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REVIEW

The impact of brief high-intensity exercise on blood glucose levels

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Background: Moderate-intensity exercise improves blood glucose (BG), but most people fail to achieve the required exercise volume. High-intensity exercise (HIE) protocols vary. Maximal cycle ergometer sprint interval training typically requires only 2.5 minutes of HIE and a total training time commitment (including rest and warm up) of 25 minutes per session. The effect of brief high-intensity exercise on blood glucose levels of people with and without diabetes is reviewed.

Methods: HIE (≥80% maximal oxygen uptake, VO_{2max}) studies with ≤15 minutes HIE per session were reviewed.

Results: Six studies of nondiabetics (51 males, 14 females) requiring 7.5 to 20 minutes/week of HIE are reviewed. Two weeks of sprint interval training increased insulin sensitivity up to 3 days postintervention. Twelve weeks near maximal interval running (total exercise time 40 minutes/week) improved BG to a similar extent as running at 65% VO_{2max} for 150 minutes/week. Eight studies of diabetics (41 type 1 and 22 type 2 subjects) were reviewed. Six were of a single exercise session with 44 seconds to 13 minutes of HIE, and the others were 2 and 7 weeks duration with 20 and 2 minutes/week HIE, respectively. With type 1 and 2 diabetes, BG was generally higher during and up to 2 hours after HIE compared to controls. With type 1 diabetics, BG decreased from midnight to 6 AM following HIE the previous morning. With type 2 diabetes, a single session improved postprandial BG for 24 hours, while a 2-week program reduced the average BG by 13% at 48 to 72 hours after exercise and also increased GLUT4 by 369%.

Conclusion: Very brief HIE improves BG 1 to 3 days postexercise in both diabetics and nondiabetics. HIE is unlikely to cause hypoglycemia during and immediately after exercise. Larger and longer randomized studies are needed to determine the safety, acceptability, long-term efficacy, and optimal exercise intensity and duration.

Keywords: high-intensity interval training, sprint interval training, diabetes, glucose

Video abstract

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The impact of brief high-intensity exercise on blood glucose levels

Type 2 diabetes is a worldwide epidemic associated with obesity and a sedentary lifestyle.[1] The estimated lifetime risk of developing diabetes for a person born in the United States in 2000 is 32.8% for males and 38.5% for females.[2] Diabetes increases morbidity and mortality due to heart disease, stroke, blindness, kidney failure, foot problems, and periodontal disease,[3] and has a significant impact on quality of life.[4] In 2010 it accounted for US$376 billion or 12% of the global health expenditure. This is approximately US$1330 per person per year.[5]

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Treatment goals for patients with diabetes include achieving and maintaining optimal blood glucose, blood pressure, and lipid levels in order to prevent or delay the progression of chronic complications.[6] Exercise, along with diet and weight control, is considered essential for the prevention and management of diabetes. Epidemiological studies suggest that physical activity can reduce the risk of type 2 diabetes by 30% to 50% in the general population.[7] Exercise helps treat the glucose, blood pressure, and lipid abnormalities often found in people with diabetes, and assists with weight loss maintenance.[8] In the United States, only 39% of adults with diabetes are active compared to 58% of those without the condition.[9]

VO_{2max}, the maximum amount of oxygen in milliliters that can be used in one minute per Kg of body weight, is a measurement of cardiovascular fitness. It correlates with insulin sensitivity in people at risk of developing type 2 diabetes.[10] Moderate aerobic exercise requires 40% to 60% of VO_{2max} or 50% to 70% of the maximum heart rate. Aerobic exercise is considered vigorous when it requires $>$ 60% VO_{2max} or $>$70% of the maximum heart rate.[11] For many persons with diabetes, moderate aerobic exercise would be the equivalent of brisk walking.

Endurance aerobic exercise is usually performed continuously over a prolonged period of time at submaximal intensity. Most recommendations are for 150 to 210 minutes per week of moderate-intensity endurance aerobic exercise, plus some resistance exercise, spread over three to five sessions.[8,12–14] This time commitment is in addition to all of the other self-care activities recommended for people with diabetes, and a lack of time is often cited as a reason for not exercising.[15] A cardiac evaluation may be required especially when vigorous physical activity is being contemplated and in the presence of additional risk factors for coronary artery disease.[16]

Effect of aerobic and resistance exercise training on glycemic control

Meta-analyses on the effects of exercise have estimated that for people with type 2 diabetes, both aerobic and resistance exercise improve glycemic control to an extent comparable to some oral antidiabetic drugs.[17–23] Exercise should theoretically be an attractive option for people who prefer not to use drugs, or wish to obtain additional blood glucose control benefits.

