Low-Volume High-Intensity Interval Training as a Therapy for Type 2 Diabetes

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Introduction

Type 2 diabetes mellitus (T2DM) is a highly prevalent disease associated with increased levels of morbidity, mortality, and health care expenditure [28, 39]. Regular physical activity has been recognized as an important tool for preventing and managing T2DM and its complications, including glycemic control, cardiometabolic risk, and psychological well-being [9]. In this context, physical activity is a first-line treatment for T2DM patients, and a minimum of 150 min/wk (30 min, 5 d/wk) of moderate to vigorous aerobic exercise, in association with 2–3 sessions per week of resistance training, has been recommended in the current American Diabetes Association and American College of Sports Medicine guidelines [9]. Continuous activities that cause a sustained heart rate (HR) increase (i.e., walking, cycling, or jogging at ~55–70% of maximal HR) has been commonly recommended to meet this aerobic exercise recommendation [9]. However, high-intensity interval training (HIIT), which consist of several bouts of high-intensity exercise interspersed with intervals of rest or active recovery [8], may have superior effects for improving glycemic control [10] and other health-related markers [5, 8, 37]. For example, HIIT showed greater improvements on cardiorespiratory fitness [6, 7, 25, 31, 38], endothelial function and its markers [6, 31], blood lipoprotein and glucose [31], insulin sensitivity and fasting insulin [31, 32], markers of sympathetic activity [6, 7] and arterial stiffness [6, 13] compared to energy-expenditure-matched continuous moderate exercise.

It is noteworthy that only 2 weeks (6 exercise sessions) of low-volume HIIT has shown improvements in glycemic control of T2DM patients [20, 27]. Low-volume HIIT is also time-efficient, with a weekly time commitment 56–25% lower than the minimal recommended in current guidelines. These findings suggest that low-volume HIIT may be a time-efficient intervention to treat T2DM women.

Abstract

Our purpose was to investigate the effects of low-volume, high-intensity interval training (HIIT) on cardiometabolic risk and exercise capacity in women with type 2 diabetes mellitus (T2DM). Sedentary overweight/obese T2DM women (age = 44.5 ± 1.8 years; BMI = 30.5 ± 0.6 kg/m²) were randomly assigned to a tri-weekly running-based HIIT program (n = 13) or non-exercise control follow-up (CON; n = 10). Glycemic control, lipid and blood pressure levels, endurance performance, and anthropometry were measured before and after the follow-up (16 weeks) in both groups. Medication intake was also assessed throughout the follow-up. Improvements (P<0.05) on fasting glucose (14.3 ± 1.4 %), HbA1c (12.8 ± 1.1 %), systolic blood pressure (3.7 ± 0.5 mmHg), HDL-cholesterol (21.1 ± 2.8 %), triglycerides (17.7 ± 2.8 %), endurance performance (9.8 ± 1.0 %), body weight (2.2 ± 0.3 %), BMI (2.1 ± 0.3 %), waist circumference (4.0 ± 0.5 %) and subcutaneous fat (18.6 ± 1.4 %) were found after HIIT intervention. Patients of HIIT group also showed reductions in daily dosage of antihyperglycemic and antihypertensive medication during follow-up. No changes were found in any variable of CON group. The HIT-induced improvements occurred with a weekly time commitment 56–25% lower than the minimal recommended in current guidelines. These findings suggest that low-volume HIT may be a time-efficient intervention to treat T2DM women.
barrier to regular exercise participation [33], these findings may have important implications from a public health perspective. However, low-volume HIT studies with T2DM patients are of short-duration (only 2 weeks), small sample size, and lack an appropriate control group [10, 27]. Studies analyzing the effects of longer periods of low-volume HIT on glycemic control and others treatments goals in T2DM are lacking (i.e., lipid and blood pressure levels, drug therapy optimization) [9]. Thus, the aim of the present study was to investigate the effects of 4 months of low-volume HIT on glycemic control, lipid and blood pressure levels, endurance performance, medication intake and anthropometry of T2DM women.

