Impact of high-intensity interval training on HbA1c in patients with type 2 diabetes mellitus

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Received 21 September 2015
Accepted 10 November 2015

Bulletin of Faculty of Physical Therapy
2015, 20:168–175

Background

Exercises are often recommended for patients with type 2 diabetes mellitus (T2DM) to improve physical conditioning and glycemic control.

Objective

The aim of this study was to determine the impact of high-intensity interval training (HIIT) on glycated hemoglobin (HbA1c) in T2DM on a short-term basis (after 12 weeks of training).

Patients and methods

Forty patients women diagnosed with T2DM were selected from the outpatient clinic of Faculty of Physical Therapy, Cairo University; their ages ranged from 55 to 65 years.
Patients were assigned randomly to two equal groups (n = 20). Group A, the study group, received HIIT and training by treadmill and group B, the control group, received training by treadmill. Exercise training was performed for 20–38 min for group A and for 20–30 min for group B three times a week for 12 weeks. HbA1c was evaluated before training and after 3 months of training (after training).

Results

There was a statistically significant difference in the two groups in HbA1c, where the mean values for group A before and after treatment were 6.290 ± 0.130 and 5.460 ± 0.092, respectively, and those for group B before and after treatment were 6.405 ± 107 and 6.025 ± 0.156, respectively. Also, there was a statistically significant difference between the two groups in HbA1c (P = 0.04), where group A showed greater improvement in HbA1c than group B on a short-term basis.

Conclusion

Regular participation in HIIT was more effective and an alternative to aerobic training in improving HbA1c in T2DM.

Keywords:

HbA1c, high-intensity interval training, type 2 diabetes mellitus

Bulletin of Faculty of Physical Therapy 20:168–175

1110-6611

Introduction

Diabetes is a global endemic with a rapidly growing prevalence in both developing and developed countries [1]. Diabetes is associated with premature mortality, predominantly through atherosclerotic vascular disease and microvascular complications that affect small blood vessels in the eye, kidney, and nerves, and considerable morbidity [2].

Exercise is one of the cornerstones of diabetes management; it remains by far the most underused. Its beneficial health effects for almost everyone are well established and include improvements in glycemic control, insulin action, cardiovascular fitness, systemic inflammation, diabetes-related health complications, and mental health. Given its positive health impact, it is critical that practitioners encourage almost all of their diabetic and prediabetic patients to become and remain regularly physically active. Recommendations of physical activity are a crucial part of effective care for patients with diabetes [3]. Interval training refers to intermittent exercise involving periods of exercise, followed by periods of recovery, which enables anyone to increase the intensity of the exercise workload. The problem, however, with the term 'high intensity' is that it is descriptive and, obviously, relative to an individual's level of fitness and dependent on one's tolerance to exertion [4].

High-intensity interval training (HIIT) or sprint interval training is a strategy that is intended to improve performance with short training sessions. A HIIT session involves a warm-up period, several short, maximum-intensity efforts separated by moderate recovery intervals, and a cool-down period [5].

A combination of aerobic and resistance exercise improves physical fitness, glycemic control, and insulin

 DOI: 10.4103/1110-6611.174710

sensitivity in patients with diabetes [6–8]. Moderate-intensity progressive resistance exercise for 3 months resulted in a significant improvement in insulin sensitivity, glycemia, and lipids in patients with type 2 diabetes mellitus (T2DM). Resistive training should be an integral part of an exercise regimen in T2DM patients [9]; thus, the aim of this study was to determine the impact of HIIT on glycated hemoglobin (HbA1c) in T2DM on a short-term basis (after 12 weeks of training).

Patients and methods

Patients

Forty diabetic patients, ranged in age from 55 to 65 years, were screened and selected randomly to be enrolled into this 12-week blinded randomized-controlled trial. They were recruited from outpatient clinics of the Faculty of Physical Therapy, Cairo University, to participate in this study. This study was approved by the Ethics Committee for Scientific Research of the Faculty of Physical Therapy, Cairo University.

Forty patients with T2DM (40 women) fulfilled the inclusion criteria of the study, provided informed consent to participation and publication of the results of the study, underwent the initial evaluation, and completed the training course and the final statistical analysis.

Inclusion criteria were as follows: established T2DM for more than 7-year duration, treatment only with oral hypoglycemic agents (not taking insulin), BMI less than or equal to 40, an inactive previous lifestyle for at least the previous 6 months, and patient HbA1c more than or equal to 6.2.

