Original research

Acute response of blood glucose to short-term exercise training in patients with type 2 diabetes

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Abstract

It is unclear whether the glucose lowering effects of an exercise session are augmented by training. Therefore, we sought to assess the effects of a four-week exercise training program on the acute response of blood glucose to a single exercise session in patients with T2DM. A Quasi experimental design was used. Thirty-four patients with T2DM (18 males) completed a four-week exercise regime consisting of two 1-h supervised sessions and one 30 min unsupervised home session per week. The sessions contained cardiorespiratory and resistance exercises. Blood glucose was measured prior to and after each training session. Resting heart rate (HR), blood pressure (BP), body composition, lipid profile and cardiorespiratory fitness (VO\(_2\)max) were determined before and after the four week training program. Decreases in blood glucose (pre to post exercise session) over the four weeks were (mean ± SD); week 1: 13.3 ± 18.6%, week 2: 19.7 ± 18.5%, week 3: 18.1 ± 20.8%, week 4: 22.8 ± 17.9%. General linear modelling with repeated measures ANCOVA showed that there was a significant (\(p<0.01\)) time effect over this period. Additionally, there were small, but significant decreases in resting heart rate (−6.6 ± 10.3 bpm, \(p=0.001\)), systolic blood pressure (−5.6 ± 14.9 mm Hg, \(p=0.043\)) and fat mass (−1.6 ± 3.2%, \(p=0.024\)) and an increase in VO\(_2\)max (1.6 ± 3.7 ml/kg/min, \(p=0.025\)) over the four weeks. Four weeks of exercise training augments the exercise-induced decrease in blood glucose that occurs in a single exercise session.

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1. Introduction

Exercise training is an important therapy in the treatment and management of type 2 diabetes (T2DM) and a large amount of research has been devoted to formulating the ideal exercise regimen. Current guidelines for exercise training in T2DM are available,\(^1\) however, there are still important questions about the exercise response in these patients.

It is well established that exercise training can decrease blood glucose levels acutely over an exercise bout\(^2\) and over an exercise intervention\(^3\) in patients with T2DM. However, it remains unknown whether this acute response to an exercise bout can be influenced by training or whether the response is independent of training. A number of possible mechanisms have been proposed to explain the improvements in glycaemic control from exercise training in T2DM.\(^4\) First, the acute decrease in blood glucose in response to a single exercise bout is independent of a training effect. Second, these acute decreases in blood glucose levels from a single exercise bout can accumulate if the sessions are frequent enough for the effect to overlap. Third, the acute decrease in blood glucose from a single exercise bout increases with

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\(^1\) This trial is registered with the Australian Clinical trial registry http://www.actr.org.au/default.aspx-ACTRN1260700060448.
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training. Importantly, the contribution of these mechanisms to improvements in glycaemic control is not clear and has important implications to frequency and maintaining exercise in patients with T2DM.

Therefore, we investigated the short-term exercise-induced acute changes in blood glucose over a period of short-term (four-week) exercise training in patients with T2DM. It was hypothesized that the acute blood glucose lowering response seen during a single exercise bout would increase over a four-week training period.

2. Methods

A Quasi experimental design study was conducted with a cohort of 34 patients selected from individuals in the intervention arm of the Diabetes Lifestyle Intervention Study.\(^3\) Patients younger than 18 years, older than 75 years and those with occult coronary artery disease (determined by exercise stress echocardiography), serious co-morbidity (life expectancy <6 months) and pregnancy were excluded. Patients randomized to the intervention were allocated into training groups of between 10 and 15 and trained individually for four weeks. The cohort for this study was a sub group of patients from three consecutive training groups. The trial was approved by the Ethics Committees of the Princess Alexandra Hospital and The University of Queensland and written informed consent was obtained from all participants.

