(2):122–31.

43. Shirvani H, Arabzadeh E. Metabolic cross-talk between skeletal muscle and adipose tissue in high-intensity interval training vs. moderate-intensity continuous training by regulation of PGC-1 α [Internet]. *Eat Weight Disord.* 2018; doi:10.1007/s40519-018-0491-4.
44. Talanian JL, Galloway SDR, Heigenhauser GJF, Bonen A, Spriet LL. Two weeks of high-intensity aerobic interval training increases the capacity for fat oxidation during exercise in women. *J Appl Physiol.* 2007;102(4):1439–47.
45. Sabag A, Najafi A, Michael S, Esgin T, Halaki M, Hackett D. The compatibility of concurrent high intensity interval training and resistance training for muscular strength and hypertrophy: a systematic review and meta-analysis. *J Sports Sci.* 2018;36(21):2472–83.
46. Martins FM, de Paula Souza A, Nunes PRP, et al. High-intensity body weight training is comparable to combined training in changes in muscle mass, physical performance, inflammatory markers and metabolic health in postmenopausal women at high risk for type 2 diabetes mellitus: A randomized controlled clinical trial. *Exp Gerontol.* 2018;107:108–15.
47. Nunes PRP, Martins FM, Souza AP, et al. Effect of high-intensity interval training on body composition and inflammatory markers in obese postmenopausal women: a randomized controlled trial. *Menopause.* 2019;26(3):256–64.

Figure Legends

Figure 1: Flowchart of participants' recruitment.

HIIT: high-intensity interval training; MICT: moderate-intensity continuous training; HIIT + RT: high-intensity interval training + resistance training.