Exclusion criteria were BMI more than equal to 40, age older than 65 or younger than 55 years, severe retinopathy, neuropathy, visual problems not corrected, nephropathy, patients who had scars under their feet, history of serious cerebrovascular or cardiovascular diseases, and severe musculoskeletal problems restricting physical activity.

Initial medical screening was performed for each patient by the physician and clinical history was documented for all participants. Study protocol and the objectives of the study were thoroughly explained to all participants, who were asked to maintain their pharmacological treatment, regular diet, and normal daily activities and lifestyle throughout the study.

To avoid a type II error, a preliminary power analysis [power ($1-\alpha$ error P) = 0.85, α = 0.01, effect size = 0.5] determined a sample size of 40 for this study. This effect size was chosen because it yielded a realistic sample size [10].

To avoid bias, patients' random assignments were performed through two stages: first, colleague physical therapists who were working in the outpatient clinics of the Faculty of Physical Therapy, Cairo University, reported all patients who fulfilled the inclusion criteria of the study. Second, after medical counseling, patients were assigned randomly to either group A, the study group, which received HIIT, and group B, the control group, which received training by treadmill. This was done by opening an opaque envelope prepared by an independent individual with random number generation.

The exercise program was established in accordance with the American College of Sport Medicine (ACSM) guidelines and was conducted from July 2014 to November 2014.

Equipments

For evaluation

(1) Weight and height scale: ZT-120 (Wincom Company Ltd., Hunan, China) was used to measure the weight and height of each participant and then calculate the BMI [weight (kg)/height (m^2)] [11].
(2) Mercurial sphygmomanometer: Riester, Rudolf Riester GmbH, Bruckstr, Jungingen Germany (a classic standard unit, individually calibrated, 300 mm Hg, capillary 3.5 ± 0.1 mm) and stethoscope (3 m Littmann Classic II SE) were used for blood pressure measurement.
(3) Autoanalyzer: ADVIA 1200 (Siemens Healthcare GmbH- 2015, Jungingen, Germany) was used for analysis of plasma samples for blood glucose.

For training

(1) Electronic treadmill (Enraf Nonius, Holland, the Netherlands) was used for exercise training. The apparatus is equipped with a display screen showing time in minutes and speed in kilometers per hour.
(2) Stop watch to adjust the time for each exercise phase (warm-up, active phase, and cool-down phase).

Outcome measures

Both groups underwent an identical battery of tests: baseline (before training), after the exercise training program, and at 3 months (after training). The evaluated parameter included HbA1c measurement.

Initially, data on the participants' characteristics was collected in the first session including resting heart rate (HR) (beats/min) and resting respiratory rate (cycles/min). In addition, HR and blood pressure were measured during the sessions to exclude any signs or symptoms that may interfere with the continuity of the study. Blood sugar levels were repeatedly monitored using a glucometer. Weight (kg) was measured to the nearest 0.1 kg using a standard weight scale.

Height was measured to the nearest 0.1 cm with the participant standing in an erect position against a vertical scale of a portable stadiometer. BMI (kg/m^2) was calculated as weight in kilograms divided by squared height in meters to exclude BMI more than or equal to 40.

Laboratory investigations

Oral glucose tolerance test

(1) Participants refrained from performing any strenuous physical activity for 2 days before the oral glucose tolerance test and attended the lab after an overnight fast. Venous blood samples were collected by vein puncture.
(2) Five milliliters of blood was drained under an aseptic condition from the participants after an overnight fast (8–14 h).
(3) Two milliliters of blood was put on fluoride to perform a glucose test (HbA1c measurement).

Exercise training protocols

(1) Before starting any HIIT program, all participants were able to exercise for at least 20–30 min at 70–85% of their previously measured maximum HR, without exhaustion.
(2) Always warm up and cool down for at least 5 min before and after each HIIT session.
(3) Work as hard as she can during the high-intensity intervals, until she feels pain in her muscles indicating that she has entered her anaerobic zone.
(4) If she experiences any chest pain or breathing difficulties during the HIIT workout, cool down immediately done.
(5) If the HR does not decrease back to about 70% of the maximum during recovery intervals, we shortened the work intervals and/or lengthened the recovery intervals (Table 1).

Group A: HIIT program:
Mode: Cycling on a stationary bicycle.
Duration: 20–38 min (total session).
Frequency: 3 times/week (day after day).

Intensity: high intensity (85–95% MHR Since HR_{max} varies by individual, the most accurate way of measuring any single person's HR_{max} is 220 - age) and recovery at (60–70% MHR) [12].