There is some evidence that both exercise duration and intensity affect HbA_{1c} levels. A meta-analysis of randomized controlled trials of at least 12 weeks in duration concluded that structured exercise training of more than 150 minutes of exercise per week resulted in greater HbA_{1c} reductions (–0.89%), than those with less weekly exercise time (–0.36%).[18] Another meta-analysis of aerobic exercise studies concluded that not only did higher exercise intensity tend to produce larger improvements in VO_{2max}, but that exercise intensity predicted postintervention HbA_{1c} ($r = -0.91$, $P = 0.002$) better than exercise volume ($r = -0.46$, $P = 0.26$). Workouts were, on average, 49 minutes (including 10 to 15 minutes of warm-up and cool-down), with a mean of 3.4 sessions per week for 20 weeks.[24] However, only one study included in the meta-analysis approached high-intensity at 75% of VO_{2max}.[25] In another meta-analysis for studies involving aerobic, resistance, and combined training, the overall reduction in HbA_{1c} was 0.8% (90% CI ±0.3) with the effect of exercise intensity being unclear.[20]

Glucose metabolism during moderate-intensity exercise

Skeletal muscle is responsible for most of the uptake of glucose after a meal, and transport of glucose into the muscle is considered the limiting step in glucose disposal.[26,27] Glucose transport occurs primarily by diffusion utilizing glucose transporter carrier proteins (GLUT). Both exercise and insulin regulate glucose transport mainly by the translocation of the GLUT4 isoform from an intracellular compartment to the plasma membrane and transverse tubules.[8,28] GLUT4 levels are considered an important determinant of insulin sensitivity.[26,27]

At rest and postprandially, glucose uptake is insulin-dependent, with the major purpose being the replenishment of muscle glycogen stores.[8] Insulin-stimulated GLUT4 translocation is generally impaired in type 2 diabetes.[28] During exercise, muscle utilizes glucose made available by intramuscular glycogenolysis and by increased glucose uptake. Both aerobic and resistance exercises increase GLUT4 abundance and translocation, and hence blood glucose uptake by a pathway that is not dependent on insulin.[8] Glucose uptake into contracting muscle is therefore normal even in the presence of type 2 diabetes.[8,28,29] Following exercise, glucose uptake remains elevated, with the contraction-mediated pathway remaining active for several hours.[8]

During moderate-intensity exercise (60% VO_{2max}) of short duration in persons without diabetes, increased glucose uptake by muscle is balanced by an equal rise in hepatic glucose production, and blood glucose levels remain unchanged.[8,30] There is a decrease in insulin level, which sensitizes the liver to glucagon, thus increasing glucose production.[30] Catecholamines play a role in increasing glucose production only during moderate-intensity exercise greater than 2 hours duration. With type 2 diabetes, blood glucose uptake by muscles usually increases more than hepatic production.[31] This is also normally accompanied by a decline in plasma insulin levels, greatly reducing the risk of hypoglycemia in diabetics not using insulin or insulin secretagogues.[8] The effects of aerobic exercise vary with duration and intensity, but following a single exercise session there is generally an increase in insulin action and hence glucose tolerance for between 24 and 72 hours.[8]

High-intensity exercise

High-intensity interval training (HIT) consists of brief bursts of very vigorous exercise separated by brief recovery periods. Total exercise time is short. While there is no universal definition of HIT, it often refers to exercise performed with an "all out" effort, or at least to an intensity that approaches VO_{2max} ($\geq$90% VO_{2max}).[32]

The classic form of "all out" HIT is the Wingate test. After about 3 to 5 minutes of warm-up the subject cycles for 30 seconds at maximum effort against a standardized resistance. Typically four to six Wingate tests are performed separated by 4 minutes of rest, for a total of 2 to 3 minutes of maximal exercise spread over 15 to 30 minutes.[33] This "all out" cycle ergometer form of HIT is also referred to as sprint interval training (SIT). When used in this paper, SIT will refer only to Wingate tests as just described. Because of the intensity and short duration of the Wingate test, most of the power generated represents anaerobic as opposed to aerobic power, with an aerobic power contribution of between 16% and 19.5%.[34–36] The primary energy source is glucose derived from muscle glycogen, and as aerobic capacity is exceeded, most of this is converted to lactate to provide anaerobic ATP. The initial 30-second Wingate test can use almost a quarter of the stored muscle glycogen, and although the rate of glycogenolysis is reduced in subsequent bouts, significant amounts of lactate accumulate.[37,38] The exercise is extremely stressful with the perceived exertion being very high. Reports of nausea and light-headedness are not uncommon.[39] It requires a high level of motivation, and often sessions are supervised, with significant verbal encouragement to exert maximal effort.[40] The average person with diabetes is not likely to tolerate this well. Specialized costly equipment, usually a cycle ergometer, is also required. While time spent exercising intensely is very short, training time commitment is longer as it will include warm-up, cool-down, and rest periods.

