Canadian Journal of Cardiology 33 (2017) 1645–1651

Clinical Research

The Impact of Burst Exercise on Cardiometabolic Status of Patients Newly Diagnosed With Type 2 Diabetes

Avinash Pandey,[a,b,c] Neville Suskin, MD, MSc,[c] and Paul Poirier, MD, PhD[d,e]

[a] Cambridge Cardiac Care Centre, Cambridge, Ontario, Canada

[b] Department of Medicine, Harvard Medical School, Boston, Massachusetts

[c] University of Western Ontario, London, Ontario, Canada

[d] Faculty of Pharmacy, Laval University, Québec City, Québec, Canada

[e] Department of Cardiology, Institut de cardiologie et de pneumologie de Québec, Québec City, Québec, Canada

ABSTRACT

Background: The impact of burst high-intensity exercise on physiological, cardiometabolic, and biochemical variables compared with traditional moderate-intensity continuous exercise training (MICT) has yet to be assessed in patients with type 2 diabetes (T2D). We compared the impact of multiple short-duration, high-intensity burst exercise sessions to MICT on cardiometabolic variables in patients with T2D.

Methods: Forty newly diagnosed patients with T2D not receiving lipid lowering or hypoglycemic medications were randomized to 40 minutes of MICT (60% of maximal heart rate) 5 days per week or 3 continuous bursts of 12 minutes of high-intensity exercise (85% of maximal heart rate) 5 days per week for 3 months. Body mass index, hemoglobin A_{1C} (HbA_{1C}), and lipid profile were assessed before and after 3 months of exercise training.

Results: Burst exercise resulted in greater body mass index reduction than did MICT (-2.1 ± 1.2 kg/m^2 vs -0.7 ± 0.7 kg/m^2, respectively;

RÉSUMÉ

Contexte : Les effets de l'exercice par intervalles à haute intensité sur les variables physiologiques, cardiométaboliques et biochimiques comparativement à ceux de l'exercice continu à intensité modérée (ECIM) traditionnel n'ont pas encore été étudiés chez les patients atteints de diabète de type 2. Nous avons comparé les effets de multiples séances d'exercice par intervalles à haute intensité et de courte durée à ceux de l'ECIM sur les variables cardiométaboliques chez des patients atteints de diabète de type 2.

Méthodologie : Quarante patients ayant reçu récemment un diagnostic de diabète de type 2 et qui ne prenaient pas de médicament hypolipidémiant ou hypoglycémiant ont été répartis au hasard pour effectuer soit 40 minutes d'ECIM (à 60 % de la fréquence cardiaque maximale) à raison de 5 jours par semaine, soit 3 intervalles continus de 12 minutes d'exercice à haute intensité (à 85 % de la fréquence cardiaque maximale) à raison de 5 jours par semaine pendant 3 mois.

In patients with type 2 diabetes (T2D), multifactorial treatment, including both behavioural and pharmacologic approaches, may help to reduce the progression of diabetes complications such as microvascular and macrovascular complications.[1,2] Historically, diabetes exercise programs have focused on longer-duration, less-intense exercise,[3,4] However, regular exercise in patients with T2D has also been associated with improvements in body mass index (BMI) and numerous cardiometabolic variables. Indeed, exercise reduces blood glucose levels and enhances lipid profiles, including elevations in high-density lipoprotein (HDL) and modest reductions in triglycerides (TG) and low-density lipoprotein (LDL).[5,6] Sustained improvement in aerobic fitness has been shown to reduce the risk of myocardial infarction, stroke, and congestive heart failure in patients with diabetes.[3,7,8] The mechanisms associated with these clinical benefits have yet to be fully elucidated, although they may result in part from improved endothelial function and reduction in the development and progression of atherosclerotic disease.[6,9]

There is growing evidence supporting the potential cardiometabolic benefits of high-intensity interval training (HIIT) in individuals with T2D.[10,11] Also, it was reported that over a short-term observation period, brief bursts of high-intensity exercise after meals resulted in significant improvements in blood glucose patterns in healthy volunteers.[12] HIIT involves alternating between periods of vigorous exercise, defined as exercising at $\geq$ 70% maximal aerobic capacity, and periods of rest or active recovery.[13] Low-volume HIIT has been shown to be a time-efficient exercise option for reducing blood glucose levels in individuals with or at risk of T2D.[11]

Received for publication January 25, 2017. Accepted September 19, 2017.

Corresponding author: Dr Paul Poirier, Department of Cardiology, Institut universitaire de cardiologie et de pneumologie de Québec, 2725 chemin Ste-Foy, Québec City, Québec G1V 4G5, Canada. Tel.: +1-418-656-4767; fax: +1-418-656-4581.

