Low-Frequency HIIT Improves Body Composition and Aerobic Capacity in Overweight Men

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ABSTRACT

CHIN, E. C., A. P. YU, C. W. LAI, D. Y. FONG, D. K. CHAN, S. H. WONG, F. SUN, H. H. NGAI, P. S. H. YUNG, and P. M. SIU. Low-Frequency HIIT Improves Body Composition and Aerobic Capacity in Overweight Men. *Med. Sci. Sports Exerc.*, Vol. 52, No. 1, pp. 56–66, 2020. **Background:** The relationship between the frequency of high-intensity interval training (HIIT) and the resultant adaptations is largely unclear. **Purpose:** This study compared the effects of different frequencies of HIIT with those of moderate-intensity continuous training (MICT) on body composition in overweight or obese adults. **Methods:** Fifty-six overweight or obese (body mass index = 26.4 ± 2.9) men between 18 and 30 yr old (age = 22.8 ± 3.1 yr) were randomly assigned to the following groups: no-intervention control (CON; n = 14), MICT performed thrice weekly (MICT×3/wk; n = 9), HIIT performed thrice weekly (HIIT×3/wk; n = 14), HIIT performed twice weekly (HIIT×2/wk; n = 10), and HIIT performed once weekly (HIIT×1/wk; n = 9). Each HIIT session consisted of 12 × 1-min bouts at 90% heart rate reserve, interspersed with 11 × 1-min bouts at 70% heart rate reserve. Aerobic capacity, body composition, resting heart rate, vascular function, insulin resistance, and biomarkers of metabolic syndrome risk factor were examined at baseline, after 4 wk, and after 8 wk of intervention. **Results:** Aerobic capacity and percent fat-free mass significantly increased in all exercise groups compared with those in the CON group (CON vs all exercise groups, $P < 0.05$), whereas body fat mass and systolic blood pressure significantly decreased after 8 wk of intervention in all exercise groups compared with those in the CON group (CON vs all exercise groups, $P < 0.05$). Body fat mass significantly decreased after 4 wk in all HIIT groups compared with those in the CON group (CON vs all HIIT groups, $P < 0.05$) but not in the MICT×3/wk group. **Conclusion:** These novel results demonstrated that performing HIIT once weekly, even with a lower weekly volume of exercise, improved cardiorespiratory fitness, body composition, and blood pressure in overweight/obese adults. Low-frequency HIIT might be a feasible and effective strategy for the prescription of an initial exercise program for inactive, overweight, or obese young men.
Key Words: HIIT, HIT, INTERVAL EXERCISE, AEROBIC EXERCISE, EXERCISE FREQUENCY, EXERCISE INTENSITY

Overweight/obesity has become a severe public health concern because of the rapidly growing worldwide prevalence (1) and the associated morbidity and mortality (2). Overweight or obese individuals are more susceptible to developing diabetes mellitus (3), hypertension (4), and cardiovascular disease (5). Optimal cardiorespiratory fitness has long been recognized as a protective factor that reduces the risks of chronic diseases, particularly cardiovascular diseases (6).

Generally, the current exercise recommendations suggest that moderate to vigorous aerobic exercise is required to performed at least 3 d·wk^{-1} to induce considerable benefits in physical fitness and health (7). According to the American College of Sports Medicine's Worldwide Survey of Fitness Trends 2019, high-intensity interval training (HIIT) was regarding as the top fitness trend from 2014 to 2018 (8), but

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the exercise recommendations rarely consider the factor of exercise frequency in regard to the newly emerging popular strategies of vigorous or high-intensity exercise modality.

A growing amount of evidence suggests that HIIT might be a more effective training strategy for improving cardiorespiratory fitness than the conventional moderate-intensity continuous training (MICT) modality (9,10). Moreover, previous studies have shown that high-frequency (i.e., ≥3 sessions weekly) HIIT improves glucose tolerance in both prediabetic and untrained adults (11,12). Although HIIT has the potential to improve various cardiometabolic health parameters, the minimal exercise dose of HIIT required to improve the cardiometabolic health is not well understood.

Montero and colleagues (13) demonstrated that low-frequency MICT (i.e., less than three sessions weekly) was associated with nonresponse in changes in cardiorespiratory fitness, whereas an exercise frequency of more than three sessions weekly led to a universal increase in cardiorespiratory fitness. When the nonresponders received high-frequency MICT (i.e., more than two sessions weekly), all of them showed improvement in cardiorespiratory fitness. In addition, Gurd and colleagues (14) reported that no nonresponders to improved aerobic fitness were observed after four sessions each week of all-out effort sprint interval training (≥100% aerobic power), suggesting that a high dose of sprint interval training leads to increases in aerobic fitness. However, there is a lack of evidence delineating the role of exercise frequency in the newly emerging popular strategies of HIIT. Previous studies have shown that one session of HIIT performed every 5 d induced significant improvements in lower limb muscle power (15) and cardiorespiratory fitness (16) in sedentary older men. Furthermore, 12 wk of HIIT performed once weekly has also been demonstrated to improve cardiorespiratory fitness and cardiometabolic response in healthy young adults (17). Although the aforementioned studies compared the training effects of low-frequency HIIT to no-intervention control, there is a lack of scientific data comparing the exercise frequency of HIIT, as well as its beneficial effects in overweight and obese individuals.

The present study aimed to 1) examine the effects of different frequencies of HIIT and 2) compare the training efficacy of regular HIIT and MICT on cardiorespiratory fitness, body composition, and cardiometabolic health in overweight or obese young adults. This study tested the hypothesis that compared with a no-intervention control, an 8-wk low-frequency (i.e., once weekly) HIIT intervention improves cardiorespiratory fitness and body composition in overweight or obese young adults.

METHODS

Subjects. A total of 590 young male adults recruited from the community and university campus were invited for a screening of body mass index (BMI) and percent body fat from October 2016 to March 2017. The study started in October 2016 and ended in August 2017.

Inclusion and exclusion criteria. Individuals who fulfilled the following inclusion criteria were invited to participate in the present study: 1) Chinese male, 2) 18–30 yr old, and 3) overweight or obesity, defined as BMI ≥23 $kg \cdot m^{-2}$ (classification of overweight for Hong Kong adults according to Department of Health, Hong Kong SAR Government) (18). Subjects were excluded if they had 1) chronic medical and health conditions, such as cardiovascular diseases, diabetes, neurological disease, musculoskeletal disorder, cancers, and autoimmune diseases; 2) hypertension (blood pressure >140/90 mm Hg); 3) contraindications to participating in physical exercise; 4) any preexisting medical or physical issues that affected the experimental test; 5) high levels of physical activity (i.e., >3 h of moderate-intensity exercise weekly); or 6) a lean and overweight body composition (BMI ≥23 $kg \cdot m^{-2}$, but percent body fat ≤20%), according to the BMI data corresponding to bioelectrical impedance–estimated percent body fat cutoff value among Hong Kong Chinese adults (19).