Methods

Population and study design
We studied adult overweight or obese (BMI between 25 and 35 kg/m²) adult women with established diagnosis of T2DM for at least 12 months. Eligibility criteria included fasting hyperglycemia > 126 mg·dL⁻¹ and glycated hemoglobin (HbA₁c) ≥ 6.5% [9], unchanged drug therapy during the previous 6 months, sedentary or insufficiently active life style (according to the International Physical Activity Questionnaire previously validated in Chilean population) [26], non-involvement in regular physical activity or exercise program during the previous 6 months, and family history of T2DM (mother and/or father). Patients with musculoskeletal disorders, cardiovascular contraindications to exercise, history of stroke, asthma and chronic obstructive pulmonary disease, long-term diabetic complications (history of foot injury, retinopathy, nephropathy, and diabetic peripheral neuropathy), or smokers were not included in the study. A minimum of 70% of exercise program compliance was required in order for the intervention group patients to be included in the final statistical analyses.

84 T2DM women (age 35–55 years), with less than 5 years of diagnosis, patients of the Family Healthcare Center Tomas Rojas of Los Lagos (Chile) that answered a telephone call with explanations about the study protocol, agreed to participate in the present investigation. A structured medical records review and physical examination by a physician were performed in all patients for eligibility criteria assessment. 28 T2DM patients who met all of the inclusion criteria were included in the present study (Fig. 1). Subjects were then randomly assigned in a 1:1 ratio to 16-week HIT (n = 14, age = 46.0 ± 3.0 years, BMI = 30.8 ± 1.0 kg/m²) or non-exercise control (CON; n = 14, age = 43.0 ± 2.4 years, BMI = 30.6 ± 1.0 kg/m²) intervention, using a computer generated random assignment. Fasting glucose, HbA₁c, and lipids levels, resting blood pressure, endurance performance and anthropometry were assessed before and after the 16-week follow-up in both groups. All assessments were performed by examiner who were blinded to the patients’ intervention group. Hypoglycemic medication intake was controlled throughout the follow-up and, if necessary, changes were performed following the recommendations to continue preventing hypoglycemia events in T2DM patients under regular exercise [1]. Patients in HIT group performed a tri-weekly progressive exercise program, which consisted of jogging/running intervals interspersed with recovery periods of low-intensity walking. Patients in CON group were advised not to engage in any exercise/physical activity programs during the study. All patients (HIT and CON) were oriented to maintain their daily living physical activity and dietary patterns throughout the 16-week study period. The present study is in accordance with the ethical standards of the International Jour-
nal of Sports Medicine [14], and was approved by the ethics committees of the Department of Physical Activity Sciences of the University of Los Lagos and of the Family Healthcare Center Tomás Rojas of Los Lagos. All volunteers read a detailed description of the study protocol and provided their written informed consent.

Blood analyses
Blood samples (nearly 3.5 ml) were collected before and after the 16-week follow-up, at morning and after a 10 h overnight fasting. The post-training blood sampling of HIT patients were performed at least 48 h after the last exercise session to avoid an acute effect of exercise. Samples were immediately placed in ice and centrifuged at 4000 rpm (1 700 x g) for 5 min at ~4°C. Plasma samples were immediately transferred to pre-chilled microtubes and stored at −20°C for later analysis. HbA1c was analyzed by high performance liquid chromatography (Variant™ II Turbo Hemoglobin Testing System, Bio-Rad Inc., Hercules, CA, USA). Plasma glucose, total cholesterol and triglycerides were analyzed by enzymatic methods using standard kits (Wiener Lab Inc., Rosario, Argentina) on an automatic analyzer (Metrolab 2300 Plus™, Metrolab Biomed Inc., Buenos Aires, Argentina). Plasma HDL cholesterol was measured by the same enzymatic method after phosphotungstate precipitation. LDL cholesterol levels were calculated using the Friedewald formula [11].