E-mail: paul.poirier@criucpq.ulaval.ca

See page 1650 for disclosure information.

https://doi.org/10.1016/j.cjca.2017.09.019

$P < 0.05$). There was a greater reduction at 3 months ($P < 0.05$) in HbA_{1C} levels in the burst exercise group (8.14% ± 0.49% to 7.32% ± 0.39%) compared with the MICT group (8.18% ± 0.35% to 7.94% ± 0.41%). Compared with MICT, burst exercise was associated with a greater reduction in low-density lipoprotein cholesterol (−11 vs −4%; $P < 0.05$) and a greater increase in high-density lipoprotein cholesterol (22% vs 3%; all $P < 0.05$). After 3 months, patients in the burst exercise group attained greater exercise time on the treadmill (exercise capacity) than did those prescribed MICT (6.87 ± 1.44 minutes vs 5.40 ± 1.96 minutes; $P < 0.001$).

Conclusions: **Findings from the current study support better cardiometabolic benefits of burst exercise compared with MICT over 3 months in patients with newly diagnosed T2D.**

L'indice de masse corporelle, le taux d'hémoglobine A_{1c} (HbA_{1c}) et le profil lipidique ont été évalués avant et après cette période d'entraînement de 3 mois.

Résultats : **L'exercice par intervalles s'est traduit par une réduction de l'indice de masse corporelle plus élevée que l'ECIM (−2,1 ± 1,2 kg/m^2 vs −0,7 ± 0,7 kg/m^2, respectivement; $p < 0,05$). La réduction du taux d' HbA_{1c} après 3 mois a été plus importante ($p < 0,05$) dans le groupe affecté à l'exercice par intervalles (de 8,14 % ± 0,49 % à 7,32 % ± 0,39 %) que dans le groupe ECIM (de 8,18 % ± 0,35 % à 7,94 % ± 0,41 %). Comparativement à l'ECIM, l'exercice par intervalles a été associé à une réduction plus marquée du taux de cholestérol à lipoprotéines de faible densité (−11 % vs −4 %; $p < 0,05$) et à une augmentation plus importante du taux de cholestérol à lipoprotéines de haute densité (22 % vs 3 %; $p < 0,05$ dans tous les cas). Après 3 mois, les patients du groupe affecté à l'exercice par intervalles étaient capables de courir pendant une plus longue période sur le tapis roulant (capacité d'effort) que ceux du groupe ECIM (6,87 ± 1,44 minutes vs 5,40 ± 1,96 minutes; $p < 0,001$).**

Conclusions : **Les résultats de cette étude laissent croire que, chez les patients ayant reçu récemment un diagnostic de diabète de type 2, l'exercice par intervalles procure des bienfaits cardiométaboliques supérieurs à ceux de l'ECIM après 3 mois.**

Indeed, 15 years ago, exercise intensity was reported to be the strongest predictor of improvements in blood glucose control when compared with exercise volume in individuals with T2D.[14] However, interval training might be different from continuous training in that regard. Studies directly comparing HIIT to traditional moderate-intensity continuous exercise training (MICT) in individuals with T2D are increasing.[15-26] However, diverse HIIT protocols have been deployed in studies with varying exercise intensity levels, duration of exercise at the targeted intensity, recovery periods, or a combination, making selection of the optimal HIIT protocol very challenging.[27] Because patients with diabetes are often older, obese, sedentary, and out of shape and are not excited about exercising for long periods, we based our exercise protocol on the popularity of HIIT, searching for an alternative exercise regimen.

The impact on these physiological, cardiometabolic, and biochemical variables of continuous-burst, high-intensity exercise performed over a longer period of observation, compared with traditional MICT, has yet to be assessed in patients with T2D. The aim of this study was to compare the effects of multiple short-duration, high-intensity continuous burst exercise sessions with those of MICT on HbA_{1C} levels measured at 3 months in patients with newly diagnosed T2D.