Of those who were screened, 103 young Chinese adults were eligible to participate in this study. They were provided with written and verbal information on the study protocol and the possible associated discomforts and risks; their written informed consent to participate in this study was then obtained. The study protocol and consent form were approved by the Human Subjects Ethics Sub-Committee of The Hong Kong Polytechnic University (ethics approval reference no. HSEARS20160927005-01). The study is registered at ClinicalTrials.gov (no. NCT03904810).

Study design. This study was a single-blind randomized controlled trial. Subjects were randomly assigned to the following groups: 1) no-intervention control (CON), 2) MICT performed thrice weekly (MICT×3/wk), 3) HIIT performed thrice weekly (HIIT×3/wk), 4) HIIT twice weekly (HIIT×2/wk), and 5) HIIT once weekly (HIIT×1/wk). All subjects were instructed to maintain their usual daily activities. Outcome measures, including aerobic capacity, body composition, blood pressure, resting heart rate (HR), vascular function, fasting glucose, fasting insulin, and lipid markers, were assessed at baseline (pretest), 4 wk (midtest), and 8 wk (posttest) after the intervention (Fig. 1). All pretest, midtest, and posttest assessments involved three separate visits. Body composition, waist circumference, blood pressure, resting HR, and aerobic capacity were measured at the first visit. Fasting blood was collected in the second visit. Vascular function was collected in the third visit. The posttest assessment was performed at least 24 h after the last bout of the training session.

Exercise intervention. The HIIT groups performed 30-m shuttle runs on a rooftop-covered field, whereas the MICT group ran on a footpath with an overall flat and nonslippery road surface. All training sessions were preceded by 5 min of self-paced warm-up jogging and were followed by 5 min of a self-paced jogging or walking cooldown. Each session of MICT consisted of 30 min of continuous exercise at an intensity of 60% of HR reserve (HRR) (i.e., [maximal HR − resting HR] × intensity + resting HR). For each HIIT session, the intensity was set at 90% HRR for high-intensity bouts, interspersed with active recovery at 70% HRR. All exercise sessions were supervised by qualified athletic coach or strength and conditioning coach.

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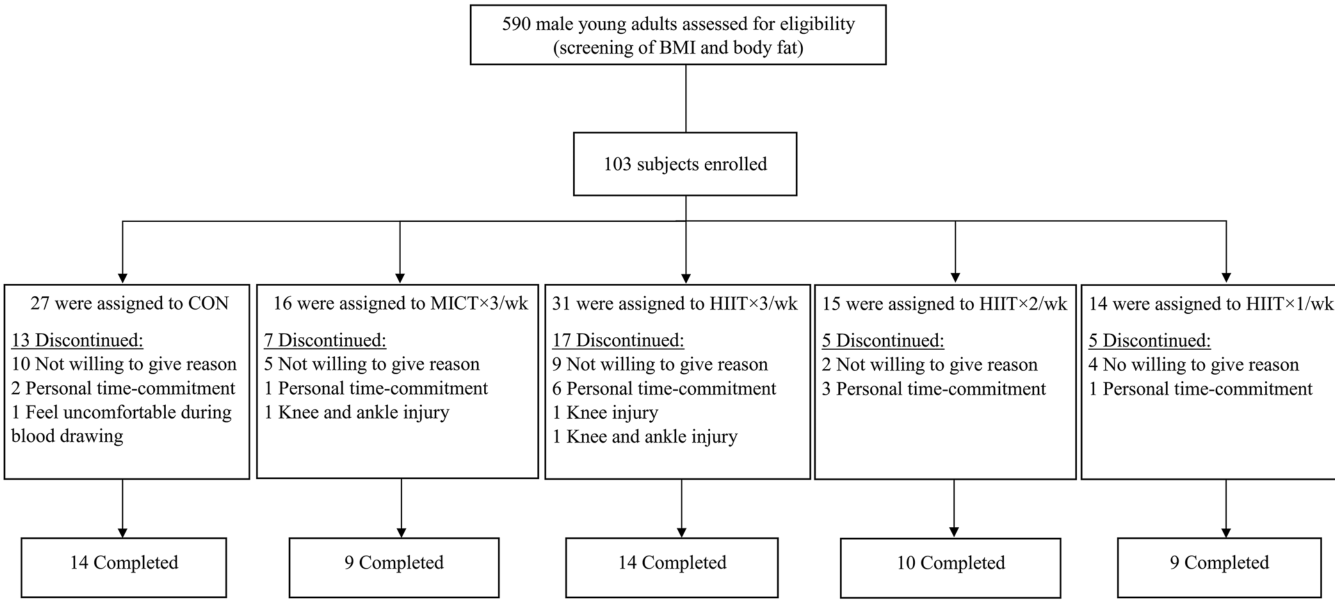

FIGURE 1—Flow diagram of study.

We adopted the method from Rognmo et al. (20), who used maximal oxygen consumption ($\dot{V}O_{2max}$) to equate the exercise volume between each session of HIIT and MICT. In the present study, oxygen consumption reserve ($\dot{V}O_2R$) (i.e., [maximal $\dot{V}O_2$ − resting $\dot{V}O_2$] × intensity + resting $\dot{V}O_2$) was used to equate the exercise volume between each session of HIIT and MICT, as HRR is equivalent to $\dot{V}O_2R$ (21,22). The average $\dot{V}O_2R$ (i.e., subtract 3.5 $mL \cdot kg^{-1} \cdot min^{-1}$ from $\dot{V}O_{2max}$) for subjects in the HIIT and MICT groups before training was 32.03 and 32.9 $mL \cdot kg^{-1} \cdot min^{-1}$, respectively. The following calculation was used to determine the number of bouts in each HIIT session:

$$\overbrace{(32.03 \times 90\% + 3.5) \times \text{bouts}}^{\text{High-intensity bouts}} + \overbrace{(32.03 \times 70\% + 3.5) \times (\text{bouts} - 1)}^{\text{Active recovery bouts}}$$
$$= (32.9 \times 60\% + 3.5) \times 30 \text{ min}$$

Each session of HIIT thus consisted of 12 bouts × 1 min of high-intensity exercise at 90% HRR and was interspersed with 11 bouts × 1 min of active recovery at 70% HRR. Subjects were instructed to reach the target HR within the first 30 s of each 1-min high-intensity interval and maintain the HR above 70% of HRR during the active recovery bouts. Polar HR monitors (M300 and H7; Polar Electro Oy, Kempele, Finland) were used to continuously monitor and record the HR throughout each exercise session. Subjects were equipped with an M300 polar watch during the training and reported the HR value to researchers at 30 s and the last 10 s of each high-intensity exercise bout and active recovery bout.