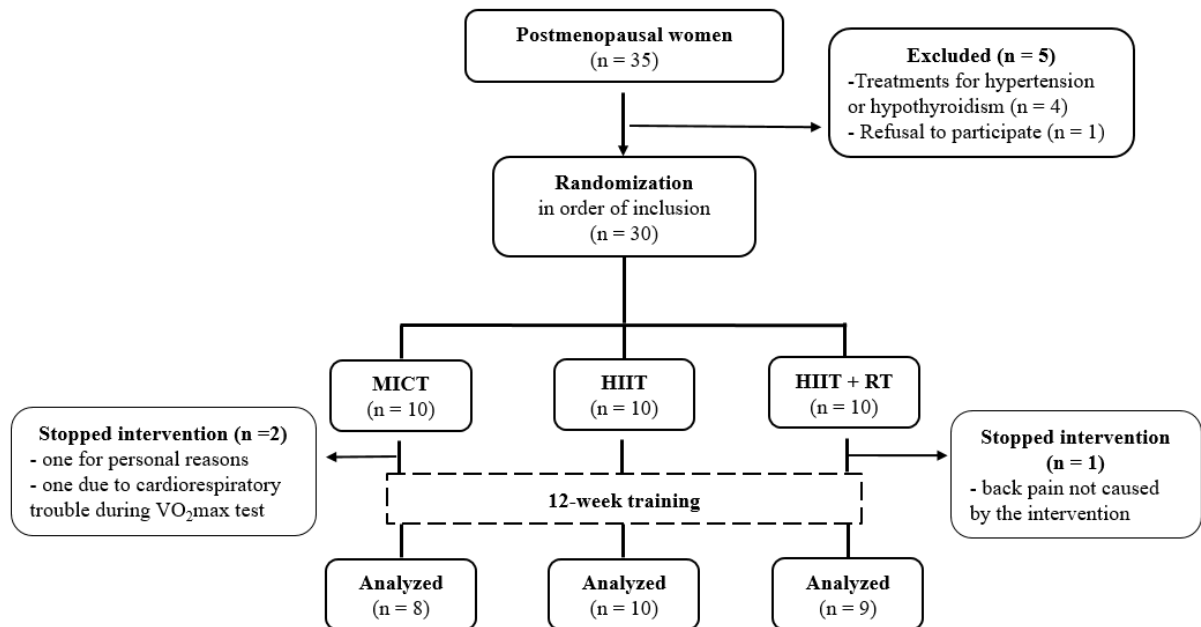


Figure 2: Body composition changes (based on dual-energy X-ray absorptiometry imaging) between baseline and the end of the 12-week training program in the MICT (n = 8), HIIT (n = 10) and HIIT + RT (n = 9) groups. Data are the mean \pm SD. MICT: moderate-intensity continuous training; HIIT: high-intensity interval training; HIIT + RT: high-intensity interval training + resistance training; FM: fat mass; delta change (%) = [(12 weeks – baseline/baseline) \times 100].
#: $p \leq 0.01$: HIIT + RT vs. MICT group; \$: $p \leq 0.01$: HIIT vs. MICT group.

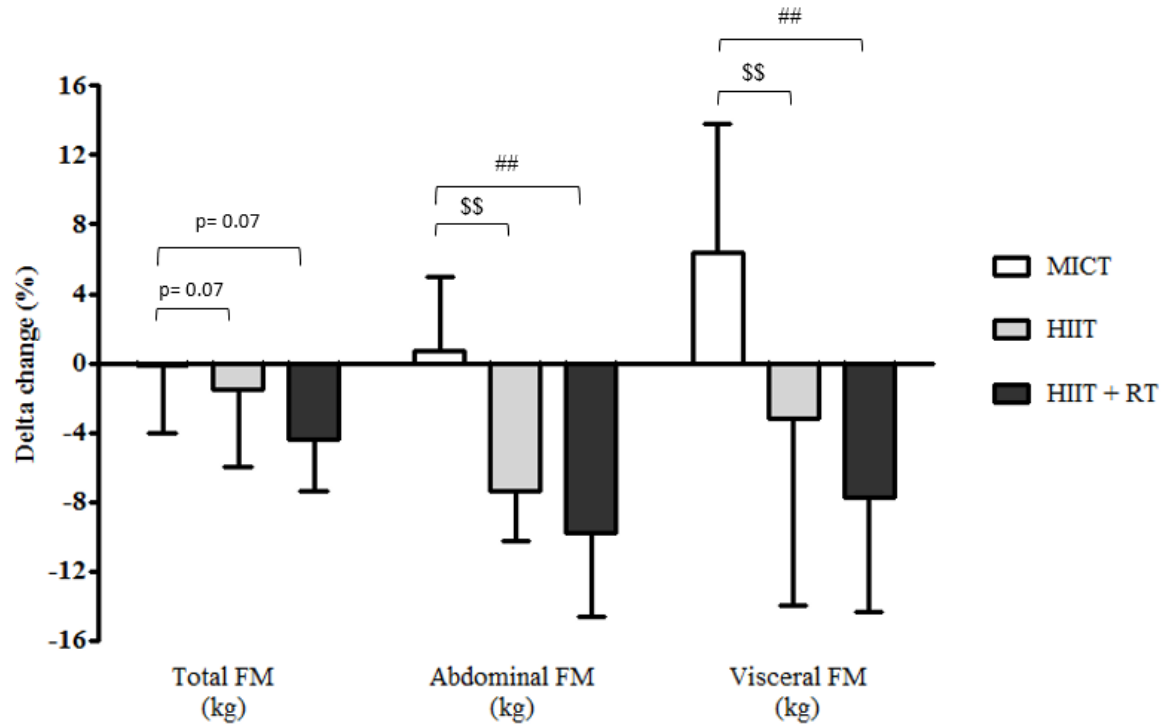
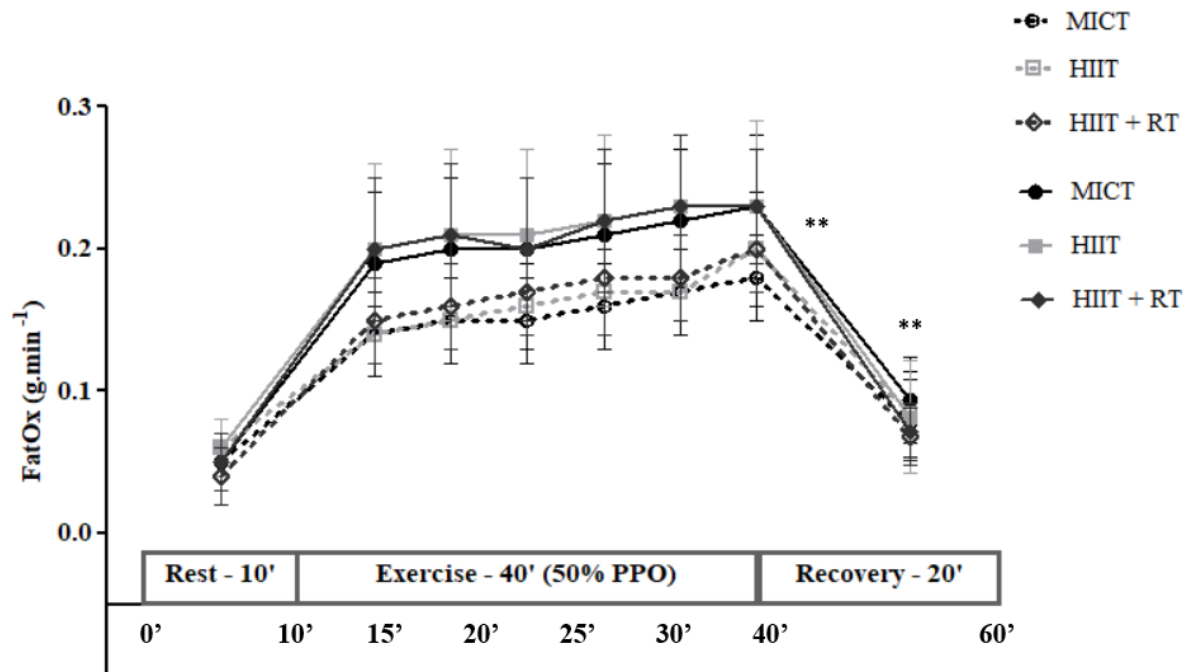