Methods

Forty patients with new-onset T2D ≥ 18 years old were recruited at a local diabetic exercise rehabilitation centre (Cambridge Cardiac Rehab Centre). New-onset (within 3 months) T2D was defined according to the Canadian Diabetes Association guidelines.[28] Before any study procedures, all patients provided written informed consent. All individuals were referred to our diabetes exercise rehabilitation program and scheduled to start exercise classes within 3 weeks of enrollment in the study. Demographic information was collected at baseline and at study completion. All patients had a maximal intensity stress test performed before randomization to assess the presence of silent ischemia. Any patient with an abnormal stress test result was excluded. Also, patients were excluded if they had any known diabetic end-organ damage; heart, kidney, cerebrovascular, or peripheral vascular disease; or an inability or contraindication to perform a maximal treadmill exercise stress test. Patients were excluded if they were receiving hypoglycemic or lipid-lowering medications at any time during the study. Demographic information was collected by telephone interview as well as review of medical chart information. All enrolled patients had bloodwork at baseline and after 3 months of exercise training as part of routine care in our diabetes rehabilitation centre. As part of usual care, all patients received dietary counselling at entry into the program. All onsite exercise regimens were supervised by kinesiologists; patients performed exercise sessions on site twice weekly and were given exercise prescriptions to perform 3 days of exercise at home. Patients were randomized to a usual care group (MICT) or an intervention group (burst continuous high-intensity exercise). Participants in the MICT group were asked to perform 30 minutes of continuous sustained moderate-intensity exercise (60% of maximal heart rate), 5 days per week, with 5 minutes of warm up and cool down. An age-predicted target heart rate was used as a measure of intensity in this study. Participants in the burst exercise group were asked to perform 10-minute continuous exercise sessions of burst high-intensity exercise (85% of maximal heart rate) with 1 minute of warm up and cool down, 3 times daily 5 days per week. This exercise burst training was continuous and was not performed in an interval fashion. The cardiac rehabilitation kinesiologist taught patients to estimate their own heart rate—counting the number of beats by palpating the carotid artery for 30 seconds at 3-minute intervals during their exercise sessions—to ensure that they were achieving their prescribed intensity of 60% maximal heart rate in the MICT group and 85% maximal heart rate in the burst exercise group. Patients were asked to track the exercise at home using provided exercise logbooks for self-reported adherence data. In the biweekly on-site exercise sessions, intensity of achieved exercise was monitored by the kinesiologist, and monitored heart rate was used as a marker of intensity of exercise achieved.

Each period of 12 minutes of exercise was to be separated from the next period by at least 2 hours. While exercising on site, heart rate was monitored by the kinesiologist. Patients were also taught how to estimate their own heart rate and were instructed to measure heart rate while exercising at home.

Height and body mass were measured at baseline and at 3 months on the same scale and in the same state of dress (light clothing and no shoes). Aerobic capacity, measured with a maximal treadmill exercise test using the Bruce protocol, hemoglobin A_{1C} (HbA_{1C}), LDL (Frederickson formula), HDL, and TG levels were measured at baseline and at 3 months. Variables were measured 3 days after the last exercise session. Exercise adherence was recorded by participants in specially prepared supplied logbooks. Because monthly exercise duration could differ between groups, we prospectively decided to examine LDL, HDL, and TG levels for a subset of the patients with statistically comparable average monthly exercise duration.

Statistical analysis

Results are expressed as mean ± standard deviation unless otherwise specified. Data were analyzed using a 1-way analysis of variance or a 1-way analysis of covariance adjusted for minutes of exercise achieved on the Bruce protocol, when appropriate. Log transformation was performed before statistical analyses for data not normally distributed, and reported P values are based on these transformations. A P value $\leq$ 0.05 was considered statistically significant. Data were analyzed using the statistical package SPSS, version 23 (IBM, Armonk, NY).

Results

A total of 225 patients were screened, 40 of whom were enrolled in this study. Ninety-six patients did not meet the inclusion and exclusion criteria, whereas 86 patients declined to participate (Supplemental Table S1). There was no significant difference in baseline demographics between those who participated and those who declined to participate in the study. Baseline patient characteristics are reported in Table 1. Patients were given options by the cardiac rehabilitation kinesiologists on the type of exercise to perform at home based on what they had available; 60% used treadmills, 30% used stationary bikes, and 10% used outdoor walking in both groups. Over the 3-month period of exercise training, BMI decreased more in the burst high-intensity exercise group than in the MICT group (−2.2 ± 1.3 kg/m^2 vs −0.7 ± 0.7 kg/m^2; $P < 0.001$). Consequently, after 3 months of exercise training, patients in the burst high-intensity exercise group had a lower BMI than those in the MICT group (30.1 ± 1.5 kg/m^2 vs 31.7 ± 1.8 kg/m^2; $P < 0.001$). Patients who performed the burst high-intensity exercise regimen reported a greater number of minutes of exercise per month (Table 2). In addition, patients who performed burst high-intensity exercise also had a significantly greater improvement in aerobic fitness compared with patients in the MICT group, as assessed by the exercise duration achieved on the Bruce treadmill exercise stress test (6.87 ± 1.44 minutes vs 5.40 ± 1.96 minutes; $P < 0.001$).

After 3 months of exercise training, patients in the burst high-intensity exercise group experienced a 10% ± 4% drop in HbA_{1C} levels compared with only a 3% ± 3% decrease in the MICT group (Table 3). To assess the effect of exercise on HbA_{1C} levels, we plotted the number of minutes of exercise per month against the change in HbA_{1C} levels for both groups. The slope of the trend line gives the change in HbA_{1C} level per minute of exercise per month for each group (Fig. 1). Patients who performed the burst high-intensity exercise regimen on average had more significantly improved HbA_{1C} levels per minute compared with the MICT group (Fig. 1). Participants in the burst exercise arm appeared to achieve a greater HbA_{1C} reduction per minute of exercise (0.0376% change in HbA_{1C} per minute of self-reported minute of monthly exercise) compared with the sustained exercise arm (0.0197%). Similarly, LDL and TG levels decreased significantly more in the burst high-intensity exercise group than in the MICT group (Table 3). Likewise, patients who performed the burst exercise regimen decreased their TG levels by 25% ± 14% vs 5% ± 9% in the MICT group (P <0.05). Finally, patients in the burst high-intensity exercise group experienced a 23% ± 14% increase in HDL levels vs a 3% ± 5% increase in the MICT group ($P < 0.05$). Greater reductions in non-HDL levels were also noted with the burst high-intensity exercise regimen (13% ± 6% vs 5% ± 4%; $P < 0.05$).