Maximal exercise testing. We conducted the 20-m shuttle multistage run test, which is a validated test to estimate cardiorespiratory fitness in adults (r = 0.94) (23). During the test, an audio speaker sounds a "beep" at designed time intervals, and the "beep" sounds with a shorter interval indicate an increase in the required running velocity of the subjects. The test was terminated if the subjects failed to maintain the pace and did not reach the lines in time twice in a row. The results achieved from the test were transferred to a value of estimated $\dot{V}O_{2max}$ (24). The estimated $\dot{V}O_{2max}$ collected at baseline was used to equate the exercise volume between each session of MICT and HIIT. The total running distance achieved during the test was also recorded for the assessment of aerobic fitness. The $\dot{V}O_{2max}$ prediction error of the 20-m shuttle multistage run test was 4.5 $mL \cdot kg^{-1} \cdot min^{-1}$ (25). A polar HR monitor was used to continuously monitor the HR throughout the test, and the maximal attainable HR was recorded as the maximal HR (HR_{max}) for the calculation of the targeted exercising intensity of MICT and HIIT.

Assessment of body composition and waist circumference. Total body fat mass, fat-free mass, trunk fat mass, body weight, and BMI were assessed by a bioelectrical impedance analyzer (BIA) (BC-418; Tanita, Tokyo, Japan). To ensure euhydration, subjects were instructed to drink at least 500 mL of plain water 30 min before the measurement. Waist circumference was determined to the nearest 0.1 cm of a contact tension tape. The tape was applied directly to the skin at the midpoint between the lower margin of the last palpable rib and the top of the iliac crest (26). Subjects adopted a standing position with arms relaxed at the sides during the test. The Tanita BC-418 BIA has a retest coefficient of variation of 1.4%, and the measurement error of the BIA was 0.02% body fat (27).

Assessment of resting blood pressure and HR. Systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and resting HR were determined by an electronic sphygmomanometer (Accutorr Plus, Datascope, USA). Blood pressure measurement was examined after 5 min of seated rest. A blood pressure cuff was applied on the brachial artery region of the left arm with the arm supported at heart level. The average of three measurements taken with a 1-min interval between them was recorded for analysis.

Biochemistry analysis. Venous blood was drawn from an antecubital vein in the forearm by a phlebotomist after a minimum of 10 h of overnight fasting. Subjects were required to avoid alcohol, tobacco, and caffeine consumption and avoid strenuous exercise 2 d before blood sample collection. Fresh blood samples were sent to an accredited medical laboratory to measure the serum fasting glucose, triglycerides, and HDL-C concentrations by commercial test kit methods with an automatic clinical chemistry analyzer (Architect CI8200; Abbott Diagnostics, Lake Forest, IL). The remaining blood samples were stored at −80°C for subsequent analysis. Clotted blood samples were centrifuged at 2400 rpm for 10 min at room temperature for the collection of serum samples. Commercially available enzyme-linked immunosorbent assay kits (DINS00, R&D systems, Minneapolis, MN) were used to determine the fasting insulin level in serum.

Metabolic syndrome severity score and homeostasis model assessment insulin resistance. Serum fasting glucose, triglycerides, HDL-C, waist circumference, and blood pressure were used to calculate the continuous metabolic syndrome (METs) severity score. The MET severity score was calculated based on the *z*-score of 3653 Korean young men 20–39 yr old (28). The following equation was used to examine the metabolic syndrome severity: $-8.7125 + 0.0176 \times$ fasting glucose $+ 0.0117 \times$ SBP $+ 0.0386 \times$ waist circumference $-0.0172 \times$ HDL-C $+ 0.7168 \times$ triglycerides. Serum fasting glucose and insulin were used to evaluate insulin resistance by homeostasis model assessment insulin resistance (HOMA-IR) index; then the following formula was used: fasting glucose ($\mathrm{mmol \cdot L^{-1}}$) $\times$ fasting insulin ($\mathrm{mU \cdot L^{-1}}$)/22.5 (29).

Assessment of endothelial function and arterial stiffness. Endothelial function and arterial stiffness were measured by digital plethysmography using an EndoPAT 2000 device (ITAMAR Medical, Caesarea, Israel) and were expressed as the natural log of the reactive hyperemia index (LnRHI) and the augmentation index normalized to an HR of 75 bpm (AI@75), respectively. The procedure was conducted according to the manufacturer's instructions. Briefly, subjects underwent the procedure after a minimum of 4 h of fasting and avoiding alcohol, tobacco, caffeine, and vigorous exercise for 24 h before the test. The room temperature was set at 25°C during the test. After 10 min of rest in a quiet environment, two single-use pneumatic probes were equipped to surround the forefingers of both hands to continuously measure the peripheral arterial tone with a supine position. A blood pressure cuff was placed on the brachial artery region of the left arm, with the right arm serving as an intralateral control. After 5 min of baseline recording, the blood pressure cuff was inflated to avoid distal venous pooling for 5 min. Occlusion was confirmed by the complete attenuation of the signal displayed by the computer; then the cuff was deflated, and the reactive hyperemia phase was recorded for 5 min.

Statistical analysis. The statistical approach of this study was adapted from Tiwari and colleagues (30). The intervention effects on the dependent variables were analyzed by a generalized estimated equation (GEE) model. The baseline value was taken as a covariate. The GEE analysis was conducted using the R package "geeM." A closed test procedure was used for *post hoc* comparison among groups by the R package "multcomp." The Pearson product-moment correlation coefficient test was used to test the relationship between changes in primary outcomes (i.e., aerobic fitness and body fatness), changes in metabolic risk factors (i.e., blood pressure, waist circumference, fasting glucose, HDL-C, and triglycerides), and changes in vascular function (LnRHI and AI@75) from pretest to posttest. The software application used to analyze the data was the R package (version 3.5.1). The acceptable P value for the level of significance was set at $P < 0.05$. Data are presented as the mean ± SD.