Blood pressure and anthropometric measurements
Blood pressure measurements were performed one week before and after the 16-week follow-up, with an automatic monitor (Omron HEM 7114™, Omron Healthcare Inc., Lake Forest, IL, USA), in triplicate (2 min of interval between measurements), after 15 min of resting, and with the patients in seated position. The blood pressure measurements were repeated in 3 non-consecutive days, at the same time of morning (between 8:00 and 11:00 a.m.). The mean of the 9 blood pressure measurements, performed both before and after the follow-up, were registered and used for inter- and intra-group analyses [4]. Anthropometric measurements were also performed one week before and after the 16-week follow-up in all patients. Body mass (kg) was measured (to the nearest of 0.1 kg) by a digital scale (Omron HBF-INT™, Omron Healthcare Inc., Lake Forest, IL, USA), with minimum of clothes and no shoes. Height (m) was measured without shoes, using a standard stadiometer (Health o Meter™ Professional, Sunbeam Products Inc., Chicago, IL, USA), to the nearest of 0.1 m. Body mass index (BMI) was calculated as body mass divided by height squared (kg/m²). Waist circumference (cm) was measured to the nearest of 0.1 cm, using a flexible and inextensible measuring tape (Hoechstmass™, Sulzbach, Germany). Assessment of skinfolds thickness was performed using a Lange™ skinfold caliper (Beta Technology Inc., Santa Cruz, California, USA), according to the International Society for the Advance of Kinanthropometry [21], in 4 sites (tricipital, sub-scapular, sub-sitiliac and mid-leg).

Endurance performance assessment
Endurance performance was assessed one week before and after the 16-week follow-up by the 2 km walking test [19]. In brief, the test was performed in an indoor sports court (100 m track), after a 10 min warm-up (low-intensity walking and slow movements involving the knee and ankle joints). Patients were then instructed to walk as fast as possible with a steady pace. Heart rate was continuously monitored (ProTrainer 5™, Polar Electro Inc., Kempele, Finland). In order to warrant an accurate test [19], patients were encouraged to walk faster if their heart rate was lower than 75% of maximum age-predicted heart rate. The time spent in walking the 2 km was measured and used for analysis. All tests were carried out between 8:00 and 10:00 a.m.

Exercise training intervention
Participants of HIT group performed a tri-weekly progressive HIT program for 16 weeks. All exercise sessions were performed on a flat surface (indoor sports court), and supervised by an exercise specialist. The progressive HIT program was based on high-intensity exercise intervals (jogging/running) interspersed with low-intensity active recovery (walking). Patients’ heart rate was continuously monitored (ProTrainer 5™, Polar Electro Inc., Kempele, Finland). During all HIT sessions, patients were instructed by the exercise specialist to jog/run and walk using a steady pace, which should be controlled by maintaining a perceived exertion between 15–17 (jogging/running) and <9 (walking) in the 15-point rating of perceived exertion scale [2]. The goal was to reach 90–100% and less than 70% of their age-predicted reserve heart rate [18] at the end of each jogging/running and walking interval, respectively. Thus, all patients were continuously oriented to adjust their jogging/running or walking pace, if their heart rate was not in the goal at the end of the previous interval. The progressive HIT program started (week 1–2) with 8 jogging/running intervals of ~30s interspersed with ~120s of low-intensity walking. To promote sufficient workload for eliciting improvements throughout the follow-up, there was a 7–10% increase in the high-intensity interval duration and a 4% decrease in the recovery interval duration every 2 weeks. There was also an increase of 2 exercise intervals every 4 weeks of follow-up. With the exercise intensity/volume progression, total working duration ranged from 4 to 13.5 min (week 1–16), total recovery duration ranged from 18 to 24 min (week 1–16) and number of intervals ranged from 8 to 14 (week 1–16). Thus, the exercise session duration ranged from 22 min to 37.5 min (week 1–16), totaling 66 min/wk (week 1) to 112.6 min/wk (week 16) of exercise. A detailed description of the HIT volume and intensity progression during follow-up is showed in Table 1.