Table 1. Baseline characteristics and body mass index of patients prescribed sustained exercise or burst exercise

Variable	Control group MICT (n = 19)	Intervention group burst exercise (n = 21)	P value
Women, n (%)	7 (37)	5 (24)	0.39
Age (y)	65 ± 9	68 ± 9	0.25
BMI (kg/m^2)			
Baseline	32.4 ± 1.9	32.3 ± 2.1	0.82
3 mo	31.7 ± 1.8	30.1 ± 1.5	0.01
Changes at 3 mo	−0.7 ± 0.7	−2.2 ± 1.3	< 0.001

Data are presented as mean ± SD unless otherwise indicated.

BMI, body mass index; MICT, moderate-intensity continuous exercise training.

Table 2. Self-reported exercise adherence and cardiac endurance measured by stress test in patients prescribed sustained exercise or burst exercise

Variable	Control group MICT (n = 19)	Intervention group burst exercise (n = 21)	P value
Minutes of exercise achieved on the Bruce protocol			
Baseline	5.47 ± 1.65	5.60 ± 1.41	0.81
3 mo	5.71 ± 1.96	6.87 ± 1.44	0.03
Change at 3 mo	0.24 ± 1.39	1.27 ± 0.63	< 0.001
Self-reported min of exercise per mo	362 ± 109	460 ± 97	0.006
METS achieved on the Bruce protocol			
Baseline	5.35 ± 1.61	5.44 ± 1.37	0.81
3 mo	5.54 ± 1.90	6.48 ± 1.36	< 0.001
Change at 3 mo	0.19 ± 1.10	1.04 ± 0.52	< 0.001

Data are presented as mean ± SD unless otherwise indicated.

METS, metabolic equivalents; MICT, moderate-intensity continuous exercise training.

Table 3. Biochemical parameters measured at baseline and at 3 months in patients prescribed sustained exercise or burst exercise

Variable	Control group MICT (n = 19)	Intervention group burst exercise (n = 21)	*P* value
HbA_{1C} (%)			
Baseline	8.18 ± 0.35	8.14 ± 0.49	0.76
3 mo	7.94 ± 0.41	7.32 ± 0.39	< 0.001
Change at 3 mo	−0.25 ± 0.23	−0.82 ± 0.37	< 0.001
LDL (mmol/L)			
Baseline	3.31 ± 0.22	3.34 ± 0.20	0.68
3 mo	3.15 ± 0.28	2.97 ± 0.16	0.01
Change at 3 mo	−0.16 ± 0.13	−0.37 ± 0.18	< 0.001
HDL (mmol/L)			
Baseline	0.64 ± 0.07	0.61 ± 0.08	0.39
3 mo	0.66 ± 0.08	0.75 ± 0.08	0.003
Change at 3 mo	0.02 ± 0.03	0.14 ± 0.08	< 0.001
TG (mmol/L)			
Baseline	3.29 ± 0.25	3.35 ± 0.41	0.64
3 mo	3.12 ± 0.33	2.49 ± 0.42	< 0.001
Change at 3 mo	−0.17 ± 0.28	−0.86 ± 0.54	< 0.001
Non-HDL (mmol/L)			
Baseline	3.96 ± 0.23	4.01 ± 0.23	0.62
3 mo	3.78 ± 0.32	3.46 ± 0.21	0.001
Change at 3 mo	−0.19 ± 0.17	0.54 ± 0.27	0.001

Data are presented as mean ± SD unless otherwise indicated.

HbA_{1C}, glycated hemoglobin; HDL, high-density lipoprotein; LDL, low-density lipoprotein; MICT, moderate-intensity continuous exercise training, TG, triglycerides.

Patients were prescribed 30 minutes of exercise per day 5 days per week in both arms of the study; this results in 600 minutes of exercise monthly. Patients in the sustained exercise arm of the study exercised at 60.3% ± 18.2% of the goal, whereas patients in the burst exercise arm of the study exercised at 76.7% ± 16.2% of the goal (600 minutes). An exploratory analysis with a subgroup of individuals achieving a similar duration of exercise of 350-400 minutes of exercise per month was performed to assess if the same number of minutes of burst exercise vs the same number of minutes of MICT exercise resulted in different impacts on cardiometabolic parameters. In the matched groups for monthly exercise duration, there was a greater relative decrease in HbA_{1C}, LDL, and TG levels and a greater rise in HDL levels in patients who performed burst high-intensity exercise vs those who performed MICT (Table 4).