RESULTS

Exercising HR, adherence, and adverse events. The exercise HR and adherence of the exercise training are presented in Figure 2. Low-frequency HIIT showed relatively higher adherence among the subjects than did HIIT of other exercise frequencies. Three subjects withdrew from the study because of training-related adverse events. One subject in the MICT×3/wk group reported knee and ankle injuries after the

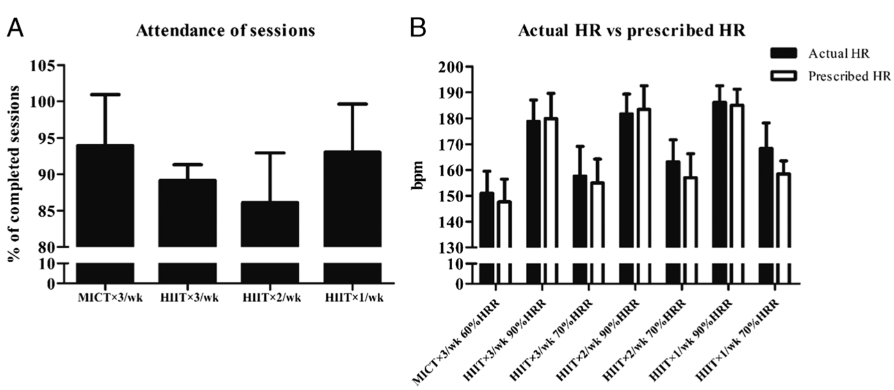

FIGURE 2—A, Percentage of completed session in each exercise group. All subjects are required to complete at least 80% of the training session. B, Difference between actual HR response and targeted HR. Subjects maintained the exercise HR not more or less than 10 bpm from prescribed HR. The highest exercising HR and lowest active resting HR were collected and presented as the actual HR response during each HIIT session. Values are expressed as mean ± SD.

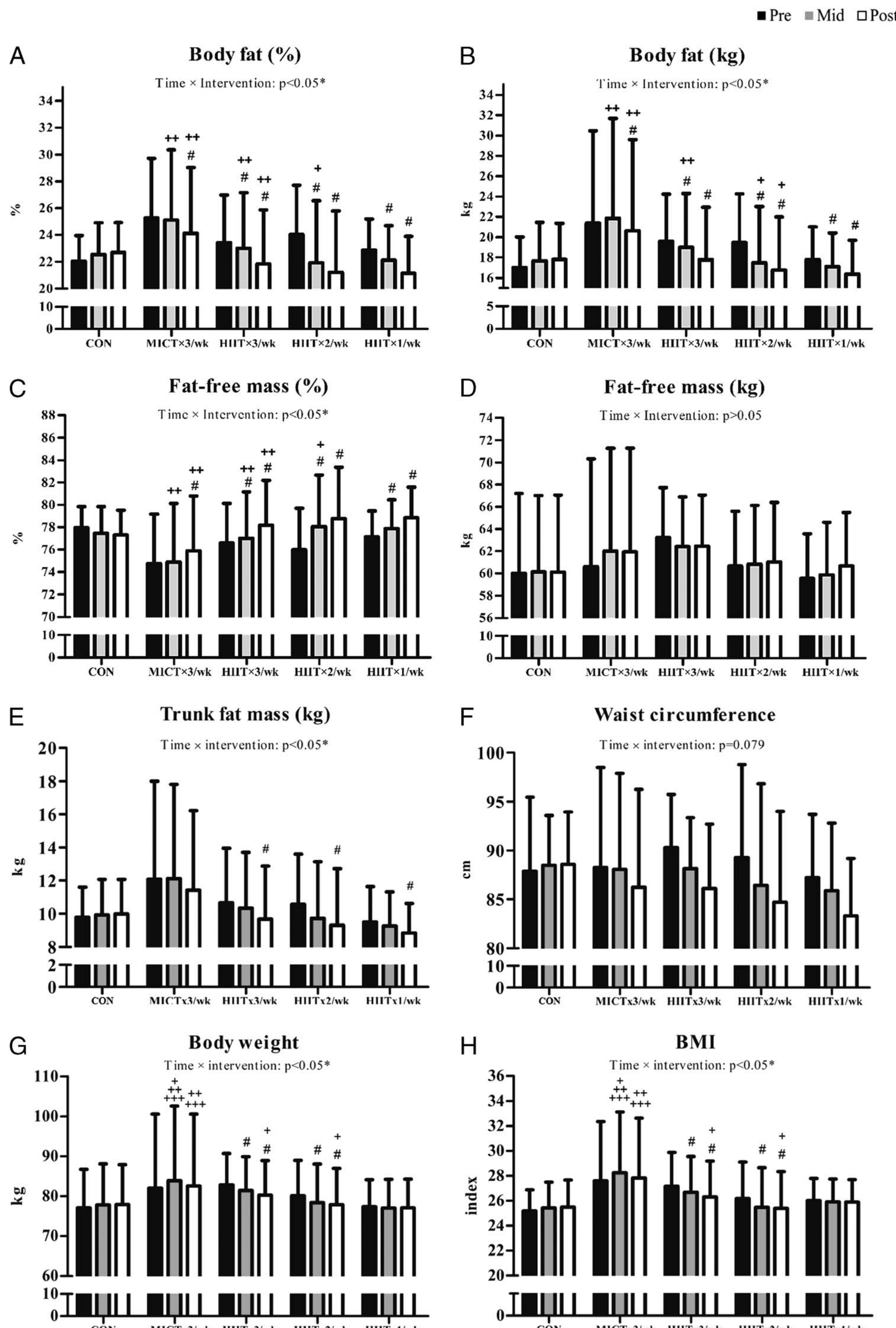

FIGURE 3—Percent body fat (A), total body fat mass (B), percent fat-free mass (C), total fat-free mass (D), trunk fat mass (E), waist circumference (F), body weight (G), and body mass index (H) were examined at baseline (Pre), 4 wk (Mid), and 8 wk (Post) throughout the 8-wk experimental period in subjects who did not receive exercise intervention (CON), underwent MICT thrice weekly (MICT×3/wk), underwent HIIT thrice weekly (HIIT×3/wk), twice weekly (HIIT×2/wk), and once weekly (HIIT×1/wk). Values are expressed as mean ± SD. #Significantly different with control at same time point. †††Significantly different with HIIT×3/wk at same time point. ††Significantly different with HIIT×2/wk at same time point. †Significantly different with HIIT×1/wk at same time point.

training, and two subjects in the HIIT×3/wk group reported knee and ankle injuries (Fig. 1).