Figure 3: Fat oxidation (FatOx, g.min⁻¹) at rest, during exercise (50% of PPO) and during the 20min recovery in the MICT (n = 8), HIIT (n = 10) and HIIT + RT (n = 9) groups at baseline and after the 12-week intervention. Data are the mean \pm SD. The values at rest correspond to the mean of the last 5 minutes. The values during the recovery period correspond to the mean of the 20min post-exercise period. Six values are presented for the cycling exercise period (at 15, 20, 25, 30, 35 and 40min of exercise).

***: time effect (pre- vs post-intervention), $p \leq 0.005$.

MICT: moderate-intensity continuous training; HIIT: high-intensity interval training; HIIT + RT: high-intensity interval training + resistance training.



	MICT		HIIT		HIIT +RT		ANOVA (<i>p</i>)		
	Pre	Post	Pre	Post	Pre	Post	η^2	<i>G</i>	<i>T</i>
BMI (kg.m ²)	31.2 ± 3.0	30.9 ± 2.8	31.5 ± 4.3	31.1 ± 4.4	31.4 ± 4.0	31.1 ± 3.7	0.99 0.00	0.02 0.21	0.98 0.00
Waist circumference (cm)	100.8 ± 5.4	99.2 ± 6.0	100.9 ± 9.3	97.1 ± 8.8	101.4 ± 10.0	98.8 ± 10.8	0.91 0.00	0.01 0.44	0.44 0.09
Hip circumference (cm)	109.7 ± 6.6	107.2 ± 7.3	110.1 ± 9.1	107.8 ± 7.6	106.3 ± 9.6	104.3 ± 8.1	0.58 0.04	0.001 0.44	0.97 0.09
Body weight (kg)	80.5 ± 7.1	79.7 ± 7.3	81.6 ± 12.7	80.8 ± 12.9	75.6 ± 8.9	74.9 ± 8.0	0.41 0.07	0.02 0.21	0.95 0.00
Total FM (kg)	30.7 ± 5.3	30.7 ± 5.4	27.7 ± 10.7	27.1 ± 10.6	28.1 ± 1.9	26.8 ± 1.8	0.50 0.06	0.002 0.34	0.06 0.21
Total FM (%)	37.9 ± 4.0	38.3 ± 4.4	33.7 ± 11.6	33.4 ± 11.5	36.9 ± 3.8	35.5 ± 3.8**	0.66 0.03	0.02 0.20	0.03 0.25
Total FFM (kg)	49.8 ± 3.7	49.1 ± 4.0	45.1 ± 15.6	44.9 ± 15.5	47.6 ± 4.2	48.1 ± 3.6	0.41 0.07	0.88 0.00	0.19 0.13
Total FFM (%)	62.1 ± 4.0	61.7 ± 4.4	56.3 ± 19.3	56.7 ± 19.3	64.1 ± 3.8	64.5 ± 3.9**	0.67 0.03	0.02 0.20	0.03 0.25
Muscle mass (kg)	47.7 ± 3.6	47.1 ± 3.9	43.3 ± 14.9	43.1 ± 14.9	45.7 ± 4.0	46.1 ± 3.3	0.44 0.07	0.79 0.00	0.29 0.10

Muscle mass (%)	59.5 ± 3.9	59.2 ± 4.2	54.0 ± 18.5	54.3 ± 18.6	60.7 ± 3.8	62.0 ± 3.9**	0.61 0.04	0.02 0.19	0.03 0.25
Total abdominal FM (kg)	7.6 ± 1.7	7.6 ± 1.7	7.4 ± 1.9	6.9 ± 1.9**	7.2 ± 1.7	6.5 ± 1.7**	0.67 0.03	≤ 10 ⁻⁸ 0.73	≤ 10 ⁻⁴ 0.48
Visceral FM (kg)	4.2 ± 1.7	4.4 ± 1.8	4.5 ± 1.1	4.3 ± 1.0	3.1 ± 1.4	2.9 ± 1.4#£	0.08 0.19	0.48 0.02	0.02 0.27
VO₂max (mL.min⁻¹.kg⁻¹)	25.3 ± 2.8	28.5 ± 2.9	30.5 ± 6.9	35.6 ± 6.4	31.5 ± 4.1	35.0 ± 4.1	0.04 0.24	≤ 10 ⁻⁷ 0.71	0.25 0.11
PPO (Watts)	85 ± 9	102 ± 12	96 ± 23	122 ± 21	104 ± 13	120 ± 14	0.04 0.24	≤ 10 ⁻⁷ 0.71	0.34 0.09
PPO (Watts.kg⁻¹)	1.1 ± 0.1	1.3 ± 0.2	1.2 ± 0.4	1.4 ± 0.7	1.4 ± 0.2	1.6 ± 0.2	0.1 0.18	≤ 10 ⁻⁷ 0.76	0.30 0.10

Table 1: Anthropometric measurements, body composition and aerobic fitness in the MICT, HIIT and HIIT + RT groups at baseline (pre) and at the end (post) of the training programs.

Values are the mean ± SD.

G: group effect; T: time effect; G×T: group × time interaction.

BMI: body mass index; FM: fat mass; FFM: free-fat mass; Muscle mass = FFM – Bone Mineral Content from DXA; PPO: peak power output.