Table 4. Relative impacts of similar duration of sustained exercise vs burst exercise on biochemical parameters

Variable	Control group MICT (n = 7)	Intervention group burst exercise (n = 8)	*P* value
Self-reported exercise duration	380 ± 36	389 ± 34	0.64
% change in HbA_{1C}	−3.7 ± 1.7	−7.9 ± 2.4	0.01
% change in LDL	−4.7 ± 3.4	−9.7 ± 3.8	0.008
% change in HDL	3.7 ± 4.5	14.5 ± 7.5	0.001
% change in TG	−4.8 ± 5.3	−18.4 ± 5.6	0.001

Data are presented as mean ± SD unless otherwise indicated.

HbA_{1C}, glycated hemoglobin; HDL, high-density lipoprotein; LDL, low-density lipoprotein; MICT, moderate-intensity continuous exercise training; TG, triglycerides.

Discussion

The key findings of the current study are that 3 months of burst high-intensity exercise is associated with greater improvements in cardiometabolic variables compared with 3 months of MICT. As expected, in the group prescribed the MICT regimen, we observed modest improvements in HbA_{1C} levels, minutes achieved on a symptom-limited exercise stress test, BMI, and lipid profiles. To our knowledge, no HIIT study in patients with T2D have used a burst high-intensity exercise strategy like the one used in our study. This exercise regimen is novel and has not been looked at in previous published works. We chose 3 × 10-minute intervals to improve adherence so that participants could link it to other activities that they do 3 times a day, eg, meals. Despite participation in an on-site diabetes rehabilitation program consisting of biweekly exercise counselling, adherence to the exercise regimen measured in self-reported duration of exercise remained poor (Table 2). In addition, monthly duration of self-reported exercise was found to be significantly higher despite the fact that the same duration of exercise was prescribed to both groups.

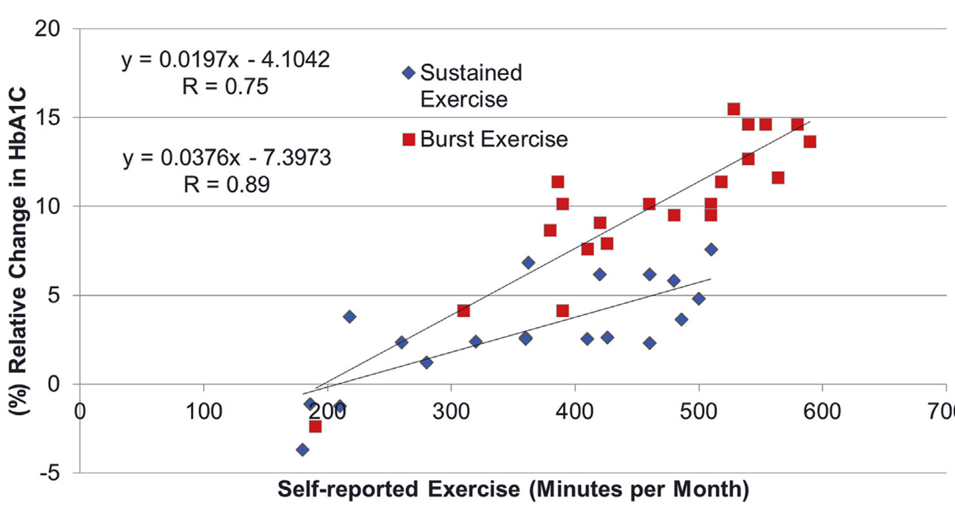

Figure 1. Relationship between exercise duration with relative change in glycated hemoglobin (**HbA_{1c}**). **Red**, burst high-intensity exercise; **blue**, sustained exercise.

Because T2D is characterized by a state of insulin resistance, it is important to note that regular exercise is highly beneficial for blood glucose control and is an important therapy in the prevention, management, and treatment of T2D and its associated comorbidities.[5] Actually, it is well known that a single session of exercise increases insulin sensitivity for up to 48 hours afterward because it also improves long-term glycemic control in patients with T2D.[29,30] Moderate-intensity continuous aerobic exercise training is still the cornerstone of exercise training programs in patients with cardiac conditions and is recommended worldwide.[31-34] However, a recent study suggests that MICT may not have a sustained effect on insulin sensitivity in nondiabetic patients (without weight loss and accounting for the effect of acute exercise on insulin sensitivity).[35] Indeed, HIIT consists of a continuous session of exercise in which patients alternate between high-intensity exercise and rest/lower-intensity exercise periods. In this study, we used a burst exercise regimen consisting of short periods of high-intensity exercise spread throughout the day, which may potentially be associated with a greater impact on insulin resistance.[36] Over the past decade, there has been an increasing interest in the benefits of HIIT over MICT in patients with coronary heart disease and heart failure.[33] Actually, HIIT is now widely mentioned as an exercise modality in the most recent North American and European guidelines for patients with cardiac conditions.[31,32] Given that a lack of time is an important barrier to regular exercise, it may be possible that the shorter duration required for HIIT may be an attractive option for increasing physical activity levels.