Other forms of HIT may not require "all out" effort and may be performed at only half the intensity of an "all out" SIT protocol but with longer sessions, more repetitions, and shorter rest periods, and are tolerated much better.[41,42] High-intensity exercise may also be performed on a continuous basis, but even very fit persons can usually maintain an intensity of $\geq$80% VO_{2max} for only 10 to 15 minutes.[30] The exercise load needed depends on the individual's exercise capacity. For people with a low VO_{2max} of 20 mL/Kg per minute, the necessary exercise load may be equivalent to walking up a slight grade at 3 mph.[42]

Glucose metabolism during high-intensity exercise

In intense exercise (>80% VO_{2max}), unlike at lesser intensities, glucose is the exclusive muscle fuel.[30] Catecholamine levels rise markedly, causing glucose production to rise seven- to eightfold while glucose utilization is only increased three- to fourfold. In people without diabetes there is a small blood glucose increase during intense exercise that increases further immediately at exhaustion and persists for up to 1 hour. Plasma insulin levels rise, correcting the glucose level and restoring muscle glycogen. This physiological response would be absent in type 1 diabetics.

Aerobic endurance and high-intensity exercise

HIT is effective in improving aerobic endurance. In one study six "all out" SIT sessions over 2 weeks improved the mean cycle endurance time to fatigue while cycling at approximately 80% of pretraining VO_{2max} by 100% (from 26 to 51 minutes).[43] This required a total high-intensity exercise time of only 15 minutes with a total training time commitment of approximately 2.5 hours. In another study, a less intense version of HIT (6–10 cycling bouts of 30 seconds each at 125% of the power at VO_{2max} with 2 minutes recovery) produced a similar improvement in VO_{2max} after 4 weeks of training, as was seen in the more intense SIT group (three to five "all out" 30-second cycling bouts with 4 minutes of recovery).[41] The less intense HIT required only half the intensity but double the repetitions of the SIT, and may be more practical for the nonathlete.

Many people do not exercise despite the proven benefit of endurance exercise. An exercise program requiring less time commitment may appeal to some people. The aim of this paper is to review the impact of high-intensity exercise of short duration on blood glucose levels in diabetic and nondiabetic people.

Methods

A narrative review was done. PubMed was searched in July 2012 using the following search terms: high-intensity interval training, sprint interval training, and high-intensity exercise each combined with glucose and/or diabetes. To be included: (1) exercise intensity had to be at least 80% VO_{2max} or 90% maximum heart rate, or include maximal cycle ergometer sprints; (2) the duration was no more than 15 minutes of high-intensity exercise and 30 minutes of total exercise time per session; and (3) glycemic control was assessed. Review articles and references retrieved were hand searched for additional primary studies.

Results

High-intensity interval training and insulin sensitivity in healthy nondiabetic adults

Six studies with a total of 51 male and 14 female participants in the high-intensity exercise groups are reviewed. Four of these used SIT (maximal effort cycle ergometer) exercise protocols of 2 to 6 weeks duration,[39,44–46] and two used near maximal running as the intervention (Table 1).[47,48] Although near maximal running would not be as intense as the cycle ergometer, it was not surprising that in the study with the heavier subjects,[47] overuse shin splint injuries caused three out of eight participants in the intense running group to miss between one and four training sessions. Three studies divided participants into an intervention and comparison group,[39,47,48] with two stating that allocation was random.[39,48]