Statistical analyses
Data are reported as mean ± standard error of the mean (SEM) or median and interquartile ranges. Statistical analyses were performed using SPSS™ statistical software version 18.0 (SPSS Inc., Chicago, IL, USA). Normality and homoscedasticity of variables were determined using the Shapiro-Wilk and Levene tests, respectively. Two-way ANOVA with repeated measures (group vs. time) was used to indicate inter- and intra-interventions differences in the data presenting Gaussian distribution. The Bonferroni’s post hoc test was performed to identify significant differences indicated by ANOVA.

Results
Four patients of CON group were lost to follow-up because of failure to communicate a change in residence address (N=2) or in health center of treatment (N=2). One patient of HIT group was excluded from final analysis because she did not have the minimal exercise training compliance of 70%. Thus, 23 overweight or obese T2DM patients completed the 16-week follow-up and were included in the final analysis (Fig. 1). No
significantly, baseline differences between HIT and CON patients were found in any variable (Table 2, Fig. 2). There was also no significant differences in baseline characteristics between patients who completed the follow-up and those who did not (data not shown).

The exercise program was well tolerated by all patients, and there were no injuries during the training program. The exercise compliance was 89 ± 5% during the 16-week follow-up. 7 patients of HIT group reduced their daily dosage of metformin and glibenclamide during the follow-up. First, the dosage was reduced only in the exercise training days (tri-weekly) due to episodes of post-exercise hypoglycemia that started 1 h after the exercise session (from the 11th week of follow-up). Then, the dosage was reduced in all days of week (from the 11th week of follow-up) due to increasing episodes of hypoglycemia in the non-exercise days. The 3 HIT patients under antihypertensive drug therapy before follow-up stopped taking the medication after physician recommendation at a routine medical consultation (from the 11th week of follow-up). There were no changes in any medication dosage intake in the CON group during follow-up (Table 2).

The 2-way ANOVA indicated significant interactions between inter- and intra-intervention in fasting glucose ($F_{1,9} = 87.78$, $P < 0.001$), HbA1c ($F_{1,9} = 128.29$, $P < 0.001$), HDL cholesterol ($F_{1,9} = 57.81$, $P < 0.001$), triglycerides ($F_{1,9} = 20.27$, $P = 0.001$), systolic ($F_{1,9} = 37.29$, $P < 0.001$) and diastolic blood pressure.

### Table 1 Characteristics of low-volume, high-intensity interval training during follow-up.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Weeks 0–4</th>
<th>Weeks 5–9</th>
<th>Weeks 10–13</th>
<th>Weeks 14–16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise intensity (% HR$_{RESERVE}$)</td>
<td>90–100</td>
<td>90–100</td>
<td>90–100</td>
<td>90–100</td>
</tr>
<tr>
<td>Exercise duration (s)</td>
<td>30–34</td>
<td>38–44</td>
<td>46–50</td>
<td>52–58</td>
</tr>
<tr>
<td>Number of exercise bouts</td>
<td>8</td>
<td>10</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Exercise time commitment/day (min)</td>
<td>4–4.5</td>
<td>6.3–7.3</td>
<td>9.2–10</td>
<td>12.1–13.5</td>
</tr>
<tr>
<td>Exercise time commitment/week (min)</td>
<td>12–13.5</td>
<td>19–21.9</td>
<td>27.6–30</td>
<td>36.4–40.6</td>
</tr>
<tr>
<td>Exercise method</td>
<td>jogging/running</td>
<td>jogging/running</td>
<td>jogging/running</td>
<td>jogging/running</td>
</tr>
<tr>
<td>Recovery intensity (% HR$_{RESERVE}$)</td>
<td>≤ 70%</td>
<td>≤ 70%</td>
<td>≤ 70%</td>
<td>≤ 70%</td>
</tr>
<tr>
<td>Recovery duration (s)</td>
<td>120</td>
<td>108</td>
<td>100</td>
<td>96</td>
</tr>
<tr>
<td>Number of recovery bouts *</td>
<td>9</td>
<td>11</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Recovery method</td>
<td>walking</td>
<td>walking</td>
<td>walking</td>
<td>walking</td>
</tr>
<tr>
<td>Total time commitment/day (min)</td>
<td>22–22.5</td>
<td>26.1–27.1</td>
<td>30.9–31.7</td>
<td>36.1–37.5</td>
</tr>
<tr>
<td>Total time commitment/week (min)</td>
<td>66–67.5</td>
<td>78.3–81.3</td>
<td>92.6–95</td>
<td>108.4–112.6</td>
</tr>
</tbody>
</table>