(1) Maximum HR was determined as participants performed an incremental cycling increasing 1 W every 2 s while being monitored using the telemetry until reaching the symptom-limiting exercise; then, the maximum HR was recorded.
(2) The training protocols were initiated several days after the first experimental trial.
(3) All participants were instructed not to change their dietary or lifestyle.

Aerobic exercise program

After warm-up, participants of this group performed walking on treadmill activity using treadmill three times per week (on nonconsecutive days). Time of exercise was increased from 20 min/session (at 60% of maximum HR) to 30 min/session (at 75% of maximum HR) [10]. Aerobic exercise intensity was determined using the Karvonen formula in which target HR = [(maximum HR−resting HR)´%intensity]+resting HR, where maximum HR = 220−age [13]. The participants of this group were directed to maintain their rate of perceived exertion between 13 and 14 on Borge's score scale. All 40 participants showed better adherence and agreed to complete the training programs. No serious adverse effect was reported in either training group.

Data collection

Data from each patient in both groups (A and B) were taken obtained in terms of the following:

For each group, study and control, demographic and clinical characteristics of patients and the measured variable, HbA1c, before and after training were collected.

Statistical analysis

Descriptive statistics for all parameters in the form of:

(1) Mean of demographic and clinical characteristics, and HbA1c.
(2) Standard error of demographic and clinical characteristics, and HbA1c.
(3) Percentage of change in HbA1c after training.

Inferential statistics in the form of:

(1) Paired *t*-test to examine the change in HbA1c before and after training in each group.

(2) Independent *t*-test to compare the two groups (study and control) in terms of HbA1c before and after training.
(3) The level of significance was set at *P*-value less than or equal to 0.05.

Results

This study was carried out to determine the impact of HIIT on HbA1c in T2DM (12 weeks after training).

Demographic and clinical characteristics of patients in both groups

In the baseline (before training) evaluation, results showed that there were nonsignificant statistical differences between the two groups (HIIT group (group A) and treadmill training group (group B) in the demographic characteristics including age, height, weight, BMI, duration of diabetes mellitus, and HbA1c (%) (P>0.05), as shown in Table 2.

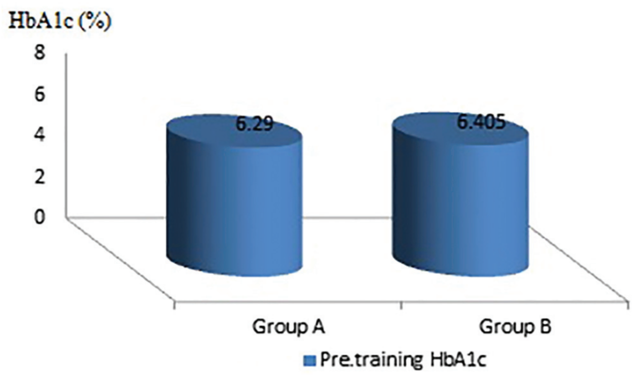
Baseline (before training) glycated hemoglobin in the two groups (A and B)

The results of this study showed that there was a nonsignificant statistical difference between the two groups before treatment in the measured variable, HbA1c, where the *t*-value was 0.679 and the *P*-value was 0.501, respectively, as shown in Table 3. Results are shown in Fig. 1.

Glycated hemoglobin in the two groups before and after training

Table 4 shows that both types of exercise (HIIT and treadmill training) have an effect on HbA1c, with a highly significant effect in group A relative to group B. For group A, there was a highly significant difference in HbA1c before and after treatment, where the mean value before treatment

Figure 1



Baseline (before training) glycated hemoglobin (HbA1c) in the two groups (A and B).

Table 1 High-intensity interval training program

Weeks	Warm up (min)	Work interval (maximum intensity) (min)	Recovery interval (60–70% MHR) (min)	Repeat (times)	Cool down (min)	Total workout time (min)
1	5	1	4	2	5	20
2	5	1	4	3	5	25
3	5	1	4	4	5	30
4	5	1.5	4	2	5	21
5	5	1.5	4	3	5	26.5
6	5	1.5	4	4	5	32
7	5	2	5	2	5	24
8	5	2	5	3	5	31
9	5	2	5	4	5	38
10	5	2	5	4	5	38
11	5	2	5	4	5	38
12	5	2	5	4	5	38

Table 2 Demographic and clinical characteristics of patients in both groups (mean ± SE)