Both Richards et al[39] and Babraj et al[44] studied young healthy subjects who were sedentary or recreationally active and found that 2 to 3 days after a 2-week exercise program consisting of six sessions of SIT, insulin sensitivity but not fasting blood glucose improved compared to baseline. Whyte et al[46] studied overweight and obese sedentary men, and after a similar SIT protocol found no improvement in fasting blood glucose; moreover, insulin sensitivity was improved compared to baseline at 24 but not 72 hours. Richards et al[39] randomized subjects to one of three groups: (1) six sessions of SIT; (2) a single session of SIT; and (3) no exercise. Insulin sensitivity was estimated before and 72 hours after the intervention by means of a hyperinsulinemic euglycemic clamp, considered the gold standard test. It increased in the group that did six sessions of SIT (mean change of glucose infusion rate: +1.7 ± 0.6 mg/kg per minute, $P = 0.04$) but not in the single session SIT and no exercise groups. The intervention had no effect on the thermogenic response to beta-adrenergic receptor stimulation, which is considered an important determinant of energy expenditure and by extension a major regulator of energy balance and body mass. Babraj et al[44] estimated insulin sensitivity before and 48 to 72 hours after the intervention by means of oral glucose tolerance tests and the Cederholm index. While FBG and fasting insulin levels were unchanged, both glucose area under the curve (AUC; −12%), and insulin AUC (−37%), were significantly reduced during the oral glucose tolerance tests. In addition, aerobic cycling performance was improved by about 6% ($P < 0.01$) compared to baseline. Endurance aerobic and strength training studies of up to 16 months duration have generally demonstrated only a reduction in insulin AUC in response to a glucose load following training, without a concurrent reduction in glucose AUC.[44]

Burgomaster et al[45] demonstrated that SIT increased muscle GLUT4 content, a determinant of insulin sensitivity, by 20% compared to baseline after 1 week of exercise, and that the levels remained elevated over the remaining 5 weeks of training and a subsequent 6 weeks of detraining. Muscle oxidative capacity, as estimated by the protein content of cytochrome c oxidase subunit 4 (COX4) also increased by 35% after 1 week of HIT, and remained higher compared with baseline after 6 weeks of detraining ($P < 0.05$).

Nybo et al[47] found that 20 minutes of near maximal running (40 minutes of total exercise time) per week for 12 weeks was as effective as 150 minutes of running at 65% VO_{2max} per week over the same period, in improving both fasting blood glucose and blood glucose 2 hours after the ingestion of 75 g of glucose. For the latter, blood glucose was improved from a mean of 6.1 (standard error (SE) ± 0.6) mmol/L to 5.1 (SE ± 0.4) mmol/L ($P < 0.05$) in the maximal running group and from 5.6 (SE ± 1.5) mmol/L to 4.9 (SE ± 1.1) mmol/L ($P < 0.05$) in the prolonged running group. Sandvei et al[48] had similar findings, with only 7.5 to 15 minutes of near maximal running per week, but a longer total exercise time when warm-up and rest periods were included.

These studies therefore demonstrate that in young nondiabetic adults, as little as 15 minutes of high-intensity exercise spread over 2 weeks is enough to improve insulin sensitivity without a change of body weight. Energy expended would be equivalent to about 500 Kcal. In contrast, a typical aerobic training program consumes 2000 to 3000 kcal/week with guidelines recommending 150 minutes of training per week. It was postulated that despite the negligible energy expenditure, HIT improved insulin action by depleting muscle glycogen stores.[44]

High-intensity training and glucose regulation in people with diabetes

There has been little testing of brief high-intensity exercise in either type 1 or type 2 diabetic patients. Eight studies were

Table 1 Characteristics of reviewed high-intensity exercise studies on healthy people without diabetes, and effects on insulin sensitivity and blood glucose