* All sessions started and ended with a recovery bout

### Table 2 Subjects’ characteristics before and after the experimental protocol.

<table>
<thead>
<tr>
<th>Variable</th>
<th>HIT (N = 13)</th>
<th>CON (N = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Age (y)</td>
<td>45.6 ± 3.1</td>
<td>43.1 ± 1.5</td>
</tr>
<tr>
<td>Time elapsed from diagnosis (y)</td>
<td>3.4 ± 1.1</td>
<td>3.6 ± 1.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>1.56 ± 0.02</td>
<td>1.58 ± 0.02</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>73.8 ± 2</td>
<td>72.2 ± 1.9</td>
</tr>
<tr>
<td>Body mass index (kg/m$^2$)</td>
<td>30.6 ± 1.1</td>
<td>29.9 ± 1.1</td>
</tr>
<tr>
<td>Waist circumference (cm)</td>
<td>101.1 ± 2.4</td>
<td>97.0 ± 2.1</td>
</tr>
<tr>
<td>$\Sigma 4$ Skin-folds (mm)</td>
<td>147 ± 6</td>
<td>119 ± 4.4**</td>
</tr>
<tr>
<td>Endurance performance (min) *</td>
<td>23.2 ± 0.2</td>
<td>21.0 ± 0.3***</td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic (mmHg)</td>
<td>132 ± 1</td>
<td>129 ± 1*</td>
</tr>
<tr>
<td>Diastolic (mmHg)</td>
<td>77 ± 1</td>
<td>77 ± 1</td>
</tr>
<tr>
<td>Current medication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metformin (N) (mg/day)</td>
<td>13 (700 ± 0)</td>
<td>13 (1242 ± 122)</td>
</tr>
<tr>
<td>Glibenclamide (N) (mg/day)</td>
<td>12 (5 ± 0)</td>
<td>12 (3.7 ± 0.4)</td>
</tr>
<tr>
<td>ACE inhibitor (N) (mg/day)</td>
<td>3 (10 ± 0)</td>
<td>0</td>
</tr>
<tr>
<td>Levothyroxine (N) (mg/day)</td>
<td>1 (100 ± 0)</td>
<td>1 (100 ± 0)</td>
</tr>
</tbody>
</table>

ACE: angiotensin converting enzyme; HIT: high-intensity interval training group. CON: non-exercise control group. T2DM: type 2 diabetes mellitus. * Endurance performance was measured by the time to complete the 2-km walking test. Asterisks denote significant difference from pre follow-up in the same group (\(* = P < 0.05; \** = P < 0.01; \*** = P < 0.001\)). Daggers denotes significant difference from HIT during the same period (\(* = P < 0.05; \** = P < 0.01\)).
group during follow-up (Table 2). HIT group also showed a reduced body mass (1.6±0.2 kg, P<0.05), BMI (2.1±0.3, P<0.05), waist circumference (4.1±0.6 cm, P<0.01) and skinfold thickness (18.6±1.4, P<0.001) during follow-up (Table 2). Finally, the HIT group improved its endurance performance as shown by a reduced time (9.8±1.0, P<0.001) to complete the 2KWT. The CON group did not change any variable during follow-up. With these results, the HIT group displayed improved levels of fasting glucose, HbA1c, HDL cholesterol, triglycerides, endurance performance, waist circumference and skinfold thickness compared to the CON group after the experimental protocol.