Body composition. As shown in Figure 3, there are significant group–time interaction effects in percent body fat (interaction effect, $P = 0.01$; time effect, $P = 0.68$), body fat mass (interaction effect, $P = 0.01$; time effect, $P = 0.83$), percent fat-free mass (interaction effect, $P = 0.01$; time effect, $P = 0.83$), trunk fat mass (interaction effect, $P = 0.0497$; time effect, $P = 0.85$), body weight (interaction effect, $P = 0.01$; time effect, $P = 0.48$), and BMI (interaction effect, $P = 0.01$; time effect, $P = 0.01$). According to the *post hoc* analyses, percent body fat mass and absolute body fat mass in all exercise groups were significantly lower than those in the CON group at posttest. Furthermore, percent body fat mass and absolute body fat mass in all HIIT interventions were significantly lower than those in the CON group after 4 wk of training, but the decrease was not observed in the MICT×3/wk group after 4 wk of training. Moreover, all HIIT groups showed a significantly higher value of percent fat-free mass than the CON group did after 4 wk of intervention, but no significant improvement was found in the MICT×3/wk group. All groups that received HIIT interventions showed lower values of absolute trunk fat mass than the CON did at posttest. Waist circumference tended to be reduced in all exercise groups, but the time–group interaction effect did not reach statistical significance (interaction effect, $P = 0.079$; time effect, $P = 0.28$). Body weight and BMI in the HIIT×3/wk group and the HIIT×2/wk group were significantly lower than those in the CON group at midtest and posttest. Body weight and BMI in the MICT×3/wk group and the HIIT×1/wk group were significantly different from those in the HIIT×3/wk group and the HIIT×2/wk group at posttest.

Aerobic capacity. The estimated $\dot{V}O_{2max}$ and total running distance data obtained from the maximal exercise test are shown in Figure 4. GEE analysis revealed a significant group–time interaction effect on estimated $\dot{V}O_{2max}$ (interaction effect, $P = 0.01$; time effect, $P = 0.12$) and total running distance (interaction effect, $P = 0.01$; time, $P = 0.08$). The *post hoc* comparisons showed that the estimated $\dot{V}O_{2max}$ and total running distance in all exercise groups were significantly higher than those in the CON group at 4 and 8 wk. The estimated $\dot{V}O_{2max}$ and the total running distance in the MICT×3/wk group were found to be significantly different from those in the HIIT×3/wk group (MICT×3/wk vs HIIT×3/wk; estimated $\dot{V}O_{2max}$, $P = 0.03$; total running distance, $P = 0.02$) and the HIIT×2/wk group (MICT3/wk vs HIIT×2/wk; estimated $\dot{V}O_{2max}$, $P = 0.04$; total running distance, $P = 0.02$) at posttest. The HIIT×3/wk group showed greater improvement in estimated $\dot{V}O_{2max}$ and total running distance than the MICT×3/wk group did after 8 wk of the intervention (estimated $\dot{V}O_{2max}$: increased by 12.1% in MICT×3/wk, increased by 19.6% in HIIT×3/wk; total running distance: increased by 23.9% in MICT×3/wk, increased by 42.5% in HIIT×3/wk).

Blood pressure, resting HR, and vascular function. The results of resting blood pressure, resting HR, and vascular function are presented in Figure 5. GEE analysis revealed significant time–group interaction effects on SBP (interaction effect, $P = 0.005$; time effect, $P = 0.80$), DBP (interaction effect, $P = 0.002$; time effect, $P = 0.52$), and MAP (interaction effect, $P = 0.002$; time effect, $P = 0.76$). Based on the *post hoc* analyses, the SBP values of all exercise groups were significantly lower than that of the CON group at posttest. No group effect was detected between the MICT×3/wk and the HIIT×3/wk groups. DBP and MAP were significantly decreased after 8 wk of training in the MICT×3/wk and HIIT×3/wk groups when compared with the CON group. Our GEE analyses indicated no time–group interaction effect for resting HR, LnRHI, and AI@75.

Blood biomarker and metabolic syndrome severity score. Our GEE analyses indicated no significant time–group interaction in fasting blood glucose, fasting blood insulin, triglycerides, HDL, and HOMA-IR (Table 1). Furthermore, the Pearson product-moment correlation coefficient test revealed a negative correlation between the change in aerobic fitness and the change in triglycerides ($\Delta\dot{V}O_{2max}$: $r = -0.34$, $P = 0.01$; Δtotal running distance: $r = -0.34$, $P = 0.01$). No significant difference was detected in the metabolic syndrome severity score. However, we detected significant correlations between the changes in aerobic fitness and SBP ($\Delta\dot{V}O_{2max}$: $r = -0.30$, $P = 0.03$; Δtotal running distance: $r = -0.31$, $P = 0.02$), the changes in body fatness and waist circumference (ΔFat%: $r = 0.28$, $P = 0.04$; ΔFat(kg): $r = 0.34$, $P = 0.01$), the changes in aerobic fitness and waist circumference ($\Delta\dot{V}O_{2max}$: $r = -0.54$, $P = 0.0001$; Δtotal running distance: $r = -0.55$, $P = 0.0001$), and the changes in fatness and the change in LnRHI (ΔFat%: $r = 0.31$, $P = 0.02$; ΔFat(kg): $r = 0.30$, $P = 0.02$).

DISCUSSION

The purposes of this study were 1) to examine the effects of different exercise frequencies of HIIT and 2) to compare the

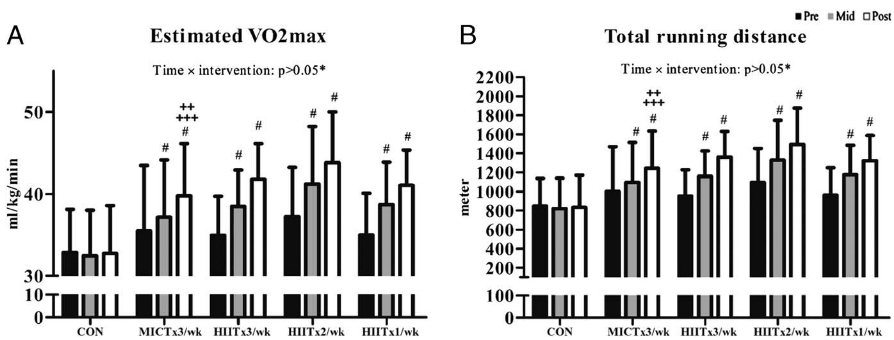

FIGURE 4—Estimated $\dot{V}O_{2max}$ (A) and total running distance during beep test (B) were examined at baseline (Pre), 4 wk (Mid), and 8 wk (Post) throughout the 8-wk experimental period in subjects who did not receive exercise intervention (CON), underwent MICT thrice weekly (MICT×3/wk), underwent HIIT thrice weekly (HIIT×3/wk), twice weekly (HIIT×2/wk), and once weekly (HIIT×1/wk). Values are expressed as mean ± SD. #Significantly different with control at same time point. †††Significantly different with HIIT×3/wk at same time point. ††Significantly different with HIIT×2/wk at same time point.