Study	Gender	Intervention group Age (years) BMI (Kg/m^2) Weight (Kg) Mean ± SD	Number in intervention group	Intervention	Study duration	Number in comparison group	Effect on measure of blood glucose
Richards et al[39]	5 male 7 female (sedentary or recreationally active)	Age: 29 ± 3 BMI: 26.2 ± 1.3 Weight: 76 ± 6	12	SIT (4 to 7 × 30 sec maximal cycle ergometer efforts separated by 4 minutes of rest).	Six SIT sessions over 2 weeks. Eight minutes of high-intensity exercise/week.	Single SIT control: 9 Sedentary control: 10	Six SIT sessions increased insulin sensitivity significantly 3 days after the last session compared to baseline, and comparison groups. No effect on FBG.
Babraj et al[44]	Male (sedentary or recreationally active)	Age: 21 ± 2 BMI: 23.7 ± 3.1 Weight: 82 ± 17	16	SIT (4 to 6 × 30 seconds of maximal cycle ergometer efforts separated by 4 minutes of rest). Total time commitment of 17 to 26 minutes per session.	Six SIT sessions over 2 weeks. Average of 7.5 minutes of high-intensity exercise/week.	Compared to baseline	2 to 3 days after the last session, insulin sensitivity improved 23% ($P < 0.01$), and plasma glucose area under the curve decreased ($P < 0.01$) compared to baseline. No effect on FBG.
Burgomaster et al[45]	Male (active)	Age: 22 ± 1 Weight: 80 ± 4	8	SIT (4 to 6 × 30 seconds maximal cycle ergometer efforts separated by 4 minutes of rest).	Three sessions per week for 6 weeks. An average of 7.5 minutes of high-intensity exercise per week.	Compared to baseline	Muscle GLUT4 increased 20% after 1 week of SIT and remained elevated 6 weeks postexercise.
Whyte et al[46]	Male Sedentary	Age: 32 ± 9 BMI: 31 ± 4 Weight: 94 ± 13	10	SIT (4 to 6 × 30 seconds of maximal cycle ergometer efforts separated by 4.5 minutes of rest).	Six sessions over 2 weeks.	Compared to baseline	No change in FBG and glucose area under the curve at 24 and 72 hours after exercise, but insulin sensitivity index higher at 24 hours ($P = 0.027$).
Nybo et al[47]	Male Sedentary	Age: 37 ± 3 Weight: 96 ± 3	8	5-minute warm-up, then 5 × 2-minute intervals of running with heart rate 95% of maximum at the end of the interval (total exercise time 40 minutes/week).	Two sessions per week for 12 weeks. Twenty minutes of high-intensity exercise/week.	9, performed 1-hour continuous running at 65% VO_{2max} (about 150 minutes/week) 11, no exercise	Similar lowering of FBG and blood glucose 2 hours after a 75 g glucose tolerance test, done 48 hours after the last exercise session.
Sandvei et al[48]	4 males 7 females Sedentary to moderately trained	Age: 18 to 35 BMI: 23 ± 1 Weight: 70 ± 3.5	11	10-minute warm-up, then 5 to 10 × 30 seconds near maximal sprints with 3-minute rest periods.	Three sessions/week for 8 weeks.	12 performed continuous running at 70% to 80% maximal heart rate for 90 to 180 minutes/week	High-intensity running, but not continuous running, improved insulin sensitivity 60 hours after last exercise session. FBG significantly improved in both groups.

Abbreviations: BMI, body mass index; SD, standard deviation; SIT, sprint interval training; FBG, fasting blood glucose; GLUT4, glucose transporter protein 4; VO_{2max}, maximal oxygen uptake.

identified with only three of these involving type 2 diabetics. In addition to maximal cycle ergometer SIT, HIT protocols included a less intense form of HIT not requiring "all out" effort, and protocols requiring very short bursts of exercise (as little as 4 seconds) interspersing up to 30 minutes of moderate exercise. Noninterval high-intensity exercise protocols included continuous exercise at 80% to 110% VO_{2max} for up to 13 minutes. Six studies measured the effects of single exercise sessions, and the other two studies were of 2 and 7 weeks duration. All involved small numbers of subjects (up to eight different subjects in an intervention group), and except for three studies the mean age was <35 years (Table 2).

Effects of high-intensity exercise on blood glucose in type 2 diabetic patients

A single session of continuous high-intensity exercise resulted in 60 minutes of postexercise hyperglycemia,[49] while both a single session of HIT,[50] and a 2-week training program[51] have been shown to improve postprandial glucose control over a 24-hour period following exercise.

Little et al[51] evaluated the effects of six sessions of HIT over 2 weeks on glucose regulation 48 to 72 hours after the last training session in people with type 2 diabetes. Most participants engaged in 60 minutes or less of exercise per week prior to entering the study. The HIT protocol required only 30 minutes of high-intensity exercise per week, with a total time commitment (including warm-up, cool-down, and rest) of 75 minutes. The exercise intensity was less and may be more acceptable than "all out" SIT protocols. When asked how enjoyable would engaging in HIT three times per week for the next 4 weeks be, the mean response was 7.9 ± 1.0 on a scale ranging from 1 (not enjoyable at all) to 9 (very enjoyable). Additionally, it elicited ratings of perceived exertion of 4 to 8 on a 10-point scale. Before training and from 48 to 72 hours after the last training session, glucose regulation was assessed using 24-hour continuous glucose monitoring under standardized dietary conditions. The average 24-hour blood glucose concentration was reduced by 13%, from 7.6 mmol/L (SD ± 1) to 6.6 mmol/L (SD ± 0.7) after training ($P < 0.05$). The sum of the 3-hour postprandial glucose AUC for breakfast, lunch, and dinner was reduced by 30% ($P < 0.05$). GLUT4 protein content was 369% higher after 2 weeks of training.