Discussion

The present study investigated the effects of a low-volume HIT program in T2DM women. The primary finding was that the HIT program was effective for reducing fasting glucose and HbA1c levels during 16 weeks of follow-up, which occurred even with a reduction in the daily dosage of antihyperglycemic medication. In addition, the HIT program was also effective for improving lipid profile, blood pressure levels, endurance performance and body composition of T2DM women. To the best of our knowledge, this is the first randomized controlled study that evaluated the effects of a long-term (>12 weeks) low-volume HIT program in T2DM women.

Aerobic and resistance exercise training have shown improvements over the glycemic control in T2DM patients [3, 29, 35, 36]. Although a pioneer meta-analysis showed that exercise intensity was a stronger predictor for HbA1c improvements than exercise volume [3], recent meta-analyses did not confirm this association [35, 36]. For example, an absolute 0.89% (95% CI, −1.26% to −0.51%) reduction in HbA1c levels has been found after exercise programs with volume >150 min/wk, which were greater than the absolute 0.36% (95% CI, −0.50% to −0.23%) reduction observed after exercise programs with volume <150 min/wk [35]. Accordingly, a minimum of 150 min/wk (30 min, 5d/wk) of moderate to vigorous aerobic exercise, in association with 2–3 sessions per week of resistance training, has been recommended in the current American Diabetes Association and American College of Sports Medicine guidelines [9]. However, recent studies with HIT programs have suggested that exercise intensity may have a key role in T2DM management. When compared to energy expenditure-matched continuous moderate exercise, HIT programs have shown greater improvements in HbA1c [23], fasting insulin [17, 23], glucose control assessed by continuous glucose monitoring [17] and others cardiovascular risk factors [17, 23] in T2DM patients. In the present study, it was shown for the first time that a 16-week progressive low-volume HIT program, with a weekly time commitment 56–25% (66–112.6 min/wk divided in 3 exercise sessions) lower than the minimum recommended by current guidelines [9], resulted in improvements of glycemic control (HbA1c, and fasting glucose levels), lipid profile, blood pressure, endurance performance and body composition (BMI, waist circumference and subcutaneous fat) in T2DM women. It is noteworthy that the mean absolute reduction of 0.9% on HbA1c levels was similar to the reductions found in exercise programs with volume >150 min/wk [35], and occurred even with a reduction in daily dosage of diabetes medication. These results confirm the time-efficiency of low-volume HIT to T2DM management, which has been sug-

![Figure 2](https://example.com/figure2.png)
gested by uncontrolled studies with short-duration (only 2 weeks) and small sample size [20,27]. The mechanism involved in the superior effects of HIT on glycemic control of T2DM patients is not completely understood. One might speculate that the −1.6 kg reduction on body mass, which was probably due to the reductions on visceral (−4.1 cm reduction on waist circumference) and subcutaneous fat (−28.0 mm reduction on sum of 4 skinfold thickness), may be involved in the glycemic control improvements found after the low-volume HIT program. However, a previous study showed that a greater HIT-induced reduction on body mass (−4.2 kg), which was due to reduction on fat mass (no changes on fat free mass was found), accounted for maximally 25% of the glycemic control improvements found after a HIT program [16]. Therefore, improvements on skeletal muscle insulin sensitivity, explained by increased peripheral glucose disposal probably due to increased GLUT4 protein content and mitochondrial capacity [16,20], appears to be involved in the low-volume HIT-induced improvements on glycemic control found in the present study. In addition, the −14.3 mg/dL reduction on plasma fasting glucose observed after low-volume HIT, but not after CON intervention, does not allow to rule out a training-induced improvement on hepatic glucose output.