**: p ≤ 0.005 (pre vs. post in the same group); #: p ≤ 0.05 (HIIT + RT vs. MICT); £: p ≤ 0.05 (HIIT + RT vs. HIIT).

	MICT		HIIT		HIIT +RT		ANOVA (<i>p</i>)		
	Pre	Post	Pre	Post	Pre	Post	η^2 <i>G</i>	<i>T</i>	<i>G</i> × <i>T</i>
REST									
RMR (kcal.day ⁻¹)	1403 ± 259	1430 ± 259	1615 ± 206	1514 ± 230	1426 ± 317	1392 ± 317	0.23 0.11	0.56 0.01	0.68 0.03
FatOx (g.min ⁻¹)	0.05 ± 0.02	0.05 ± 0.02	0.06 ± 0.02	0.06 ± 0.02	0.04 ± 0.02	0.05 ± 0.01	0.23 0.12	0.47 0.02	0.98 0.00
FatOx (%)	48.5 ± 17.5	50.3 ± 15.0	48.0 ± 14.5	53.7 ± 12.8	44.2 ± 15.5	48.8 ± 8.5	0.67 0.03	0.26 0.05	0.90 0.00
CHOOx (g.min ⁻¹)	0.14 ± 0.04	0.14 ± 0.03	0.16 ± 0.05	0.13 ± 0.04	0.16 ± 0.06	0.14 ± 0.05	0.73 0.02	0.16 0.08	0.95 0.05
CHOOx (%)	51.5 ± 17.5	49.7 ± 15.0	52.0 ± 14.5	46.3 ± 12.8	55.9 ± 15.5	51.3 ± 8.5	0.67 0.03	0.26 0.05	0.90 0.00
EE (kcal.min ⁻¹)	0.97 ± 0.18	0.99 ± 0.17	1.12 ± 0.14	1.05 ± 0.16	0.99 ± 0.22	0.97 ± 0.22	0.23 0.11	0.56 0.01	0.69 0.03
EXERCISE									
FatOx (g.min ⁻¹)	0.17 ± 0.03	0.21 ± 0.05	0.16 ± 0.03	0.22 ± 0.06	0.18 ± 0.03	0.22 ± 0.05	0.68 0.03	≤ 10⁻⁵ 0.48	0.81 0.02
FatOx (%)	41.9 ± 5.7	51.8 ± 10.8	39.8 ± 5.5	50.7 ± 11.1	40.6 ± 5.2	53.6 ± 10.9	0.72 0.03	≤ 10⁻⁴ 0.44	0.89 0.01
CHOOx (g.min ⁻¹)	0.60 ± 0.7	0.52 ± 0.12	0.67 ± 0.18	0.57 ± 0.15	0.72 ± 0.18	0.52 ± 0.17	0.46	0.006	0.46

							0.06	0.27	0.06
CHOOx (%)	58.1 ± 5.7	48.2 ± 10.8	60.2 ± 5.5	49.3 ± 11.1	59.4 ± 5.2	46.3 ± 10.9	0.72 0.03	≤ 10⁻⁴ 0.44	0.89 0.01
EE (kcal.min⁻¹)	3.7 ± 0.3	3.9 ± 0.4	4.0 ± 0.8	4.0 ± 0.7	4.3 ± 0.9	4.0 ± 0.6	0.45 0.06	0.63 0.00	0.29 0.10
RECOVERY									
FatOx (g.min⁻¹)	0.08 ± 0.03	0.09 ± 0.03	0.08 ± 0.03	0.08 ± 0.04	0.07 ± 0.02	0.07 ± 0.02	0.69 0.03	≤ 10⁻⁵ 0.48	0.81 0.02
FatOx (%)	52.5 ± 10.8	57.2 ± 12.1	52.6 ± 10.8	55.9 ± 11.0	47.6 ± 12.3	53.9 ± 10.0	0.72 0.03	≤ 10⁻⁴ 0.44	0.89 0.01
CHOOx (g.min⁻¹)	0.20 ± 0.05	0.21 ± 0.10	0.18 ± 0.04	0.18 ± 0.09	0.21 ± 0.06	0.17 ± 0.06	0.47 0.06	0.006 0.27	0.45 0.06
CHOOx (%)	47.5 ± 10.8	42.8 ± 12.1	47.4 ± 10.8	44.1 ± 11.0	52.4 ± 12.3	46.0 ± 10.0	0.72 0.03	≤ 10⁻⁴ 0.44	0.89 0.01
EE (kcal.min⁻¹)	1.5 ± 0.3	1.6 ± 0.4	1.4 ± 0.3	1.4 ± 0.6	1.4 ± 0.3	1.3 ± 0.3	0.45 0.06	0.63 0.01	0.29 0.10