Gillen et al,[50] studying 7 of the 8 individuals who participated in the study by Little et al,[51] and using an identical exercise protocol, demonstrated that a single exercise session also reduced the sum of the 3-hour postprandial glucose AUC ($P = 0.01$) and the proportion of time spent above 10 mmol/L in the 24-hour postexercise period when compared to a nonexercising control day. Average 24-hour blood glucose was, however, not significantly reduced ($P = 0.16$). The results of the two studies might be clinically significant, as controlling postprandial hyperglycemia is a treatment goal with type 2 diabetics.

Kjaer et al[49] investigated the effect of 5 minutes of high-intensity exercise on blood glucose control during and for 3 hours immediately following exercise in type 2 diabetic patients (two on a sulfonylurea and five on diet only). There was a greater and more sustained rise in glucose levels in type 2 diabetics compared to controls. In type 2 diabetic subjects, blood glucose increased from a pre-exercise level of 147 mg/dL (SD ± 21) to a peak 30 minutes postexercise at 169 mg/dL (SD ± 19). This value was maintained until 60 minutes postexercise, and then plasma levels decreased over the remainder of the 180-minute recovery period. For the controls, blood glucose increased from a pre-exercise level of 90 mg/dL (SD ± 4) to a peak at 10 minutes postexercise at 100 mg/dL (SD ± 5). Glucose concentrations at 60 minutes postexercise did not differ significantly from pre-exercise levels. In both groups, plasma insulin levels increased after exercise above pre-exercise levels, and returned to baseline about 120 minutes postexercise. Plasma epinephrine and glucagon responses to exercise were higher in type 2 diabetics than in control subjects ($P < 0.05$). However, 24 hours after exercise in the type 2 diabetic group and not the controls, there was an increased effect of insulin on glucose uptake compared to the pre-exercise state as estimated by the insulin clamp technique. Other studies have found similar increases in insulin-mediated glucose disposal after short-term high-intensity exercise in insulin-resistant subjects.[52,53] It was concluded that because of exaggerated counter-regulatory hormonal responses, maximal dynamic exercise results in a 60-minute period of postexercise hyperglycemia and hyperinsulinemia in type 2 diabetics.[49]

Effects of high-intensity exercise on blood glucose in type 1 diabetic patients

The high-intensity studies involving type 1 diabetics mainly investigated blood glucose control during and in the 2 hours after exercise.

Harmer et al[54] studied the effects of 7 weeks of SIT. The number of cycle bouts per training session was increased from four in week 1, to six in week 2, eight in week 3, and ten in weeks 4–7. SIT resulted in a greater rise in plasma glucose during and immediately after exercise (a 20-minute period) in diabetics compared to nondiabetic controls. This increase was significantly attenuated by 7 weeks of training. HbA_{1c} was not altered.

Table 2 Characteristics of the reviewed high-intensity exercise studies on people with diabetes, and changes in BG control