Variables	Group A (N = 20)	Group B (N = 20)	*t*-value	*P*-value
Age (years)	57.15 ± 2.32	58.25 ± 2.65	1.94	0.17
Height (m)	1.62 ± 0.04	1.64 ± 0.05	2.87	0.09
Weight (kg)	89.03 ± 5.84	89.11 ± 6.33	0.002	0.96
BMI (kg/m^2)	33.99 ± 2.57	33.13 ± 2.11	1.35	0.25
Average duration of diabetes mellitus (years)	5.1 ± 0.66	4.9 ± 0.88	0.66	0.42
HbA1c (%)	6.55 ± 0.84	7.21 ± 0.92	0.55	0.46

HbA1c, glycated hemoglobin; SE, standard error; Level of significance at $P < 0.05$.

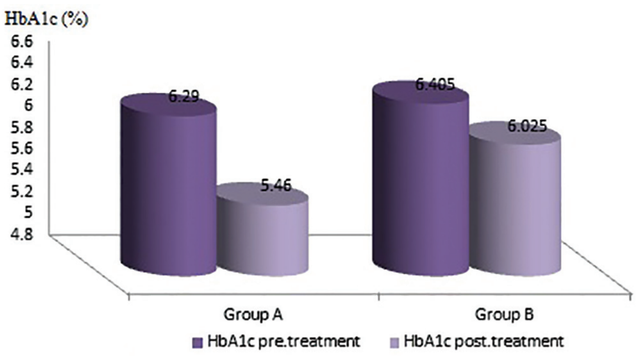
was 6.290 ± 0.130 and that after treatment was 5.460 ± 0.092, with a percentage of change −13.19%, where the *t*-value was 6.873 and the *P*-value was 0.0001.

However, in group B, the mean value before treatment was 6.405 ± 0.107 and that after treatment was 6.025 ± 0.156, with a percentage of change -5.93%, where the *t*-value was 2.039 and the *P*-value was 0.056. Results are shown in Fig. 2.

Post-training glycated hemoglobin in the two groups (A and B)

Table 5 shows that there was a significant statistical difference between the two groups after treatment in the measured variable, HbA1c, where the *t*-value was 3.105 and the *P*-value was 0.004. Results are shown in Fig. 3.

Figure 2



Glycated hemoglobin (HbA1c) in the two groups (A and B) before and after training.

Table 3 Baseline (before training) glycated hemoglobin in the two groups (A and B)

Variables	HbA1c (%)	
	Group A (*N* = 20)	Group B (*N* = 20)
Mean ± SE	6.290 ± 0.130	6.405 ± 0.107
t-value	0.679	
P-value	0.501	

HbA1c, glycated hemoglobin; SE, standard error; Level of significance at *P*<0.05.

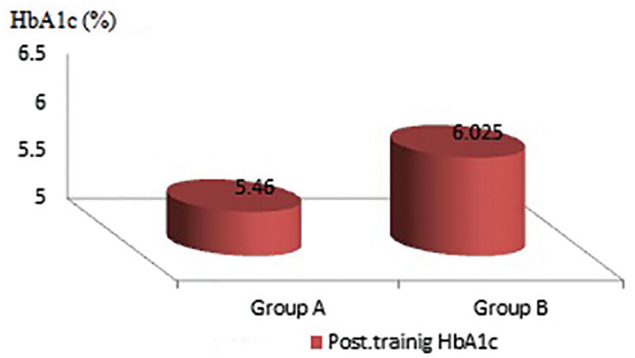
Discussion

T2DM is one of the most common metabolic disorders characterized by hyperglycemia and disturbances of carbohydrate, fat, and protein metabolism. The prevention and management of diabetes represent a major health issue worldwide. As the skeletal muscles are the primary sites of insulin-dependent glucose disposal, resistance of the skeletal muscles to insulin-dependent glucose uptake may be an early step in the development of T2DM [14].

Insulin resistance in skeletal muscle is particularly important as it is normally responsible for more than 75% of all insulin-mediated glucose disposal. However, the molecular mechanisms responsible for skeletal muscle insulin resistance remain poorly defined. Accumulating evidence indicates that low-grade chronic inflammation and oxidative stress play fundamental roles in the development of insulin resistance and inflammatory cytokines likely contribute toward the link between inflammation, oxidative stress, and skeletal muscle insulin resistance [15].

Diet, exercise, and weight loss are cornerstones of diabetes management to improve glycemic control, and reduce muscle wasting and mortality. Targeted interventions are needed to improve long-term diabetes control [16,17].

Figure 3



Post-training glycated hemoglobin (HbA1c) in the two groups (A and B).