Height, body mass (Seca, Vogel & Aalke GmbH, Hamburg, Germany), body fat composition (Body Stat 1500, Isle of Man, UK), resting supine blood pressure (Baumanometer, W.A. Baum Co., New York, USA), fasting blood lipid profile, glucose and insulin were measured in all patients prior to and after the four-week intervention period. HbA1c was measured only at baseline to assess diabetes control. Pathological measures of lipids, fasting plasma glucose and insulin were done using standard procedures by Queensland Health Pathology Service (Brisbane, Australia). Measurements were taken pre and post the four-week intervention after an overnight fast and at least 24 h since the last exercise session.

Cardiorespiratory fitness was assessed by indirect calorimetry (Vmax29c, SensorMedics, California, USA), measuring maximal oxygen consumption (VO\(_{2\text{max}}\)) during a graded exercise test to exhaustion. Blood pressure and cardiac status (using a 12-lead electrocardiogram) were monitored during the exercise test (CASE, GE Medical Systems, Milwaukee, USA). Physical activity levels were measured at baseline and at four weeks using the Active Australia questionnaire.\(^5\) Based on physical activity recommendations, being physically active was defined as performing ≥150 min of moderate physical activity per week.

Acute changes in blood glucose were determined from measurements taken postprandially, immediately prior to, and after the completion of each exercise session using blood glucose monitors. These measurements were undertaken only minutes before and after the completion of the exercise session. Glucose monitors were verified routinely and patients were instructed on technique, and measurements were supervised to ensure accuracy. The patients used their same blood glucose monitor for all readings and were instructed to adhere to the same diet and timing of food intake prior to the session.

Patients received four weeks of supervised exercise training under the guidance of an Accredited Exercise Physiologist, which has been described elsewhere.\(^6\) Briefly, participants performed two 1-h supervised gym-based sessions and at least an additional 30 min of home-based exercise per week. Compliance data was not collected for the home-based training component. The goal of the training was to achieve a minimum of 150 min of moderate-intensity exercise each week. Relative intensity was kept constant during the four weeks (RPE; 12–13 on the 20 point scale). During each training session patients performed a combination of aerobic and resistance training to achieve the training goals. Aerobic training was performed as interval training and consisted of walking and cycling. Interval training was selected as most participants were unable to reach the training goals with continuous exercise. Upper and lower body resistance training exercises were performed between aerobic intervals and participants were encouraged to reach failure (not able to complete another repetition) between 12 and 15 repetitions for each exercise for three sets. The resistance was adjusted to maintain the repetitions and set range. Exercises included seated row, bench press, squats, lunges and abdominal exercises. Each patient exercised consistently at the same time of day through the four weeks.

Each patient’s diet was also assessed prior to and after the conclusion of the four-week training period. Diet was derived from seven-day food records and analysed using a nutrition software program (Foodworks Professional 2006, Xyris Software Pty Ltd., Brisbane, Australia).

Average and percentage improvement in postprandial blood glucose for each week were calculated from the two sessions. General linear modelling with repeated measures ANCOVA was used to identify the differences across the four-week intervention. Pre-exercise blood glucose levels where used as covariates to account for this variation. One-way ANOVA was used to assess the difference between pre and post exercise and pre and post intervention period. Sample size was based on previously reported data,\(^2\) which indicated that an exercise session would decrease blood glucose by approximately 10%. We assumed that an additional 10% decrease in blood glucose would be clinically significant and to achieve this with an SD of 20% 33 patients were required with 80% power and alpha at 0.05. Significance was also set at \(p < 0.05\) for all comparisons.

3. Results

Table 1 contains baseline and post-intervention (four week) data. There were no changes in the type or dosage of T2DM medication (oral hypoglycaemic agents
or insulin) over the intervention period. All patients completed the required two supervised exercise sessions each week. To ensure full compliance some sessions were rescheduled. Sixty-eight percent of the patients were categorized as physically active at baseline. Over the intervention patients reported an increase in vigorous activity \( (p=0.03) \) from baseline \( (93 \pm 131.1 \text{ min/week}) \) to follow-up \( (164.8 \pm 104.9 \text{ min/week}) \), despite no significant change in moderate activity \( (79.8 \pm 183.4 \text{ min/week} \) to \( 35.4 \pm 64.7 \text{ min/week}) \). All the patients in this cohort attended two exercise sessions per week.

