Glycemic response varies between resistance and aerobic exercise in inactive males with long-term type 2 diabetes

Brett A. Gordon, Stephen R. Bird, Richard J. MacIsaac, and Amanda C. Benson

Abstract: The glycemic response to aerobic exercise is well understood; however, the response to resistance exercise is not. Eight inactive males (61.0 ± 7.2 years) with insulin-treated type 2 diabetes randomly completed single sessions of whole-body resistance exercise or cycling, 7 days apart. There were different 24-h glucose responses (p < 0.001) between the resistance exercise and the aerobic exercise, with short-term (24-h) impairment of glycemic control following the resistance exercise (p = 0.004). Cycling did not reduce glucose concentrations (p > 0.05), which contrasts with previous findings.

Key words: continuous glucose monitoring, resistance exercise, aerobic exercise, type 2 diabetes, hyperglycemia, inactivity.

Introduction

Adhering to aerobic exercise guidelines of 150 min·week⁻¹ of moderate-intensity activity is appropriate and effective for improving the health status of individuals with type 2 diabetes (T2D) (American Diabetes Association 2012). However, a large proportion of individuals with T2D fail to meet these guidelines (Zhao et al. 2012), which may be because of an inability to achieve the recommended duration, frequency, and intensity (Dela and Kjaer 2008), which may be because of an inability to achieve the recommended duration, frequency, and intensity (Dela et al. 2006; Praet and van Loon 2008). Although previous research has reported significant benefits associated with completing on-going resistance exercise, the joint position statement on exercise for diabetes from the American Diabetes Association and the American College of Sports Medicine recognizes that the glycemic response to a single session of resistance exercise is yet to be established (Colberg et al. 2010).

A single session of low-intensity, but not high-intensity, continuous aerobic exercise has reduced the mean 24-h glucose concentration compared with no exercise (Manders et al. 2010); in addition, high-intensity aerobic interval training has shown reductions in the postprandial glucose response and the prevalence of hyperglycemia (Gillen et al. 2012). The insulin sensitivity and glycemic response to acute resistance exercise in people with T2D is equivocal (Fluckey et al. 1994; Fenichia et al. 2004; Gordon et al. 2013; Praet et al. 2006; van Dijk et al. 2012); however, it has been suggested that aerobic and resistance exercise result in a similar glycemic response (van Dijk et al. 2012).

We hypothesized that resistance and aerobic exercise would result in similar reductions in the continuous glucose response. Therefore, the aim of this study was to compare the continuous glucose response after resistance and aerobic exercise and, second, to determine how long any change to glucose control remains following a single session of either exercise modality, in inactive males with insulin-treated T2D.

Materials and methods

Participants and study design

A randomized cross-over design was used in which computer-generated concealed randomization allocated 8 inactive (Sigal et al. 2004) males with insulin-treated T2D to either aerobic or resistance exercise first. Following the assessment of all baseline variables and the fulfilment of all inclusion criteria, randomization was completed using individual opaque envelopes, administered by an independent investigator. Participants had a mean ± SD age of 61.0 ± 7.2 years, height of 173.9 ± 8.4 cm, and body mass of 102.8 ± 35.4 kg.

Human research ethical approval was granted, and all participants provided written informed consent. This study conformed to the principles of the Declaration of Helsinki and was registered with the Australian New Zealand Clinical Trials Registry (ACTRN12610000906055). Inclusion criteria were being aged 50–70 years, not having completed regular resistance training over the preceding 3 months, taking a stable dose of medications, being weight stable, and having glycated hemoglobin (HbA1c) between 7.0% and 10.0%. Exclusion criteria included taking β-blocking or oral hypoglycemic medications for less than 6 months or any medical condition that contraindicated resistance or aerobic exercise. A standardized meal was provided to be consumed the night before all visits; it contained 1932 kJ of energy, 24.8 g of protein, 10.4 g of fat, and 61.6 g of carbohydrate.

Received 19 December 2012. Accepted 18 April 2013.

B.A. Gordon. Discipline of Exercise Sciences, School of Medical Sciences and Health Innovations Research Institute, RMIT University, Melbourne, Australia; Physiotherapy Department, Austin Hospital, Austin Health, Melbourne, Australia.

S.R. Bird and A.C. Benson. Discipline of Exercise Sciences, School of Medical Sciences and Health Innovations Research Institute, RMIT University, Melbourne, Australia.

R.J. MacIsaac. Endocrinology and Diabetes, St. Vincent’s Hospital and University of Melbourne, Melbourne, Australia.

Corresponding author: Brett A. Gordon (e-mail: brett.gordon@rmit.edu.au).

Otherwise, participants were free living but were asked to record what and when they ate.