Table 2: Substrate utilization and energy expenditure at rest, during moderate intensity continuous exercise (50% of PPO) and during the 20min recovery time in the MICT, HIIT, and HIIT + RT groups at baseline (pre) and after (post) the training programs.

Values are the mean ± SD.

G: group effect; T: time effect; G×T: group × time interaction.

RMR: resting metabolic rate; EE: energy expenditure; FatOx: fat oxidation; CHOOx: carbohydrate oxidation.

	MICT		HIIT		HIIT + RT		ANOVA (<i>p</i>)		
	Pre	Post	Pre	Post	Pre	Post	<i>G</i>	η^2 <i>T</i>	<i>G</i> × <i>T</i>
Glycemia (mmol.L ⁻¹)	1.2 ± 0.7	1.2 ± 0.4	1.2 ± 0.3	1.2 ± 0.3	1.2 ± 0.6	1.2 ± 0.7	0.19 0.13	0.47 0.02	0.74 0.03
Insulinemia (μU.L ⁻¹)	11.2 ± 3.	9.1 ± 3.3	12.9 ± 14.8	12.5 ± 13.0	11.5 ± 3.3	11.7 ± 4.4	0.82 0.02	0.27 0.05	0.79 0.03
HbA1c (%)	5.6 ± 0.5	5.5 ± 0.4	6.1 ± 0.9	6.0 ± 0.7	5.8 ± 0.2	5.7 ± 0.2	0.19 0.13	0.52 0.02	0.50 0.06
HOMA-IR	3.0 ± 1.2	2.2 ± 0.8	3.9 ± 4.7	3.8 ± 4.4	2.8 ± 0.8	3.0 ± 1.4	0.64 0.04	0.39 0.03	0.42 0.07
Total Cholesterol (mmol.L ⁻¹)	6.3 ± 1.3	6.3 ± 1.3	5.6 ± 1.1	5.4 ± 1.2	6.2 ± 1.0	6.2 ± 1.0	0.27 0.10	0.43 0.03	0.86 0.01
HDL-C (mmol.L ⁻¹)	1.7 ± 0.4	1.6 ± 0.1	1.7 ± 0.9	1.7 ± 0.5	1.7 ± 0.5	1.7 ± 0.4	0.82 0.01	0.77 0.00	0.69 0.03
LDL-C (mmol.L ⁻¹)	3.5 ± 1.6	3.6 ± 1.4	3.3 ± 0.8	3.4 ± 0.8	3.9 ± 1.0	3.9 ± 0.8	0.40 0.08	0.83 0.00	0.79 0.02
TG (mmol.L ⁻¹)	1.4 ± 1.1	1.1 ± 0.5	1.2 ± 0.7	0.9 ± 0.4	1.2 ± 0.5	1.2 ± 0.6	0.43 0.07	0.02 0.22	0.41 0.07

720 **Table 3: Glycemic control and lipid profile in the MICT, HIIT and HIIT + RT groups at baseline (pre) and after (post) the training**
721 **programs.**

722 Values are the mean \pm SD.

723 G: group effect; T: time effect; G \times T: group \times time interaction.

724 HDL: High Density Lipoproteins, LDL: Low Density Lipoproteins, C, cholesterol; TG: Triglycerides.

725

726

727