Another important finding of our study pertains to exercise adherence. Most sedentary individuals cannot maintain a high-intensity exercise regimen for extended periods. Adherence to prescribed exercise regimens in patients with new-onset diabetes who are prescribed routine MICT was found to be poor.[37] The goal of this study was to test a novel high-intensity exercise regimen that was divided into 3 parts to make it more manageable for sedentary participants to sustain the high intensity. We were not trying to make generalizations about the impact of breaking up exercise throughout the day. Comparatively, patients prescribed the burst high-intensity exercise regimen were found to exercise for a longer duration per month, suggesting that it may be easier for patients to perform short-duration, high-intensity exercise multiple times per day rather than longer-duration, low-moderate intensity continuous exercise. Nevertheless, when we controlled for the amount of exercise performed, the burst exercise regimen remained superior to MICT for metabolic and aerobic fitness improvements, suggesting that high-intensity burst exercise may be more efficient than MICT for these variables in patients with T2D. These analyses suggest that the benefits noted in this study did not result solely from an increase in exercise adherence/exposure with the newly prescribed exercise regimen but may be related to other mechanisms. It is plausible that the mechanism by which HIIT enhances glucose homeostasis may be secondary to the ability of this peculiar exercise regimen to engage more muscle fibers while depleting muscle glycogen levels, which potentiates a greater increment in postexercise muscle insulin sensitivity[37]; the same phenomenon involving increased glycogen mobilization and storage could be play a role in our findings in the burst high-intensity exercise regimen group. Because the post-exercise increment in muscle insulin sensitivity lasts for ∼ 24-48 hours after a single bout of exercise, HIIT or burst high-intensity exercise may be an effective strategy to improve glucose control acutely and over the longer term. Of importance, our patients did not report any episodes of hypoglycemia, which may be explained by the fact that our patients did not use any hypoglycemic medications.[38-41]

However, a number of limitations should be noted. This was a single-centre study with a small sample size. This represents a sample of convenience for feasibility and also for gathering clinical useful data in the field of exercise training in patients with T2D. Patients with cardiovascular disease, diabetic end-organ damage, cerebrovascular disease, peripheral vascular disease, arthritis, joint disease, antiglycemic medication use, and lipid-lowering medication use were excluded from the study, limiting the generalizability of our findings. We wanted to test the impact of burst high-intensity exercise training per se on the metabolic profile of patients with newly diagnosed T2D using no concomitant medications to isolate the effect of the exercise training regimen, which should be considered a strength of our study design. Also, we have manipulated 2 important exercise training variables in the study (ie, pattern of exercise and mean exercise intensity). Thus, we cannot isolate which of these 2 parameters is more important regarding the metabolic benefit observed. A 3-month study duration was selected because 3 months is the usual duration of several cardiac rehabilitation programs and is the duration of the cardiac rehabilitation program at the site where this study was conducted. Because we studied patients with T2D, a 3-month period was expected to be long enough to observe changes in HbA_{1C}, but a longer period of exercise training would have been necessary to determine a time course for adaptation of other parameters. We acknowledge the limitation of self-reported heart rates. A heart rate monitor would have been ideal but was not used in this study because of cost in that it was a pilot feasibility study. Patients were taught to measure their own heart rate while exercising at home. Although this method may lack device-type precision, it has been reported that manual heart rate assessment more closely correlated to the device readings than did systolic and diastolic blood pressure readings.[42] Unfortunately, rate of perceived exertion was not recorded for this study.

Conclusions

We found greater improvements in BMI, aerobic fitness, glucose metabolism, and lipid profiles in patients with T2D prescribed the burst high-intensity exercise regimen. In addition, patients demonstrated greater adherence to the burst regimen intervention over the 3-month study duration. Further research is needed to examine the long-term adherence to burst high-intensity exercise and its impact on metabolic control, development of diabetic end-organ damage, and cardiovascular health.

Acknowledgements

We would like to thank Dr Tejal Patel, Dr Niteesh Choudhry, Dr David Alter, Dr Sunita Shankar, Dr Susan Sykes, Ms Sandra Clarus, Ms Danielle Bennett, and the

40 patient volunteers who participated in this study. Without their support and involvement, this study would not have been possible. Avinash Pandey is an undergraduate student at the University of Western Ontario. Dr Neville Suskin is the medical director of the cardiac rehabilitation and secondary prevention program at the University of Western Ontario. Dr Paul Poirier is a senior clinical researcher of FRQS.

Disclosures

The authors have no conflicts of interest to disclose.