Study	Type of diabetes	Number in HIE group Gender Activity status	Intervention group Age (years) BMI (Kg/m^2) HbA_{1c} (%) Mean ± SD	Intervention	Study duration	Number in comparison group	Effect on measure of BG
Little et al[51]	Type 2	Number: 8 Gender: not stated Activity: most sedentary	Age: 63 ± 8 BMI: 32 ± 6 HbA_{1c}: 6.9% ± 0.7%	Ten 60-second efforts at 90% maximal HR on a cycle ergometer interspersed with 60 seconds of rest (allowed to rest or pedal slowly)	Three 25-minute sessions per week for 2 weeks. Each session included 3 minutes of warm-up and 2 minutes of cool-down.	Compared to baseline	Average 24-hour BG reduced 13% ($P < 0.05$), and sum of the 3-hour postprandial glucose AUC reduced 30% ($P = 0.05$) 2 to 3 days after HIT compared to preintervention.
Gillen et al[50]	Type 2	Number: 7 Gender: not stated Activity: most sedentary	Age: 62 ± 3 BMI: 31 ± 2 HbA_{1c}: 6.9% ± 0.7%	Ten 60-second efforts at 90% maximal HR on a cycle ergometer interspersed with 60 seconds of rest (allowed to rest or pedal slowly)	Single 25-minute session including 3 minutes of warm-up and 2 minutes of cool-down.	7 (same individuals as intervention group) not exercising	Average 24-hour BG not significantly reduced ($P = 0.16$), but sum of the 3-hour postprandial glucose AUC reduced for24 hours following HIT ($P = 0.01$) compared to no exercise.
Kjaer et al[49]	Type 2	Number: 7 Gender: male Activity: sedentary	Age: 55 ± 4 BMI: 27 ± 2	Cycling 7 minutes at 60% VO_{2max}, 3 minutes at 100% VO_{2max}, and 2 minutes at 110% VO_{2max}	Single 12-minute exercise session with 5 minutes of HIE.	7 nondiabetic	BG increased more during exercise in the diabetic group, and peaked 30 minutes postexercise.
Harmer et al[54]	Type 1	Number: 8 Gender: not stated	Age: 25 ± 4 BMI: 25 ± 3 HbA_{1c}: 8.6% ± 0.8%	Four to eight 30-second maximal cycle ergometer exercise separated by 4 minutes of rest	Thrice weekly sessions for 7 weeks.	7 nondiabetic	BG increased more during and 20 minutes postexercise in the diabetic as compared to nondiabetic group. The increase was less after 7 weeks of training. HbA_{1c} not altered.
Guelfi et al[55]	Type 1	Number: 8 Gender: not stated	Age: 19 ± 2 BMI: 22 ± 2 HbA_{1c}: 7% ± 0.4%	Eleven 4-second maximal cycle ergometer sprints separated by 2 minutes of rest	Single 20-minute exercise session.	8 (same individuals as in the intervention group) not exercising	BG declined more rapidly during exercise in the HIT group, but remained stable in the 1-hour postexercise period.
Guelfi et al[56]	Type 1	Number: 7 Gender: 4 males, 3 females	Age: 22 ± 4 BMI: 25 ± 4 HbA_{1c}: 7.4% ± 1.5%	Cycling at 40% VO_{2max} interspersed by sixteen 4-second maximal cycle ergometer sprints	Single 30-minute exercise session.	7 (same individuals as the intervention group) cycling at 40% VO_{2max}	BG fell less in the HIT group, and did not continue to decline postexercise unlike with controls.
Maran et al[57]	Type1	Number: 8 Gender: male Activity: active	Age: 34 ± 7 BMI: 24 ± 2 HbA_{1c}: 7.1% ± 0.6%	Cycling at 40% VO_{2max} interspersed by 5 seconds of maximal sprints every 2 minutes	Single 30-minute session.	8 (same individuals as in the intervention group) cycling at 40% VO_{2max}	Between 12 AM and 6 AM, postexercise BG lower in the HIT group compared to the comparison group (BG AUC 147 versus 225 mg/dL, $P < 0.05$).
Mitchell et al[58]	Type 1	Number: 10 (8 different subjects with 2 studied twice at different pre-exercise BG levels) Gender: 5 males, 5 females	Age: 29	Cycle ergometer at 80% VO_{2max} until exhausted	Single 10 to 13-minute exercise session.	8 nondiabetic	BG increased more in the diabetic group and remained high 2 hours postexercise unlike normal controls.

Abbreviations: BMI, body mass index; HbA_{1c}, glycosylated hemoglobin; SD, standard deviation; HR, heart rate; BG, blood glucose; AUC, area under the curve; HIT, high-intensity training.

All the other studies involved a single exercise session. Guelfi et al[55] studied the effects of HIT (repeated 4-second cycle ergometer efforts separated by rest) on blood glucose during exercise and in the immediate 1-hour postexercise period. Participants injected their normal dose of insulin and had breakfast. After the postprandial peak in blood glucose, on alternate days, participants either exercised or rested. During exercise blood glucose declined more rapidly as compared to the nonexercising controls, indicating that high intensity exercise may increase the risk of hypoglcemia. This finding is not supported by the other studies reviewed. However during the recovery period blood glucose levels continued to decline in the controls while remaining stable in the exercise group suggesting a decreased risk of postexercise hypoglycemia. Guelfi et al[56] also compared a HIT protocol that was combined with moderate-intensity exercise (repeated 4-second cycle ergometer efforts over 30 minutes separated by cycling at 40% VO_{2max}) to moderate exercise only (cycling at 40% VO_{2max}) for 30 minutes. Exercise commenced 3.5 hours postprandially when the blood glucose was about 11 mmol/L. Blood glucose fell to a greater extent in the moderate exercise group compared to the HIT group, and remained stable in the HIT group in the 1-hour recovery period while continuing to fall in the moderate-exercise group. Blood glucose at 1-hour postexercise was 3.3 mmol/L lower than the preexercise level in the HIT group, and 6.3 mmol/L lower in the moderate exercise group ($P = 0.021$). However, Maran et al,[56] using a similar exercise protocol, demonstrated that following morning HIT, blood glucose was significantly lower between midnight and 6 AM the next day compared to when only moderate-intensity exercise was done.[57] Mitchell et al[58] showed that continuous noninterval exercise at 80% VO_{2max} until exhaustion (approximately 10 to 13 minutes) increased blood glucose during and in the 2-hour postexercise period. Thus, unlike moderate-intensity exercise, HIT is unlikely to cause hypoglycemia during or immediately postexercise in type 1 diabetics, but 14 to 20 hours later it may result in lower glucose levels.