Table 4 Glycated hemoglobin (%) in the two groups (A and B) before and after training

Variables	Groups			
	Group (A) (*N* = 20)		Group (B) (*N* = 20)	
	Before treatment	After treatment	Before treatment	After treatment
Mean ± SE	6.290 ± 0.130	5.460 ± 0.092	6.405 ± 0.107	6.025 ± 0.156
Percentage of change	−13.19		−5.93	
t-value	6.873		2.039	
P-value	0.0001*		0.056	

HbA1c, glycated hemoglobin; SE, standard error; **P* < 0.05, significant.

Table 5 Post-training glycated hemoglobin (%) in the two groups (A and B)

Variables	Groups	
	Group A (*N* = 20)	Group B (*N* = 20)
Mean ± SE	5.460 ± 0.092	6.025 ± 0.156
t-value	3.105	
P-value	0.004*	

HbA1c, glycated hemoglobin; SE, standard error; *$P < 0.05$, significant.

Physical exercise is a well-known treatment for T2DM as it improves insulin sensitivity in major insulin target tissues, predominantly skeletal muscle. The mechanisms underpinning the beneficial effects of exercise on insulin action are at present not fully resolved [18].

Most studies use traditional aerobic exercise or resistance training (i.e. strength) interventions; however, more novel interventions such as HIIT could provide a more effective and appropriate exercise modality. In the current study, the result showed that there was a significant decrease in the mean value of the fasting blood HbA1c after 3 months of HIIT.

As reported by Boutcher [19], all studies that have assessed insulin response to HIIT recorded significant improvements of between a 23 and a 58% increase in insulin sensitivity. Insulin sensitivity has typically been assessed by measuring fasting insulin (HOMA-IR) and by glucose tolerance tests.

In healthy, nondiabetic individuals, the improvement in fasting insulin and insulin resistance after HIIT ranges from 23 to 33%, whereas in individuals with T2DM, two studies have reported greater insulin sensitivity improvements of 46% [20] and 58% [21]. Thus, the aim of this study was to determine the impact of a HIIT program on HbA1c in T2DM.

The results of this study showed clearly that training by HIIT exerted more significant positive effects on glycemic control in T2DM patients on a short-term basis.

Moderately intense levels of aerobic and resistance training have been found to be effective in improving glycemic control in older adults and in patients with diabetes. There are significant improvements in measures of pain, neuropathic symptoms, and cutaneous fiber branching in patients with diabetic peripheral neuropathy [22].

The health benefits of exercise training, including improvements in insulin sensitivity and glycemic control, are commonly attributed to the adaptations associated with chronic exercise, including increases in cardiorespiratory fitness, changes in energy balance, or reductions in total or regional adiposity [23].

Seven days of exercise training typically improves insulin sensitivity measured using the hyperinsulinemic–euglycemic clamp in patients with T2DM. Daily exercise improves day-to-day glycemic control, reducing the frequency, magnitude, and duration of glycemic excursions in patients with T2DM who live a sedentary live [24].

Exercise was found to have many benefits on health status, such as cardiovascular fitness, optimum body weight, and muscle mass maintenance, decreasing abdominal fat and improving insulin sensitivity [8].

Furthermore, moderate-intensity exercise has a longer lasting effect on lipoprotein lipase in muscles and hepatic lipase in the liver, and it also increases lipid uptake and oxidation in skeletal muscles, thus leading to improvement in insulin action and decrease in glucose and TG level [25]. As exercise intensity is increased, muscle glycogen becomes a more important substrate source. The depletion of muscle glycogen stores and subsequent postexercise muscle glycogen resynthesis is coupled with the postexercise improvement in glucose tolerance and/or insulin sensitivity. Therefore, when considering the more acute glucoregulatory effects of exercise, higher exercise intensities should theoretically be more effective in stimulating insulin sensitivity and improving glucose homeostasis. Several factors, such as the release of counter-regulatory hormones, training status, and exercise performed either in the postabsorptive or the postprandial state, may explain these contradictory findings. Nevertheless, the energy equivalent of the exercise bout appears to represent the major determinant of the exercise-induced changes in glucose homeostasis. Therefore, a lower exercise intensity should be compensated for by an increase in exercise duration [26]. More recently, Sheri *et al.* [27] reported that most benefits of physical activity on diabetes management are gained through acute and chronic improvements in insulin action, accomplished by resistive exercise training. Willey and Fiatarone-Singh [28] reported that resistive exercises improve insulin sensitivity to about the same extent as aerobic exercise. Also, Casey and Nicholas [29] reported that progressive resistive exercises leads to a small but statistically significant improvement in HbA1c and therefore glycemic control. The results are likely to be clinically significant as any improvement in glycemic control that can be achieved safely is considered important. Sayer *et al.* [30] found that improvement in muscle strength is very important in diabetics as reported in their study because there is a graded association between increased glucose levels, weaker muscle strength, and impaired physical function.