References

1. Poirier P, Paquette C, Pilote B, Bogaty P. Beneficial impact of exercise in subjects with diabetes and heart disease. In: Jobin J, Maltais P, Poirier P, LeBlanc P, Simard C, eds. Advancing the Frontiers of Cardiopulmonary Rehabilitation. Champaign, IL: Human Kinetics, 2002:238-53.

2. Gaede P, Oellgaard J, Carstensen B, et al. Years of life gained by multifactorial intervention in patients with type 2 diabetes mellitus and microalbuminuria: 21 years follow-up on the Steno-2 randomised trial. Diabetologia 2016;59:2298-307.

3. Armstrong MJ, Sigal RJ, Arena R, et al. Cardiac rehabilitation completion is associated with reduced mortality in patients with diabetes and coronary artery disease. Diabetologia 2015;58:691-8.

4. Mendes R, Sousa N, Almeida A, et al. Exercise prescription for patients with type 2 diabetes—a synthesis of international recommendations: narrative review. Br J Sports Med 2016;50:1379-81.

5. Wing RR, Bolin P, Brancati FL, et al. Cardiovascular effects of intensive lifestyle intervention in type 2 diabetes. N Engl J Med 2013;369:145-54.

6. Hu G, Jousilahti P, Barengo NC, et al. Physical activity, cardiovascular risk factors, and mortality among Finnish adults with diabetes. Diabetes Care 2005;28:799-805.

7. Lopez-Jimenez F, Kramer VC, Masters B, et al. Recommendations for managing patients with diabetes mellitus in cardiopulmonary rehabilitation: an American Association of Cardiovascular and Pulmonary Rehabilitation statement. J Cardiopulm Rehabil Prev 2012;32:101-12.

8. Banzer JA, Maguire TE, Kennedy CM, O'Malley CJ, Balady GJ. Results of cardiac rehabilitation in patients with diabetes mellitus. Am J Cardiol 2004;93:81-4.

9. Montero D, Walther G, Benamo E, Perez-Martin A, Vinet A. Effects of exercise training on arterial function in type 2 diabetes mellitus: a systematic review and meta-analysis. Sports Med 2013;43:1191-9.

10. Francois ME, Little JP. Effectiveness and safety of high-intensity interval training in patients with type 2 diabetes. Diabetes Spectr 2015;28:39-44.

11. Jelleyman C, Yates T, O'Donovan G, et al. The effects of high-intensity interval training on glucose regulation and insulin resistance: a meta-analysis. Obes Rev 2015;16:942-61.

12. Francois ME, Baldi JC, Manning PJ, et al. 'Exercise snacks' before meals: a novel strategy to improve glycaemic control in individuals with insulin resistance. Diabetologia 2014;57:1437-45.

13. Lucas SJ, Cotter JD, Brassard P, Bailey DM. High-intensity interval exercise and cerebrovascular health: curiosity, cause, and consequence. J Cereb Blood Flow Metab 2015;35:902-11.

14. Boule NG, Haddad E, Kenny GP, Wells GA, Sigal RJ. Effects of exercise on glycemic control and body mass in type 2 diabetes mellitus: a meta-analysis of controlled clinical trials. JAMA 2001;286:1218-27.

15. Karstoft K, Winding K, Knudsen SH, et al. The effects of free-living interval-walking training on glycemic control, body composition, and physical fitness in type 2 diabetic patients: a randomized, controlled trial. Diabetes Care 2013;36:228-36.

16. Nose H, Morikawa M, Yamazaki T, et al. Beyond epidemiology: field studies and the physiology laboratory as the whole world. J Physiol 2009;587(Pt 23):5569-75.

17. Praet SF, Jonkers RA, Schep G, et al. Long-standing, insulin-treated type 2 diabetes patients with complications respond well to short-term resistance and interval exercise training. Eur J Endocrinol 2008;158:163-72.

18. Little JP, Gillen JB, Percival ME, et al. Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. J Appl Physiol (1985) 2011;111:1554-60.

19. Shaban N, Kenno KA, Milne KJ. The effects of a 2 week modified high intensity interval training program on the homeostatic model of insulin resistance (HOMA-IR) in adults with type 2 diabetes. J Sports Med Phys Fitness 2014;54:203-9.

20. Mitranun W, Deerochanawong C, Tanaka H, Suksom D. Continuous vs interval training on glycemic control and macro- and microvascular reactivity in type 2 diabetic patients. Scand J Med Sci Sports 2014;24: e69-76.

21. Gillen JB, Little JP, Punthakee Z, et al. Acute high-intensity interval exercise reduces the postprandial glucose response and prevalence of hyperglycaemia in patients with type 2 diabetes. Diabetes Obes Metab 2012;14:575-7.

22. Terada T, Friesen A, Chahal BS, et al. Exploring the variability in acute glycemic responses to exercise in type 2 diabetes. J Diabetes Res 2013;2013:591574.

23. Terada T, Wilson BJ, Myette-Comicronte E, et al. Targeting specific interstitial glycemic parameters with high-intensity interval exercise and fasted-state exercise in type 2 diabetes. Metabolism 2016;65:599-608.

