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ARTICLE

Acute effects of single-bout exercise in adults with type 2 diabetes: a systematic review of randomised controlled trials and controlled crossover trials

Dominic Hicks[a], Robert C Hickner[b,c,d], Usha Govinden[b] and Takshita Sookan[a*]

[a]*Discipline of Biokinetics, Exercise and Leisure Sciences, University of KwaZulu-Natal, Durban, South Africa*
[b]*Discipline of Pharmaceutical Sciences, University of KwaZulu-Natal, Durban, South Africa*
[c]*Department of Nutrition, Food, and Exercise Sciences, Florida State University, Tallahassee, United States*
[d]*Institute of Sports Sciences and Medicine, Florida State University, Tallahassee, United States*
**Correspondence: Sookan@ukzn.ac.za*

Background: Exercise interventions improve type 2 diabetes (T2D). Published randomised control trials and crossover control trials were systematically examined to establish the differences in the effect of single-bout exercise on glucose control and insulin sensitivity in individuals with type 2 diabetes.
Methods: Using PRISMA guidelines on three electronic databases, studies that tested the effects of a single bout of exercise on glucose control and insulin sensitivity in T2D were identified. To be included, studies had to meet the PRISMA criteria and contain data on the effects of a single bout of exercise on blood glucose and/or insulin resistance in individuals with T2D.
Results: Three of the 205 articles met the inclusion criteria. All of the studies prescribed a single bout of continuous aerobic exercise at 40–60% heart rate reserve (HRR), 60% HRR, or 73% VO_2 peak. Aerobic exercise was associated with improved glucose control when compared with resistance exercise. Continuous aerobic exercise significantly lowered average glucose during the first 24 hours post-exercise. Interval walking decreased mean and maximal blood glucose when compared with that in control.
Conclusions: In conclusion, the findings of this review suggest high-intensity interval training to be the most effective form of exercise.

Keywords: adults, effects, exercise, glucose control, insulin resistance, single bout, type 2 diabetes

Introduction

The pancreas is largely responsible for the regulation of blood glucose through the secretion of the hormones insulin and glucagon.[1] Insulin is secreted to maintain homeostasis when blood glucose concentrations are elevated.[1] Chronically elevated levels of insulin and glucose are indicative of insulin resistance and T2D, respectively.[2] The pathogenesis of insulin resistance is not yet fully understood; however, it is known to be complex and multi-factorial, with an array of possible causes that include genetic predisposition, lifestyle and environmental factors.[2,3] Lack of physical activity (low energy expenditure), high caloric dietary intake and obesity are amongst the environmental factors that induce insulin resistance and T2D.[2,3] Despite exercise and physical activity being reported to improve insulin resistance and T2D, exercise remains a relatively underutilised approach in the treatment of the disorders, in comparison with medicinal and/or pharmaceutical approaches.[3–5]

The glucoregulatory effects of long-term physical activity, or ongoing exercise training, have been extensively investigated, and include improvements in insulin sensitivity and glycaemic control.[4] Although single bouts of exercise of nearly any type, duration or intensity result in acute beneficial effects on insulin sensitivity and glucose control, the difference in the effects of different types, intensities and/or duration in individuals with type 2 diabetes is not clear.[6]

The current review systematically examined relevant published studies that compared the acute effects of single bouts of exercise or physical activity of any type, duration or intensity on glycaemic control and insulin sensitivity in individuals with T2D.

Methods

Search strategy

The search strategy adopted for this review was in accordance with the Preferred Reporting for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[7] Electronic searches were conducted between March 23, 2019 and February 10, 2020 in three separate databases, i.e. BMC Endocrine Disorders; Cochrane Library; and PubMed. The keywords used in the database search were: adults; glucose control; single bout; effects; exercise; insulin resistance; and type 2 diabetes. The search was restricted by the requirement that the articles had to be peer-reviewed original research, with the full text published in English. Studies were searched manually via reference lists of key articles to identify other potentially eligible studies (Figure 1).

Search terminology

Title headings used in the current review included adults AND glucose control AND single bout AND effects AND exercise AND insulin resistance AND type 2 diabetes.