The improved glycemic control after resistive exercises may be attributed to increases in nonoxidative glucose metabolism [31]. It was found that resistive exercises three times a week for 30 min increased insulin-mediated blood flow, increased the protein content of glucose transporter type 4, insulin receptor, protein kinase B, and glycogen synthase, and this may have contributed toward the training effect [7].

Hypertrophy of type I muscle fibers is important, given that these fibers are more insulin sensitive; they have greater oxidative and mitochondria capacity and higher capillary density. Therefore, it is not surprising to find that the muscle hypertrophy resulting from strength training was associated with the increases in whole-body insulin sensitivity that we observed because skeletal muscle constitutes the target tissue where most of the insulin-stimulated glucose uptake takes place [32].

Apart from increased muscle mass, improvements in muscular insulin sensitivity as a result of resistive training appear to result from similar adaptations to those that occur with endurance training. Resistance training has been shown to increase glucose transporter type 4 protein content, hypertrophy, both type I and II muscle fibers, as well as upregulate insulin receptors and signal transduction in the muscle cell [33], and improve nonoxidative glucose metabolism through increased glycogen synthase [34,35] were the first to report that muscle glucose uptake was elevated five-fold from pre-exercise rates when patients performed 45 min of lower body resistance exercise at 70–80% 1 RM. Resistance exercise has also been confirmed to be a potent stimulator of glucose uptake both during and after exercise [36]. One potential mechanism for augmented glucose uptake in resistance exercise is a three-fold increase in blood flow, which enhances glucose extraction in the muscle [35]. Long-term resistance-type exercise interventions have also been reported to improve glucose tolerance and/or whole-body insulin sensitivity [7,37,38]. Other than the consecutive effects of each successive bout of exercise, resistance-type exercise training has been associated with a considerable gain in skeletal muscle mass, thereby improving whole-body glucose-disposal capacity [38]. Besides attenuation of the loss of muscle mass with aging, resistance-type exercise training also improves muscle strength and functional capacity, thereby allowing a healthier, more active lifestyle [26]. Ekta *et al.* [39] reported that both the progressive resistive training and aerobic exercise groups showed a significant improvement in HbA1c, total cholesterol levels, systolic blood pressure, and psychological profile compared with the control group, but the percentage improvement in the progressive resistive training group, in terms of total cholesterol levels and general well-being, was better compared with the aerobic exercise group. It was found that the general well-being has improved in both groups with greater improvements was observed in the progressive resistive training group this may explain the benefits of being contact to the patient in giving instructions and advices in addition to the value of the psychological support. Resistive exercises promote favorable energy balance and reduced visceral fat deposition through enhanced basal metabolism and activity levels while counteracting age-related and disease-related muscle wasting. Resistive exercises improve insulin sensitivity and glycemic control, and increase muscle mass, strength, and endurance [40].

The observations in the present study are also consistent with those of Misra *et al.* [9], who found a significant improvement in insulin sensitivity and HbA1c, decrease in truncal and peripheral subcutaneous adipose tissue, and a decrease in lipid values after 3 months of supervised progressive resistive exercises. Thabet *et al.* [41] reported a significant reduction in HbA1c, fasting, and 2 h postprandial blood glucose level and waist-to-hip ratio after 3 months of resistive exercise.

Conclusion

Our findings support the undeniable benefits of physical activity in T2DM patients. In conclusion, this study added to the limited literature on the benefits of HIIT in T2DM patients.

The role of HIIT in the short-term effects on glycemic control was noteworthy. The significant improvement in HbA1c in response to the HIHT and treadmill training indicates the short-term effects of physical activity on glycemic control abnormalities.

It also seems that the long-term improvement in glycemic control in the HIIT was more significant than that in the control group. The results of this study supported the importance of HIIT to improve glycemic control in T2DM patients and showed that diabetic patients who follow this exercise program should be able to safely improve their glycemic response and hence decrease the incidence of diabetic complications. Also, safely improve muscular strength and reduce stress that substantially improve capacity for independent living and enhance quality of life; here, the HIIT is the matter of concern.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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