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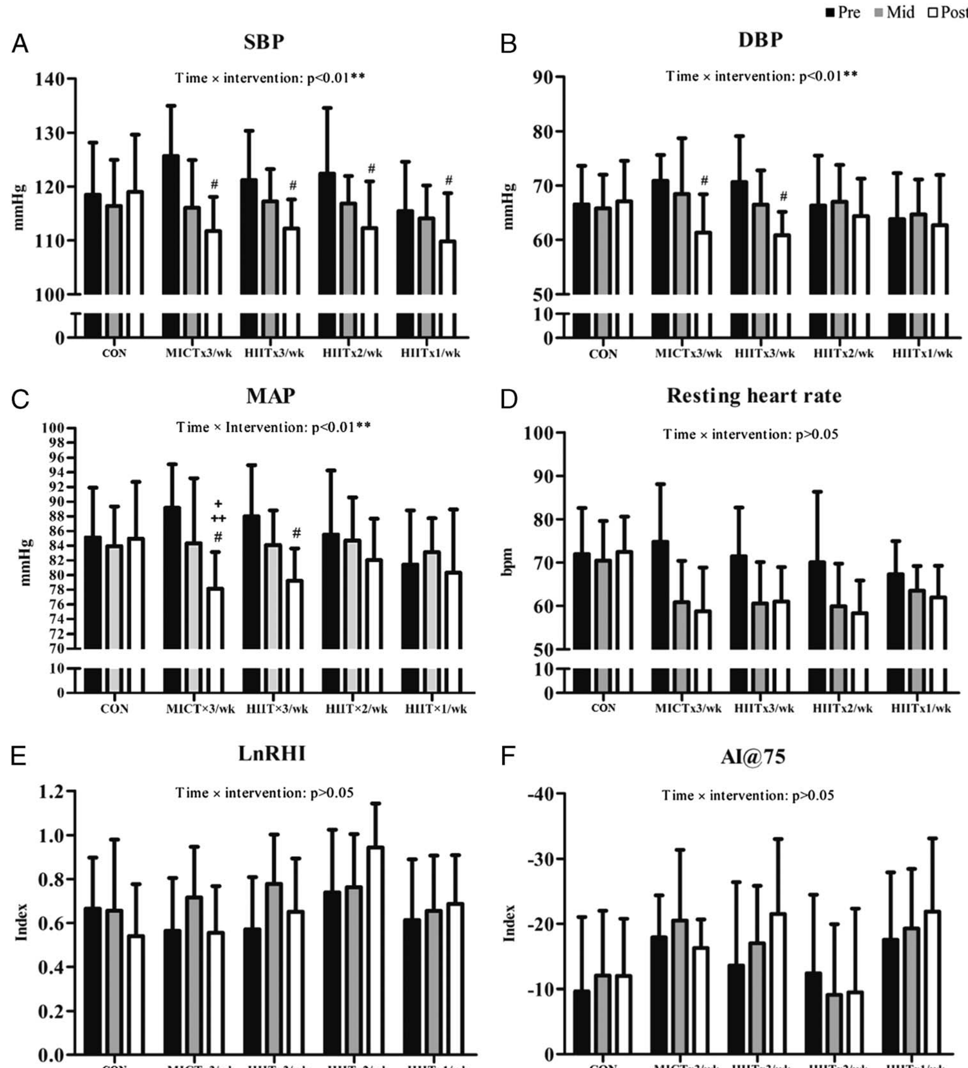

FIGURE 5—SBP (A), DBP (B), MAP (C), resting HR (D), reactive hyperemia index with nature log transformation (E), and augmentation index normalized to HR of 75 bpm (F) were examined at baseline (Pre), 4 wk (Mid), and 8 wk (Post) throughout the 8-wk experimental period in subjects who did not receive exercise intervention (CON), underwent MICT thrice weekly (MICT×3/wk), underwent HIIT thrice weekly (HIIT×3/wk), twice weekly (HIIT×2/wk), and once weekly (HIIT×1/wk). Values are expressed as mean ± SD. #Significantly different with control at same time point. ††Significantly different with HIIT×2/wk at same time point. †Significantly different with HIIT×1/wk at same time point.

effects of 8 wk of HIIT versus MICT on aerobic capacity, body composition, and cardiovascular biomarkers in a cohort of inactive, overweight, or obese young adults. The main findings of this study provided preliminary evidence on the dissimilar effects of HIIT and MICT in several respects. First, an improvement in aerobic capacity and a reduction in body fatness were observed in the low-frequency HIIT group. Second, all exercise frequencies of HIIT demonstrated a reduction in body adiposity and blood pressure. Third, either HIIT or MICT improved aerobic capacity and reduced body adiposity, but HIIT exhibited greater training efficacy of aerobic capacity than MICT did. Altogether, these data suggested that HIIT is a more effective training modality than MICT for aerobic fitness, and HIIT performed even once weekly for 8 wk improved aerobic capacity and reduced body fatness in overweight or obese individuals.

The current physical activity recommendation suggests that accumulating 150 min of moderate-intensity physical activity (i.e., 3.0–5.9 METs) or 75 min of vigorous-intensity physical activity (i.e., ≥6.0 METs) weekly could provide various health benefits, such as cardiorespiratory health, metabolic health, and musculoskeletal health (26). This physical activity recommendation shows that half of the time commitment in vigorous-intensity physical activity elicits beneficial health effects that are similar to those of moderate-intensity physical activity. In our study, the accumulation of both 69 min of three sessions of HIIT weekly and 90 min of three sessions MICT weekly elicited greater beneficial effects than those seen in the control group on cardiorespiratory health (i.e., increased aerobic fitness and reduced blood pressure) and metabolic health (i.e., reduced body fatness). Intriguingly, our study further found that even one session of 23 min of HIIT could

TABLE 1. Fasting serum glucose, triglycerides, HDL, fasting serum insulin, HOMA-IR, and metabolic z-score were examined at baseline (Pre), 4 wk (Mid), and 8 wk (Post) throughout the 8-wk experimental period in subjects who did not receive exercise intervention (CON), underwent MICT thrice weekly (MICT×3/wk), underwent HIIT thrice weekly (HIIT×3/wk), twice weekly (HIIT×2/wk), and once weekly (HIIT×1/wk).