Summary

Clinical practice guidelines typically recommend that people with type 2 diabetes perform moderate to vigorous aerobic exercise and resistance exercise three to five times per week for a total of at least 150 to 210 minutes per week. Many persons do not achieve the recommended amounts of exercise with lack of time being cited as a reason.[15] Meta-analyses have shown that non-HIT programs can produce HbA_{1c} improvements between 0.6% and 0.89%, an amount that is clinically significant and comparable to some medication regimens.

Classic SIT protocols can require as little as 2 to 3 minutes of maximal exercise spread over 15 to 30 minutes. With healthy nondiabetic subjects, 2-week protocols have resulted in improvements in muscle GLUT4 content, insulin sensitivity, and FBG. Insulin sensitivity improvement has been sustained up to 3 days post-intervention. Improvements in VO_{2max} were similar to that achieved by much longer sessions of endurance aerobic exercise.

In type 2 diabetic patients, a low-volume 2-week HIT program increased GLUT4 protein, a marker of insulin sensitivity, and decreased average blood glucose 48 to 72 hours postexercise. The protocol used was less intense than SIT and was acceptable to study participants. However, unlike with moderate-intensity exercise, blood glucose levels tend to be higher in both type 1 and 2 diabetic patients during and in the 2 hours immediately following intense exercise due to rising catecholamine levels promoting glycogenolysis, and these levels may remain high in the 2-hour post-exercise period. HIT depletes muscle glycogen and it is possible that after catecholamine levels decrease in the post-exercise phase, a period of increased peripheral uptake of glucose follows as glycogen stores are replenished.

Conclusion

The optimal exercise strategy has not been determined, but low volume SIT with as little as 7.5 minutes of high-intensity exercise per week may be a time-efficient exercise strategy to help control blood glucose in diabetic patients and improve insulin sensitivity in nondiabetic adults. Unlike moderate-intensity exercise, high-intensity exercise decreases the risk of hypoglycemia during and immediately after exercise in diabetic patients. Therefore, there may be no need for well controlled patients on insulin or insulin secretagogues to eat or decrease medication dosage shortly before high-intensity exercise. However, the perceived exertion associated with the "all out" version of HIT is very high and the acceptability, feasibility, and safety for the sedentary diabetic and nondiabetic population are in doubt. Both the risks of musculoskeletal injury and cardiovascular complications have to be considered. The cost of exercising and the provision of facilities (equipment, supervision, and gyms) also have to be taken into account if this form of exercise is to have a mass impact. The less strenuous version of HIT used by Little et al[51] might be preferred to "all out" SIT as it was well accepted while still being of short duration.

Studies on the effect of high-intensity exercise on blood glucose have been few and of short duration, and have involved a small number of patients who were probably not representative of the general diabetic population. With diabetics, it is therefore uncertain if any improvements in blood glucose achieved by a brief intervention would be sustained over a longer period, reduce HbA_{1c} levels, improve health outcomes, and can be replicated in the general diabetic population. Similarly, in the nondiabetic population it is not known whether improvements in insulin sensitivity would be sustained and result in a clinically important endpoint such as diabetes prevention. Further studies are needed to determine whether HIT programs, perhaps in the less intense form or as an adjunct to moderate-intensity exercise, would be effective in the long-term and have a high enough adherence rate to be efficacious. Large scale randomized trials lasting years may be necessary to show whether HIT can prevent diabetes, and such trials may be impractical.

Disclosure

The author reports no conflicts of interest in this work.

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