Inclusion and exclusion criteria

The following criteria were used in this review for the studies to be included: male and female adult human participants with

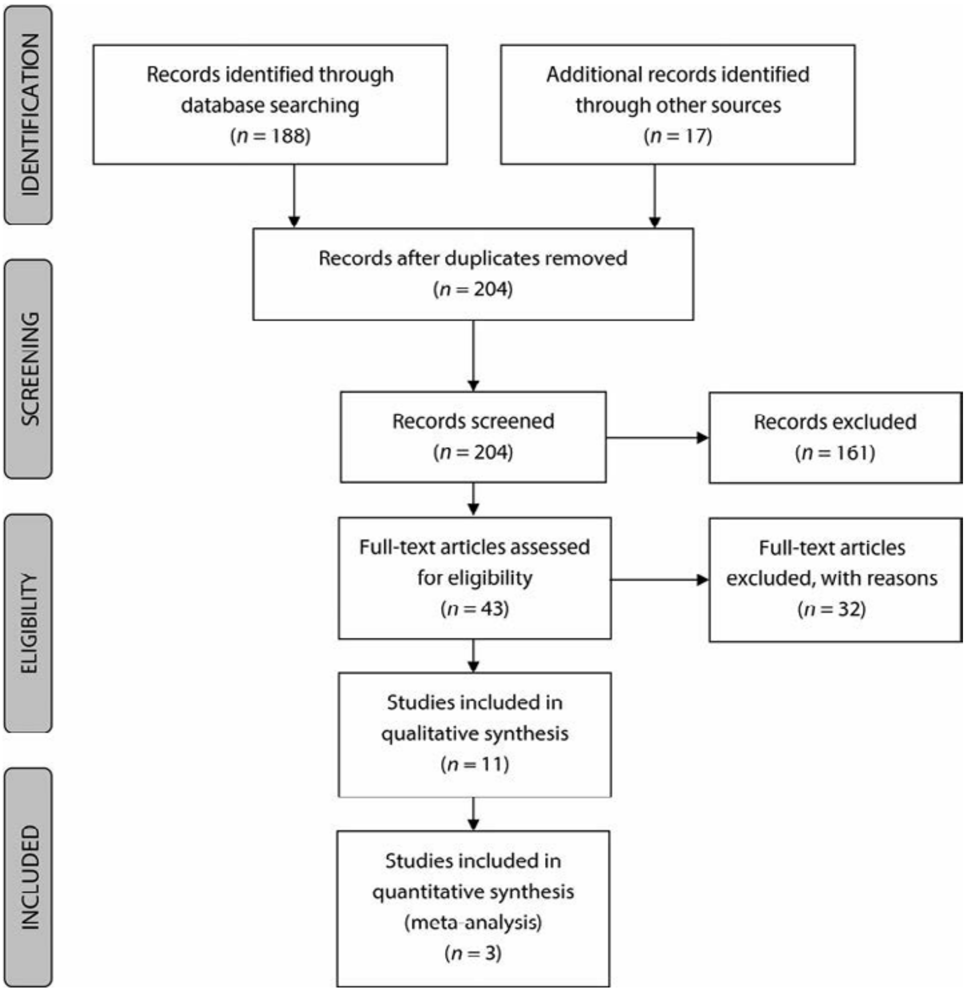

Figure 1: PRISMA 2009 flow diagram.

clearly defined type 2 diabetes; exercise of any type, frequency, duration and intensity; studies must have reported on the acute effects of a single bout of exercise in comparison with another type of acute exercise or a no-exercise control; studies must have reported pre- and post-acute exercise measurements of at least one marker of glucose control or insulin resistance.