The present low-volume HIT program also resulted in significant reduction of systolic (but not diastolic) blood pressure (−3.7 mmHg), which occurred even after the 3 patients who were under antihypertensive drug therapy prior to the intervention stopped taking the medication during the follow-up. Although there is a study showing a greater HIT-induced systolic blood pressure reduction (−13 mmHg) compared to the one found in the present study [23], other HIT intervention studies in T2DM patients have shown no training-induced improvements on blood pressure [15,17]. HIT-induced improvements on lipid profile in T2DM patients has also been inconsistent in the literature. There are studies showing improvements only in LDL cholesterol [17], in both LDL and HDL cholesterol [23], or no improvements [30]. The same studies also showed no HIT-induced improvements on triglycerides in T2DM patients [17,23,30]. In the present study, we showed improvements on HDL cholesterol and triglycerides levels, but not in LDL cholesterol levels, after the 16-week low-volume HIT. Differences in exercise intensity and volume of HIT protocol, as well as in intervention duration may explain discrepancies between studies on training-induced improvements in blood pressure and lipid profile.

The training-induced improvements observed in the present study occurred after a HIT protocol of jogging/running and walking over ground that was prescribed using an easy and inexpensive method [18]. This is an unique strength of the present study, because most of intervention studies in T2DM patients have based HIT prescription on cardiopulmonary exercise testing [17,20,23,27] and using ergometers for training [20,23,27], which are expensive and may reduce HIT access to general population [8]. However, the present study investigated only overweight or obese women with less than 5 years of diagnosis and with no disease-related complications. This limitation makes it difficult to extrapolate present findings for other populations, mainly long-standing T2DM patients with complications. We did not provide any control for dietary changes during the study and for physical activity during daily life after the intervention. However, both HIT and CON groups were instructed to maintain their dietary and daily physical activity patterns throughout the 16-week study period.

Clinical implications

It is well known that T2DM is becoming increasingly prevalent worldwide; it is also known that not only an improvement in glycemic control but a reduction in cardiovascular risk factors can positively affect disease morbidity, mortality and health care expenditures [22,28,34,39]. For example, decreases of 2.1/0.9 mmHg on systolic/diastolic blood pressure reduced major cardiovascular events by 10% in T2DM patients [34]. Decreases of 2–3% in the risk for developing coronary artery disease has been suggested for each 1 mg/dL increase in HDL cholesterol [22]. In this context, the HIT-induced improvements in systolic blood pressure (−3.7 mmHg) and HDL cholesterol (+10.1 mg/dL) may have important clinical implications. Moreover, the low-volume HIT program resulted in low daily dosage of diabetes medication in 54% (7 patients) of the trained population, and the 3 HIT patients taking anti-hypertensive medication before training stopped taking it during follow-up. Thus, the present low-volume HIT program also has important implications for reducing health care expenditures for medication. Finally, the current low-volume HIT program resulted in glycemic control improvements similar to those observed with greater volumes of exercise (>150 min/wk) [35]. Given that most T2DM patients are sedentary or insufficiently active [24], and lack of time is the most frequently cited barrier to regular exercise participation [33], these findings may have important implications for a public health perspective. In summary, the low-volume HIT program was effective to improve glycemic control, lipid and blood pressure levels, endurance performance, medication dosage used and anthropometry in T2DM women with a weekly time commitment 56–25% lower than the minimal recommended in current guidelines [9]. These findings suggest that low-volume HIT may be a time-efficient intervention to treat T2DM women.

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Conflict of interest: There are no conflicts of interest to declare.

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15 American Heart Association; 2005

14 The American College of Sports Medicine; 2007

13 American Heart Association; 2006

12 International Society for the Advancement of Kinanthropometry (ISAK); 2006

11 American Diabetes Association; 2013

10 American College of Sports Medicine; 2014

9 American Diabetes Association; 2014

8 American Diabetes Association; 2013

7 American Diabetes Association; 2012

6 American College of Sports Medicine; 2014

5 American Diabetes Association; 2014

4 American Diabetes Association; 2014

3 American Diabetes Association; 2013

2 American Diabetes Association; 2013

1 American Diabetes Association; 2013