	CON			MICT×3/wk			HIIT×3/wk			HIIT×2/wk			HIIT×1/wk			Interaction Effect
	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	
Fasting glucose ($mmol \cdot L^{-1}$)	4.70 ± 0.25	4.73 ± 0.30	4.69 ± 0.34	4.48 ± 0.34	4.63 ± 0.38	4.72 ± 0.44	4.66 ± 0.22	4.67 ± 0.41	4.76 ± 0.38	4.45 ± 0.72	4.81 ± 0.57	4.85 ± 0.52	4.39 ± 0.23	4.52 ± 0.28	4.60 ± 0.24	NS
Triglycerides ($mmol \cdot L^{-1}$)	1.00 ± 0.33	1.24 ± 0.49	1.26 ± 0.60	1.03 ± 0.72	1.24 ± 0.81	1.22 ± 0.75	0.73 ± 0.28	0.77 ± 0.28	0.73 ± 0.25	1.25 ± 0.89	0.96 ± 0.62	0.94 ± 0.47	1.03 ± 0.79	1.08 ± 0.46	0.86 ± 0.22	NS
HDL-C ($mmol \cdot L^{-1}$)	1.31 ± 0.23	1.37 ± 0.30	1.28 ± 0.32	1.26 ± 0.31	1.26 ± 0.42	1.30 ± 0.39	1.34 ± 0.26	1.32 ± 0.22	1.34 ± 0.30	1.39 ± 0.27	1.32 ± 0.21	1.41 ± 0.26	1.52 ± 0.37	1.39 ± 0.32	1.37 ± 0.24	NS
Fasting insulin ($mU \cdot L^{-1}$)	8.18 ± 3.72	8.91 ± 5.33	9.74 ± 5.32	7.02 ± 3.51	6.53 ± 2.23	8.08 ± 3.96	7.54 ± 3.21	6.80 ± 2.78	5.70 ± 2.71	7.83 ± 3.87	6.36 ± 3.54	5.69 ± 2.44	5.35 ± 1.32	6.58 ± 2.72	6.07 ± 2.10	NS
HOMA-IR	1.72 ± 0.82	1.89 ± 1.17	2.05 ± 1.20	1.41 ± 0.77	1.35 ± 0.51	1.73 ± 0.96	1.58 ± 0.74	1.42 ± 0.59	1.21 ± 0.60	1.57 ± 0.84	1.40 ± 0.88	1.23 ± 0.54	1.04 ± 0.27	1.33 ± 0.57	1.24 ± 0.45	NS
METs z-score	−3.16 ± 0.42	−2.99 ± 0.51	−2.93 ± 0.59	−3.04 ± 0.82	−3.00 ± 0.84	−3.14 ± 0.93	−3.23 ± 0.36	−3.33 ± 0.33	−3.49 ± 0.39	−2.88 ± 0.88	−3.26 ± 0.65	−3.39 ± 0.63	−3.20 ± 0.62	−3.24 ± 0.46	−3.54 ± 0.34	NS

Values are expressed as mean ± SD. NS, no significant interaction effect ($P > 0.05$).

provide the same positive cardiometabolic adaptations that are seen in the MICT group.

The results of this study support our hypothesis that a single session of HIIT weekly improves cardiorespiratory fitness and body composition in overweight or obese individuals. As we hypothesized, aerobic fitness was improved in the low-frequency HIIT intervention. According to the American College of Sports Medicine guidelines on endurance training and interval training, an exercise dose of fewer than 2 $d \cdot wk^{-1}$ might not result in a meaningful improvement in cardiorespiratory fitness (31). Contrary to these guidelines, we observed a significant improvement in aerobic fitness after 8 wk of HIIT×1/wk in comparison with CON. These findings are consistent with the data reported by Nakahara and colleagues (17), who demonstrated that healthy males who underwent 12 wk of three bouts of interval training at 80% maximum work rate (watts) once weekly induced significant improvements in aerobic fitness in comparison with subjects receiving no exercise intervention. Another study demonstrated that 6 wk of low-frequency HIIT improved aerobic fitness in sedentary and physically active individuals, but the findings were not compared with nonexercise control subjects (16). The HIIT×1/wk protocol showed greater improvement in aerobic fitness after 8 wk of the intervention than that shown in previous studies (16,17). It seems that the 12 × 1 min HIIT protocol in this study induced a greater improvement in aerobic fitness than that shown in previous studies (16,17). From a clinical perspective, low cardiorespiratory fitness is a strong predictor of cardiovascular disease (6), cardiovascular disease mortality (32), and all-cause mortality (33). Our findings of cardiorespiratory fitness improvement in HIIT×1/wk might provide a new time-efficient and practical exercise strategy to improve cardiorespiratory fitness and to reduce the risk of cardiovascular disease and related mortality. Rigorous, adequately powered, large-scale randomized controlled trials are warranted to validate the beneficial effects of low-frequency HIIT on boosting cardiorespiratory fitness and reducing cardiovascular disease morbidity and mortality.

The second aim of the present study was to compare the training efficacy between HIIT and MICT in overweight or obese individuals. Our data demonstrated that a higher intensity of exercise increased aerobic fitness to a greater extent than did moderate-intensity training. The evidence that HIIT exhibits greater aerobic training effects than does moderate-intensity exercise has been suggested by previous findings (10,34). Some studies have included molecular outcomes to provide mechanistic evidence for the observed adaptations from HIIT that exhibited greater improvements in aerobic performance. Tjonna and colleagues (35) showed that HIIT elevated PGC-1α levels and sarcoplasmic reticulum Ca^{2+} ATPase capacity in skeletal muscle to a greater extent than did moderate-intensity exercise. This finding suggested that HIIT might induce greater adaptations in mitochondrial biogenesis as well as a higher ability to maintain high-intensity muscle contractions.

Regarding body composition, two recent meta-analyses both concluded that regular HIIT and MICT showed similar

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efficacy on reductions in body fatness (36,37). Our findings are consistent with these meta-analyses; specifically, regular HIIT and MICT both reduced the percent body fat and absolute body fat mass but showed no significant difference with each other. Given the variation in the intensity between HIIT and MICT, the influence in energy metabolism during training was entirely different. When matched with the mechanical work outputs to MICT, HIIT relies more on carbohydrate oxidation for the contribution to energy expenditure (38). A higher proportion of free fatty acid oxidation was responsible for the metabolic responses of moderate-intensity exercise compared with high-intensity exercise (39). Because of the different mediation of energy expenditure between MICT and HIIT, the caloric expenses might not follow an intensity-dependent response. This might explain our findings that higher-intensity exercise did not elicit a superior effect in total body fat reduction. Although HIIT and MICT showed similar effectiveness on body fat reduction in the general or overweight population, both meta-analyses showed that HIIT is a time-efficient manner to improve body composition (36,37). Currently, we still lack evidence to delineate the time-efficient characterization of low-frequency HIIT on body fat loss. In the present study, a reduction in percent body fat and absolute body fat mass for different HIIT exercise frequencies was observed. Our data showed that even one session of HIIT weekly reduced percent body fat, absolute body fat mass, and trunk fat mass when compared with CON. This observation concurs with that of a previous study showing that one HIIT session every 5 d reduced body fat, as determined by bioelectrical impedance (15). Intriguingly, our results also showed no difference between the change in body fatness in the MICT×3/wk and HIIT×1/wk groups. This finding indicated that overweight or obese individuals might engage in a lower number of HIIT sessions weekly but still achieve benefits similar to those of regular MICT. Future studies are needed to confirm the present results and to distinguish the mechanisms of body fat reduction between high-frequency MICT and low-frequency HIIT. Furthermore, our results showed that compared with MICT×3/wk, all exercise frequencies of HIIT exhibit a faster rate of improvement. It is important to note that overweight or obesity might increase the risk of developing chronic diseases, such as diabetes mellitus (3), hypertension (4), and cardiovascular disease (5). Our results demonstrated that low-frequency HIIT might be a time-efficient strategy to reduce total body fat mass and abdominal body fat mass in overweight and obese individuals. Based on our preliminary results, it is warranted to conduct long-term, large-scale trials to confirm the favorable effects of low-frequency HIIT on alleviating obesity.