Following a 12-h overnight fast, participants had their height, body mass, and blood pressure measured before a fasting blood sample was collected on their initial visit. They were given a standardized breakfast (toast and fruit juice) and completed the self-report International Physical Activity Questionnaire (Craig et al. 2003). Cardiorespiratory fitness was determined using an incremental exhaustive cycle protocol as reported previously (Manders et al. 2010), maintaining a cadence of 60–70 r·min⁻¹. Oxygen uptake was measured using an automated computerized breath-by-breath metabolic cart (ParvoMedics2400 Truemax, Parvomedics Inc., East Sandy, Utah, USA). Two participants required the initial workload to be halved to enable them to complete the assessment.

Participants were then familiarized with the resistance exercise equipment before undertaking 1 repetition maximum testing. As reported previously (Fluckey et al. 1994), all 6 exercises included in the resistance exercise session.

Following a minimum 7-day wash-out period, participants returned to the research facility to have a continuous glucose monitor (CGM) inserted (Medtronic, iPro2 professional model). Participants were given a glucometer (Optium Xceed) to measure blood glucose values prior to each meal and before going to bed for calibration of the CGM. Two days later, participants returned to the research facility, where a fasting blood sample was collected before the standardized breakfast was consumed. Participants were instructed to take one-half their normal insulin dose approximately 15 min prior to commencing the exercise session, to minimize the risk of hypoglycemia. Apart from this, all medications were taken as prescribed by their physicians, but the remainder of the pre-exercise insulin dose was not taken. Six participants were taking mixed insulin (Humalog Mix = 3; NovoMix = 3), and 2 individuals were taking both a long-acting (Lantus) and a short-acting (NovoRapid) insulin. All but 1 individual were taking oral hypoglycemic medication along with the insulin. Participants were additionally treated with aspirin (n = 3), statins (n = 6), angiotensin-converting enzyme inhibitors (n = 4), β-blockers (n = 3), angiotensin-II receptor agonists (n = 2), and diuretic, proton-pump inhibitor, and calcium channel blocker (n = 1 of each). Immediately after the exercise session, participants resumed their regular lifestyle (free-living dietary conditions with no specific nutritional advice) for 3 days. The CGM was then removed, and participants resumed their regular lifestyle for a further 3 days before repeating the protocol with the alternate exercise intervention.

**Exercise interventions**

The resistance exercise session consisted of 6 whole-body exercises (bench press, 45° leg press, lateral pull-down, unilateral leg extension, seated row, and unilateral leg curl; 3 sets of 8–10 repetitions at 70% 1RM, with 60–90 s of rest between sets). The aerobic exercise session involved 30 min of cycling at 60% of peak oxygen uptake. Activity levels throughout the study were assessed by an accelerometer (Actigraph GT1M) worn on the hip. These data were analyzed using Actilife analysis software (version 4.4.1).

**Blood analysis**

Baseline fasting blood samples were collected and sent to a commercial laboratory for analysis of lipid profiles (total cholesterol, high-density lipoprotein cholesterol (HDL-C), and triglycerides, with coefficients of variation (CVs) of 2.8%, 3.5%, and 3.4%, respectively, with low-density lipoprotein cholesterol calculated), glycated hemoglobin (HbA1c) (CV = 2.8%), glucose (CV = 2.8%), insulin (CV = 7.0%), and high-sensitivity C-reactive protein (hs-CRP) (CV = 4.0%). Prior to each exercise session, a blood sample was collected for glucose, insulin, and hs-CRP analysis to ensure that there were no lasting effects from the testing or the previous exercise session.

### Table 1. Participant demographics.

<table>
<thead>
<tr>
<th>Outcome measure</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diabetes (y)</td>
<td>18.0±8.5</td>
</tr>
<tr>
<td>Age (y)</td>
<td>61±8.2</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>102.8±35.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173±92.8</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>33.629.4</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td>139±21</td>
</tr>
<tr>
<td>DBP (mm Hg)</td>
<td>82±8</td>
</tr>
<tr>
<td>Total cholesterol (mmol·L⁻¹)</td>
<td>3.9±0.3</td>
</tr>
<tr>
<td>LDL-C (mmol·L⁻¹)</td>
<td>2.2±0.4</td>
</tr>
<tr>
<td>HDL-C (mmol·L⁻¹)</td>
<td>1.00±0.23</td>
</tr>
<tr>
<td>Triglycerides (mmol·L⁻¹)</td>
<td>1.50±0.7</td>
</tr>
<tr>
<td>HbA1c (%)</td>
<td>8.0±0.3</td>
</tr>
<tr>
<td>Glucose (mmol·L⁻¹)</td>
<td>8.42±1</td>
</tr>
<tr>
<td>Insulin (pmol·L⁻¹)</td>
<td>268.9±528.2</td>
</tr>
<tr>
<td>hs-CRP (mg·L⁻¹)</td>
<td>6.08±0.0</td>
</tr>
<tr>
<td>Activity (MET·min⁻¹·week⁻¹)</td>
<td>1683±2524</td>
</tr>
<tr>
<td>Sitting time (min)</td>
<td>559±311</td>
</tr>
<tr>
<td>VO₂peak (mL·kg⁻¹·min⁻¹)</td>
<td>19.8±6.1</td>
</tr>
<tr>
<td>Bench press IRM (kg)</td>
<td>46.4±12.5</td>
</tr>
<tr>
<td>Leg press IRM (kg)</td>
<td>158.1±49.8</td>
</tr>
</tbody>
</table>