Outcome measures

The primary outcomes included in the current review are markers of glucose control and insulin resistance (HbA1c; HOMA-IR; QUICKI; fasting plasma glucose; fasting insulin; oral glucose tolerance test; continuous glucose monitoring; glucose area under curve). Data in the studies included in the review were expressed as means and standard deviations/standard errors of the mean and percentage change. The relationship between the selected outcomes is the reason for their choice. Insulin resistance is widely regarded as a contributing factor to impaired glucose control and other systemic and metabolic conditions.[8]

Data extraction

The current review utilised the standardised pre-piloted data extraction form (Joanne Briggs Institute [JBI] Data Extraction Form for Experimental/Observational Studies) to extract data from the identified studies. Extracted information included study method, study setting, population and sample size. The study also included the following details of the intervention: outcome measures, exercise type and frequency, and duration of the intervention period.

Study quality assessment

The current review used the JBI Critical Appraisal Checklist for Randomised Control Trials (RCT) and randomised controlled crossover (RCC) to assess the quality of the methodology and to determine the extent to which a study addressed the possibility of bias.[9]

Results

Identification and selection of studies

The current study utilised keywords in several search engines to yield a list of potentially applicable studies. The keywords utilised for the first phase of searching were: adults; glucose control; single bout; effects; exercise; insulin resistance; type 2 diabetes. Many publications were excluded from the study because no information on the effects of a single bout of exercise was provided, no information on comparison of the effects of one type of acute exercise with any other type of acute exercise, or no information was provided of the effects of one type of acute exercise on a non-exercise control. The electronic searches from the three databases yielded a total of 188 journal articles. The articles were then manually scanned by the principal investigator using the title, author(s), abstract and methodology to establish whether or not the study was suitable for the current review. If the study met the review inclusion criteria, it was added to a shortlist of potentially suitable studies. The articles on the shortlist then underwent a peer review by the co-investigators to determine whether they could be included. The total number of studies included in the current review is three.

Study characteristics

Study settings and participants

The characteristics of the included studies are given in Table 1. The protocol settings included university departments in Verona, Italy;[10] Missouri, Columbia;[11] and Copenhagen, Denmark.[12] The total number of participants in the studies ranged from 9 to 25 (the mean age ranged from 56.1 ± 2–60.3 ± 2.3 years).

Intervention

The exercise regimens in the studies in this review included individualised aerobic, resistance or interval-based exercise. Of the studies included, participants were in a postprandial state for two studies,[10,11] and in a fasted state for one study.[12]

The types of exercise used in the studies included cardiovascular exercise (using treadmills, cycle ergometers and elliptical trainers) and resistance exercise (using weight machines and free-weights).

In the study by Bacchi et al., the exercise intensity in the aerobic group ranged between 40% and 60% HRR (approximately 6 METS), and the resistance intensity ranged from 70 to 80% 1RM.[10] The aerobic exercise lasted for 60 minutes and the resistance exercise included three series (sets) of nine exercises, with 10–12 repetitions of each.[10]

In the study by Oberlin et al., the aerobic group's exercise intensity was set at 60% HRR, and was compared with that of the control group, which performed no exercise.[11] The duration of exercise, or rest for the control group, was 60 minutes.[11]

In the study by Karstoft et al., the walking interval duration was set at three minutes, with intensity alternating between three minutes at 54% (low intensity) and three minutes at 89% (high intensity) VO_{2peak} for 60 minutes. The continuous walking intensity was set at 73% (moderate intensity) VO_{2peak} for 60 minutes, and the control was set at rest for 60 minutes.[12]

Study quality

The studies included in this review were assessed using the JBI Critical Appraisal Checklist for Randomised Controlled Trials and scored positively.[13] The study by Bacchi et al. applied true randomisation in allocating participants to treatment groups; treatment groups were similar at baseline, all treatment groups were treated identically, participants were analysed in the groups to which they were randomised, and outcomes were measured identically across treatment groups using a reliable method.[10] The studies by Oberlin et al. and Karstoft et al. used two different treatments assigned to the same participants: the treatments were different in mode but identical in duration.[11,12]