24. Lee SS, Yoo JH, So YS. Effect of the low- versus high-intensity exercise training on endoplasmic reticulum stress and GLP-1 in adolescents with type 2 diabetes mellitus. J Phys Ther Sci 2015;27:3063-8.

25. Madsen SM, Thorup AC, Overgaard K, Bjerre M, Jeppesen PB. Functional and structural vascular adaptations following 8 weeks of low volume high intensity interval training in lower leg of type 2 diabetes patients and individuals at high risk of metabolic syndrome. Arch Physiol Biochem 2015;121:178-86.

26. Madsen SM, Thorup AC, Overgaard K, Jeppesen PB. High intensity interval training improves glycaemic control and pancreatic beta cell function of type 2 diabetes patients. PLoS One 2015;10:e0133286.

27. Gayda M, Ribeiro PA, Juneau M, Nigam A. Comparison of different forms of exercise training in patients with cardiac disease: where does high-intensity interval training fit? Can J Cardiol 2016;32:485-94.

28. Goldenberg R, Punthakee Z. Definition, classification and diagnosis of diabetes, prediabetes and metabolic syndrome. Can J Diabetes 2013;37(suppl 1):S8-11.

29. Devlin JT, Hirshman M, Horton ED, Horton ES. Enhanced peripheral and splanchnic insulin sensitivity in NIDDM men after single bout of exercise. Diabetes 1987;36:434-9.

30. Manders RJ, Van Dijk JW, van Loon LJ. Low-intensity exercise reduces the prevalence of hyperglycemia in type 2 diabetes. Med Sci Sports Exerc 2010;42:219-25.

31. Piepoli MF, Conraads V, Corra U, et al. Exercise training in heart failure: from theory to practice. A consensus document of the Heart Failure

Association and the European Association for Cardiovascular Prevention and Rehabilitation. Eur J Heart Fail 2011;13:347-57.

32. Vanhees L, Rauch B, Piepoli M, et al. Importance of characteristics and modalities of physical activity and exercise in the management of cardiovascular health in individuals with cardiovascular disease (Part III). Eur J Prev Cardiol 2012;19:1333-56.

33. Balady GJ, Williams MA, Ades PA, et al. Core components of cardiac rehabilitation/secondary prevention programs: 2007 update: a scientific statement from the American Heart Association Exercise, Cardiac Rehabilitation, and Prevention Committee, the Council on Clinical Cardiology; the Councils on Cardiovascular Nursing, Epidemiology and Prevention, and Nutrition, Physical Activity, and Metabolism; and the American Association of Cardiovascular and Pulmonary Rehabilitation. Circulation 2007;115:2675-82.

34. Fletcher GF, Ades PA, Kligfield P, et al. Exercise standards for testing and training: a scientific statement from the American Heart Association. Circulation 2013;128:873-934.

35. Suskin NG, Heigenhauser G, Afzal R, et al. The effects of exercise training on insulin resistance in patients with coronary artery disease. Eur J Cardiovasc Prev Rehabil 2007;14:803-8.

36. Magkos F, Tsekouras Y, Kavouras SA, Mittendorfer B, Sidossis LS. Improved insulin sensitivity after a single bout of exercise is curvilinearly related to exercise energy expenditure. Clin Sci (Lond) 2008;114:59-64.

37. Asante E. Interventions to promote treatment adherence in type 2 diabetes mellitus. Br J Community Nurs 2013;18:267-74.

38. Gaudet-Savard T, Ferland A, Broderick TL, et al. Safety and magnitude of changes in blood glucose levels following exercise performed in the fasted and the postprandial state in men with type 2 diabetes. Eur J Cardiovasc Prev Rehabil 2007;14:831-6.

39. Ferland A, Brassard P, Lemieux S, et al. Impact of high-fat/low-carbohydrate, high-, low-glycaemic index or low-caloric meals on glucose regulation during aerobic exercise in Type 2 diabetes. Diabet Med 2009;26:589-95.

40. Poirier P, Mawhinney S, Grondin L, et al. Prior meal enhances the plasma glucose lowering effect of exercise in type 2 diabetes. Med Sci Sports Exerc 2001;33:1259-64.

41. Poirier P, Tremblay A, Catellier C, et al. Impact of time interval from the last meal on glucose response to exercise in subjects with type 2 diabetes. J Clin Endocrinol Metab 2000;85:2860-4.

42. McCall KL, Raehl C, Nelson S, Haase K, Fike DS. Evaluation of pharmacy students' blood pressure and heart rate measurement skills after completion of a patient assessment course. Am J Pharm Educ 2007;71:1.

Supplementary Material

To access the supplementary material accompanying this article, visit the online version of the *Canadian Journal of Cardiology* at www.onlinecjc.ca and at https://doi.org/10.1016/j.cjca.2017.09.019.