Note: BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; LDL-C, low-density lipoprotein cholesterol; HDL-C, high-density lipoprotein cholesterol; HbA1c, glycated hemoglobin; hs-CRP, high-sensitivity C-reactive protein; VO₂peak, peak oxygen uptake; IRM, 1 repetition maximum.

**Statistical analyses**

A priori power calculation based on the primary outcome, continuous glucose response, using estimates from the literature (Praet et al. 2006) indicated that a sample size of 8 was required to achieve 80% statistical power. All data were analyzed using SPSS for Windows (version 18, IBM, Armonk, N.Y., USA), with significance set at p = 0.05. One-way repeated-measures analyses of variance (ANOVAs) with a Bonferroni adjustment were completed to assess the change over time between baseline and immediately prior to each exercise intervention for glucose, insulin, and hs-CRP. A 2-way repeated-measures multivariate ANOVA was conducted to assess the total activity counts and total steps throughout the study. Two-way repeated-measures ANOVAs, with a Bonferroni adjustment, were conducted for the primary outcomes of glucose response (24-h glucose area under the curve (AUC)) and percentage of each 24-h time period spent in a state of hyperglycemia (glucose ≥ 10 mmol·L⁻¹) to compare the 2 exercise interventions and to track the response to the intervention over 72 h.

**Results**

On average, participants were obese and borderline hypertensive and spent large amounts of time sitting (Table 1). Their fitness and upper-body strength were poor, whereas their lower-body strength was average (Thompson 2010). They also had poor glycememic control and low levels of HDL-C. One participant was currently smoking but refrained from smoking during each fasting period. There were no significant adverse events from completing either exercise intervention; however, 2 individuals could not complete the 30-min cycling protocol without frequent rest periods. All participants completed the resistance exercise session as prescribed.

Prior to each exercise session, there were no significant differences in glucose (p = 0.29), insulin (p = 0.61), or hs-CRP (p = 0.60) concentrations. Additionally, there were no statistical differences between the exercise interventions in the number of physical activity counts or total steps (p = 0.97), and this did not change throughout either intervention (p = 0.75).
In the 24 h immediately prior to completing the resistance or aerobic exercise, the mean glucose response (AUC) was 187.4 mmol·L⁻¹·24 h⁻¹ (95% CI 159.7 to 215.0 mmol·L⁻¹·24 h⁻¹) and 186.7 mmol·L⁻¹·24 h⁻¹ (95% CI 152.0 to 221.3 mmol·L⁻¹·24 h⁻¹), respectively (Fig. 1). There was a significant difference in the glucose response to the exercise interventions (p < 0.001). Pairwise analysis indicated a significant increase in glucose AUC in the first 24 h following the exercise resistance (p = 0.004) that then significantly (p < 0.05) decreased towards pre-exercise levels in the 24- to 48-h period and 48- to 72-h time periods (Fig. 1); however, the glucose response was not altered by the aerobic exercise (p > 0.05). Participants were in a state of hyperglycemia for an average of 23.0% (95% CI 8.7% to 37.3%) and 27.0% (95% CI 14.1% to 39.9%) of the day prior to the resistance or aerobic exercise, respectively (Fig. 1). The time spent in a hyperglycemic state increased in the 24 h immediately following the resistance exercise (p = 0.015) but not following the aerobic exercise (p = 0.469), and the response between exercise interventions was significantly different (p = 0.002). There was no effect for exercise order (p > 0.05).

Analysis of food consumption indicated that 4 participants consumed food within 2 h of completing the exercise session, whereas the remaining 4 participants went 3–4 h before consuming a meal. The type of food consumed by those who ate within 2 h of the exercise session varied among breakfast cereal and (or) toasted crumpets, sweets–pastries, and a fast-food breakfast burger. Each participant had the same food after each exercise session. Although we were unable to identify whether the nutritional content affected the glycemic response to exercise, it would appear that the timing of the food consumption may have had an effect. For those who ate within 2 h of the exercise session, the hyperglycemic response to the resistance exercise appeared to be exacerbated, whereas the hyperglycemic response to the aerobic exercise appeared to be blunted (Fig. 2).