Study outcomes

Glucose control

In the study by Bacchi et al.,[10] a significantly lower glucose area under the curve in the aerobic group (117 mg/(dL×h) or 6.5 mmol/l), as compared with the resistance group (133 mg/(dL×h) or 7.4 mmol/l), was reported during a 60-minute bout of exercise ($p = 0.04$). Bacchi et al. found that both aerobic and resistance exercise groups' glucose AUCs were lower during exercise than on a corresponding day with no exercise: AER: ex: 117 mg/(dL×h) (or 6.5 mmol/l) vs. non-ex: 131 mg/(dL×h) (or 7.3 mmol/l); RES: ex: 133 mg/(dL×h) (or 7.4 mmol/l) vs. no-ex: 140 mg/(dL×h) (or 7.8 mmol/l).[10] Bacchi et al. found that the glucose area under the curve was significantly lower in the aerobic exercise group, when compared with the resistance exercise group, overnight after the exercise day: AER: 363 mg/(dL×h) (or 20.2 mmol/l); RES: 476 mg/(dL×h) (or 26.4 mmol/l), than overnight after the corresponding non-

Table 1: Characteristics of studies included in the review ($n = 3$)

Reference	Sample size (M/F)	Participant age (years)	Study design	Intervention			Outcome measures	Findings
				Group	Intensity	Frequency and duration		
Bacchi et al.[10]	13 (9/4) 12 (7/5)	57.0 ± 2.1 56.1 ± 2.4	RCT	AER RES	40–60% RHR70–80% 1RM	60 minutes 3 series of 9 exercises of 10–12 reps in 60 minutes	CGMS; blood glucose AUC	Significantly lower glucose AUC during exercise than in the corresponding period of the non-exercise day in the AER group, but not in the RES group ($p = 0.04$ and $p = 0.90$, respectively)
Oberlin et al.[11]	9 (4/5)	60.3 ± 1.0	CC	EX SED	60% HRR Rest	60 minutes 60 minutes	CGMS; PPG-AUC	Significantly lower average glucose during the first 24 hours post-exercise (EX: 5.98 ± 0.049 vs. SED: 6.62 ± 0.53 mmol/l; $p = 0.3$)
Karstoft et al.[12]	10 (7/3)	60.3 ± 2.3	CC	IW CW CON	54%–89% VO_{2peak} 73% VO_{2peak} Rest	60 minutes 60 minutes 60 minutes	Fasting glucose; fasting insulin	IW decreased mean and maximal glucose during the MMTT compared with CON; and mean glucose compared with CW. Mean glucose was reduced in IW compared with CW from 2 to 6 hours post-exercise

RCT: randomised control trial; AER: aerobic; RES: resistance; RHR: reserve heart rate; 1RM: 1 repetition maximum; CGMS: continuous glucose monitoring system; AUC: area under curve; CC: crossover control; EX: exercise; SED: sedentary; HRR: heart rate reserve; IW: interval walking; CW: continuous walking; CON: control; MMTT: mixed-meal tolerance test.

exercise day: AER: 519 mg/(dL×h) (or 28.8 mmol/l); RES: 502 mg/(dL×h) (or 27.9 mmol/l).[10]

The study by Oberlin et al.[11] reported that exercise significantly reduced average glucose during the first 24 hours post-exercise (EX) when compared with the sedentary control group (SED) (EX: 5.98 ± 0.049 mmol/l vs. SED 6.62 ± 0.73 mmol/l; $p = 0.038$). This study also showed that exercise lowered the postprandial glucose area under the curve average across all six post-intervention meals ($p = 0.015$).[11]

Karstoft et al.[12] reported decreased mean and maximal incremental glucose during a mixed-meal tolerance test after interval walking, in comparison with a no-walking control (mean 1.2 ± 0.4 vs. 2.0 ± 0.5 mmol/l; maximal 3.7 ± 0.6 vs. 4.6 ± 0.7 mmol/l), and decreased mean incremental plasma glucose during MMTT when compared with continuous walking (1.2 ± 0.4 vs. 1.7 ± 0.4 mmol/l). Continuous glucose monitoring showed that mean glucose was reduced following interval walking, when compared with continuous walking, for up to 12 hours, post-intervention (8.2 ± 0.4 vs. 9.3 ± 0.7 mmol/l)[12].