In the present study, we observed that all exercise interventions did not alleviate most of the metabolic syndrome risk factors (i.e., fasting glucose, HDL-C, triglycerides, waist circumference), insulin resistance, and vascular function among overweight or obese individuals, and these observations concur with those of a recent meta-analysis showing that HIIT exhibits no effects on insulin and lipid profiles in overweight or obese individuals (40). For the reduction in blood pressure, a recent meta-analysis of randomized trials compared changes from baseline and postintervention assessment, and both regular HIIT and MICT provided comparable effects on reducing resting SBP and DBP in middle-age adults, with SBP ≥ 130 mm Hg and/or DBP ≥ 85 mm Hg (41). In our study, the effects on alleviating SBP, DBP, and MAP were observed to be homogeneous between HIIT×3/wk and MICT×3/wk. It is worth noting that although only 57% of our young adult subjects were prehypertensive or hypertensive (i.e., SBP ≥120 mm Hg) in the present study, we still observed consistent results in the improvements in SBP, as reported in the previous meta-analysis (41) concerning the effects in middle-age adults. Collectively, it seems that exercise intensity is unlikely to alter the efficacy of the reduction in blood pressure. Moreover, our findings demonstrated that even HIIT×1/wk induced a significant reduction in SBP. Additional studies are warranted to reveal the minimal exercise dose of HIIT required to reduce blood pressure in prehypertensive or hypertensive individuals. Further investigation is needed to reinforce the usefulness of low-frequency HIIT in alleviating elevated blood pressure in patients with prehypertension or hypertension.

Low-frequency HIIT generally required a period of 6 to 12 wk to induce a significant improvement in cardiovascular fitness (16,17). Interestingly, we observed that aerobic capacity was improved just after 4 wk of HIIT×1/wk. These findings further extended our understanding that low-frequency HIIT might induce a rate of improvement in cardiorespiratory fitness comparable with that of other exercising frequencies of HIIT. Although MICT and HIIT exhibited similar effects on reducing body fatness, our data revealed that all HIIT interventions, but not MICT, reduced percent body fat and absolute body fat mass after 4 wk of training. Our results suggested that the beneficial adaptations from regular and low-frequency HIIT can be acquired with shorter training periods than those associated with MICT.

With respect to safety, Rognmo and colleagues (42) have studied coronary heart disease patients for whom the risk of cardiovascular events after HIIT or MICT training was similarly low. In this study, no serious adverse events were observed. Of note, three subjects in the HIIT×3/wk and MICT×3/wk groups experienced minor overuse injury, whereas no training-related injury event occurred in HIIT×2/wk and HIIT×1/wk. These results suggested that a higher dose of HIIT weekly might lead to greater exposure to overuse injury in lower limb joints. Furthermore, a higher adherence rate was observed in HIIT×2/wk (66%) and HIIT×1/wk (64%) than that in HIIT×3/wk (45%). It seems that HIIT×2/wk and HIIT×1/wk are more feasible and safer for use as a prescription for initiating exercise training in the overweight and obese population. We speculated that a lower frequency of HIIT might have induced higher exercising motivation because of the lower time commitment. However, additional investigations with comprehensive psychological assessments are needed to verify this speculation.

Several limitations of this study need to be noted. First, this study compared only the exercise frequency of HIIT but not that of MICT, and this study design might not be able to fully delineate the role of the exercise frequency of HIIT versus that of MICT. Future studies are also needed to investigate the “weekend warrior” exercising pattern (i.e., all the recommended weekly exercising volume is accumulated on only 1 or 2 $d \cdot wk^{-1}$) to show the complete picture of the effects of different exercise patterns on aerobic training adaptations. Second, HIIT/SIT with less than 15 min of high-intensity bouts generally improves 6.5% of $\dot{V}O_{2max}$ (43), and a previous study showed that walking interval training improves 16.1% of $\dot{V}O_{2max}$ in type 2 diabetic patients (44). Compared with the aforementioned studies, a relatively greater improvement in estimated $\dot{V}O_{2max}$ (i.e., 19.6%) was observed in the HIIT×3/wk group. Therefore, further investigation is needed to confirm the training effect of this shuttle run–based HIIT with a gaseous analysis measurement approach. Third, our exercise intervention showed no significant changes in endothelial function, fasting blood glucose, blood lipid profile, and inflammatory profile in overweight and obese individuals. Given that impairments in endothelial function and aberrant blood lipid and inflammatory profiles were not used as inclusion criteria in subject recruitment in the present study, further investigations are needed to examine the effects of low-frequency HIIT in individuals with abnormal baseline values of these physiological parameters, such as patients with diagnosed diabetes mellitus, clinical hypertension, or severe endothelial dysfunction. As blood glucose was measured in the fasting state in this study, an oral glucose tolerance test might be needed to examine the effects of low-frequency HIIT on insulin resistance in obese or diabetic individuals. Fourth, the hormonal changes in female subjects could affect aerobic performance during the midtest and posttest, but this study included only overweight young men. Future studies should include female subjects to increase the generalization of the findings. Finally, subjects were instructed to maintain their dietary intake and daily physical activities during the experimental period. A standardized diet, a detailed dietary intake record, and a daily activity record might be adopted in future studies to eliminate the influence of dietary intake during the experimental period.

In conclusion, our data revealed that HIIT performed once weekly was sufficient to induce significant improvements in aerobic fitness, body composition, and blood pressure in overweight or obese young adults. The current study demonstrated the advantages attributed to field-based HIIT with minimal weekly time commitment. Furthermore, compared with regular MICT, low-frequency HIIT showed a faster rate of improvement in cardiovascular fitness and reduction in body fatness. Low-frequency HIIT might be a practical approach for inactive and overweight individuals to initiating exercise training.

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