Discussion

The major finding of this study is that the glycemic response to resistance exercise is different from the response to aerobic exercise in the initial 24 h after a single session of moderate-intensity exercise in these inactive individuals with insulin-treated, longstanding T2D. This result is in contrast to the finding of a previous study (van Dijk et al. 2012), which suggested a similar response between exercise types when compared with a nonexercise control. This previous finding may have been due to the use of a nonexercise control or because the resistance exercise was focused heavily on the legs (van Dijk et al. 2012), rather than on the whole body as has been recommended (Colberg et al. 2010). Further, there were important differences between the 2 study populations, with participants in our trial being older and, on average, having diagnosed T2D for an extra 6 years. The participants in our trial also had increased levels of obesity and lower absolute fitness and strength levels compared with the participants completing the study by van Dijk and colleagues (2012) and also previous studies by Gillen et al. (2012), Manders et al. (2010), and Praet et al. (2008). Indeed, it could have been these lower cardiorespiratory fitness and muscular strength levels, resulting in a decreased overall energy expenditure, that contributed to the varied findings.

The response to aerobic exercise is similar to that reported previously following 30 min of cycling at 70% of capacity (Manders et al. 2010). Furthermore, previous data indicate that the 24-h glucose response was not altered by a single session of low-intensity resistance exercise followed by 4 short bouts of high-intensity aerobic exercise (Praet et al. 2006). However, high-intensity interval training has been shown to reduce postprandial hyperglycemia (Gillen et al. 2012). Although we have shown the duration of hyperglycemia to be approximately 6 h...
of any 24-h period and that it increases in the initial 24 h after exercise, this exact response is not indicated in Figs. 1C or 1D. Figures 1C and 1D show the mean glucose value at any given point in time and, together with Fig. 1B, potentially indicate that individuals experience hyperglycemia at different times throughout the day. Because we did not control the volume, type, or timing of food intake, this may represent individual eating habits and may not necessarily be a difference in response to exercise; this is something that requires further investigation. Figure 2 provides further evidence that the timing of nutritional intake following exercise may influence the response, which also requires further evaluation.

Although the exact mechanisms involved in exercise-derived insulin sensitivity and modulated blood glucose levels remain unclear, AMPK phosphorylation and GLUT4 content are believed to contribute substantially (Yaspelkis 2006), with hypoxia also appearing to affect insulin sensitivity (Mackenzie et al. 2012a, 2012b). Our data do not support previous findings of improved insulin sensitivity (Bordenave et al. 2008) or glycemic profiles (MacDonald et al. 2006) following either aerobic or resistance exercise (Fluckey et al. 1994; Fenicchia et al. 2004; van Dijk et al. 2012) in individuals with T2D. However, an attenuated exercise response, with reduced muscle glycogen content but no AMPK phosphorylation, has been reported previously (Sriwijjitkamol et al. 2007), suggesting that our intervention may not have increased AMPK phosphorylation.

Although we did not investigate exercise mechanisms, by using CGM, we did identify that those who undertook our resistance exercise regimen spent a prolonged period of time in a state of hyperglycemia in comparison to those who undertook our aerobic exercise regimen, which did not change, i.e., hyperglycemia did not change in response to aerobic exercise. This could have been due to the reduced insulin administration immediately prior to exercise, and therefore, the clinical implications surrounding the timing of medications and food consumption in relation to exercise participation should be investigated further. Although CGM of participants was used during a nonexercise period prior to completing the exercise intervention and the randomized crossover design, the study did not include a formal, nonexercise control arm and therefore, the effect of the reduced pre-exercise insulin dose has yet to be fully established. Regardless, insulin administration was standardized between the exercise modes and therefore cannot explain the differences in glycemic response observed between the 2 modes. Additionally, participants resumed free-living environmental conditions immediately following the exercise intervention, which may account for the initial impairment following the resistance exercise and the lack of glucose response following the aerobic exercise. Future research should consider including an additional nonexercising control arm to enable further investigation of modified insulin administration and standardized dietary intake following exercise. However, the results of this study may actually reflect a real-world response to the type of exercise used, and therefore may have strong clinical relevance.

Acknowledgements

This study was completed thanks to funding received from the Australian Technology Network’s Centre for Metabolic Fitness. The authors have no conflict of interest to declare and are grateful to the participants who volunteered for this project.

References


Thompson, W. 2010. ACSM’s guidelines for exercise testing and prescription. Lippincott Williams & Wilkins, Hagerstown, Maryland.