Insulin

Karstoft et al.[12] reported significantly lower post-exercise fasting serum insulin concentrations ($p < 0.001$) with both interval walking (IW) and continuous walking (CW), as compared with the control (CON) (CON = 80.4 ± 10.5 pmol/l vs. IW = 47.4 ± 5.0 pmol/l vs. CW = 48.2 ± 5.1 pmol/l). No difference in serum insulin concentrations was found between interval walking and continuous walking, suggesting that both exercise modes have a similar effect on insulin levels.[12] Bacchi et al. and Oberlin et al. did not include measurements of insulin sensitivity in their respective studies[10,11]

Diet

Bacchi et al. provided preliminary healthy dietary instructions to all participants.[10] They provided the recipients with guidelines for nutritional intake, including times for eating and nutritional advice, which were to be adhered to throughout the trial period.[10] Breakfast was consumed between 05:30 and 08:30; lunch between 12:30 and 14:00; a snack between 15:30 and 16:30; and dinner was consumed between 20:00 and 21:30.[10]

Oberlin et al.[11] had each participant eat the meals provided during the course of the intervention. These study meals included three meals per day: breakfast at 8:00; lunch at 13:00 and dinner at 18:00. The meals comprised 55% carbohydrate, with glucose stable isotope tracers, and consisted of 450 kcal.[11]

Karstoft et al. had participants undergo a four-hour mixed-meal tolerance test one-hour post-exercise. The mixed-meal tolerance test consisted of 55% carbohydrate, 30% fat and 15% protein.[12]

Discussion

The studies cited in the current review demonstrate that improvements in glucose control can be detected following one single bout of exercise. Bacchi et al.[10] found that glucose control was improved both during the exercise and during the following night (01:00 am–05:30 am). Similar findings were established by Oberlin et al.,[11] where the average blood glucose was significantly reduced over the subsequent 24-hour period following exercise. Interestingly, the exercise protocols used exercise intensities of 40–60% HRR[10] and 60% HRR.[11] Karstoft et al.[12] found that continuous walking (at 73% VO_{2peak}) resulted in a decrease in blood glucose over the first 12 hours post-exercise. However, better results were found from interval walking (at intensities between 54 and 89% VO_{2peak}).[12]

There were consistent results for aerobic exercise across all three studies included in this review. Karstoft et al. presented results which suggest that interval-type training, which alternates between high- and low-level intensity, may produce more desirable effects on glucose control than would continuous exercise. The studies included in this review established positive results for lower blood glucose in response to exercise, during the exercise and for up to 24 hours post-exercise[10–12]. The study by Bacchi et al. was the only one of the three studies to include resistance exercise as an exercise protocol. Their results indicated that resistance exercise induced a smaller blood glucose-lowering effect than that of aerobic exercise, but better blood glucose-lowering improvement compared with the no-exercise control.

Karstoft et al. found that fasting serum insulin concentrations did not differ between the intervention days. However, serum insulin concentrations were lower for up to five hours post-exercise after interval walking, as compared with continuous walking.[12] Bacchi et al. and Oberlin et al. did not comment on the effects of their respective interventions on insulin parameters.

This review contributes valuable information to understanding the effects of a single bout of exercise in people with type 2 diabetes. The findings in this review, however, are to be treated with caution as the sample size is relatively small and was limited to studies published in English only.

In conclusion, interval exercise, ranging from high to low intensity, resulted in better results than continuous submaximal aerobic exercise or resistance exercise. Whilst all exercise modes discussed in this review had a beneficial acute effect on T2D, this review indicates that high-intensity interval exercise may be the most beneficial type of exercise in the treatment of individuals with type 2 diabetes. It is understood that, although all three studies reported acute benefits of glucose from a single bout of exercise, the number of studies included is low and further studies should be reported to establish more concrete evidence. It is recommended that further randomised controlled clinical trials be conducted to compare the effect of exercise of various types, durations and intensities on individuals with type 2 diabetes to improve our understanding of the effects of a single bout of exercise on type 2 diabetes.

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ORCID

Takshita Sookan http://orcid.org/0000-0002-5469-6395

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