Over the exercise training period there were significant decreases in resting heart rate \( (-6.6 \pm 10.3 \text{ bpm, } p=0.001) \), systolic blood pressure \( (-5.6 \pm 14.9 \text{ mm Hg, } p=0.043) \) and fat mass \( (-1.6 \pm 3.2\%, \ p=0.024) \) and an increase in VO\textsubscript{2max} \( (1.6 \pm 3.7 \text{ ml/kg/min, } p=0.025) \). Further, each patient’s diet showed no significant change \( (p>0.05) \) over the course of the study \( (e.g. \text{CHO as } \% \text{ of total energy; pre } = 49.1 \pm 7.9\%, \ \text{post } = 50.6 \pm 8.3\%) \).

There were no significant differences \( (p=0.977) \) between the postprandial pre exercise blood glucose levels over the four week intervention \( (\text{mean } \pm \text{SD, } 7.90 \pm 3.13, \ 7.86 \pm 2.84, \ 7.64 \pm 2.53 \text{ and } 7.89 \pm 3.36 \text{ mmol/l for weeks one to four, respectively}) \). In support of our hypothesis, there was a significant time effect in the blood glucose decrease \( (\text{pre to post exercise session}) \) during the exercise session over the four weeks \( (\text{mean } \pm \text{SD, week 1: } 13.3 \pm 18.6\%, \ \text{week 2: } 19.7 \pm 18.5\%, \ \text{week 3: } 18.1 \pm 20.8\%, \ \text{week 4: } 22.8 \pm 17.9\%) \) (Fig. 1). Further, there was a significant \( (p=0.005) \) difference between the percent decrease observed in week 1 compared to week 4.

An analysis of all those patients who were not on T2DM medication (insulin, metformin, sulfonylureas, \( n=10 \)) was

\[ \text{Table 1} \]
Baseline and post intervention data (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Post intervention</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>( n ) (M/F)</td>
<td>34 (18/16)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>58.5 ± 9.4</td>
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<tr>
<td>Duration of diabetes (years)</td>
<td>5.5 ± 6.1</td>
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<tr>
<td>HbA\textsubscript{1c} (%)</td>
<td>7.5 ± 1.5</td>
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<tr>
<td><strong>Medications</strong></td>
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<td>Insulin ( (n) )</td>
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<td>3</td>
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</tr>
<tr>
<td>Metformin ( (n) )</td>
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<td>12</td>
<td>NS</td>
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<tr>
<td>Sulfonylurea ( (n) )</td>
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<td>7</td>
<td>NS</td>
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<tr>
<td>ACE inhibitors ( (n) )</td>
<td>8</td>
<td>8</td>
<td>NS</td>
</tr>
<tr>
<td>Statins ( (n) )</td>
<td>8</td>
<td>7</td>
<td>NS</td>
</tr>
<tr>
<td><strong>Metabolic</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Body mass index (kg/m\textsuperscript{2})</td>
<td>32.5 ± 4.9</td>
<td>32.3 ± 4.9</td>
<td>NS</td>
</tr>
<tr>
<td>% Fat mass</td>
<td>38.7 ± 9.8</td>
<td>37.1 ± 10.3\textsuperscript{3}</td>
<td>0.024</td>
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<td>Blood glucose (mmol/l)</td>
<td>8.4 ± 3.3</td>
<td>8.6 ± 3.8</td>
<td>NS</td>
</tr>
<tr>
<td>Insulin (mU/l)</td>
<td>13.4 ± 7.4</td>
<td>12.7 ± 7.3</td>
<td>NS</td>
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<tr>
<td>Total cholesterol (mmol/l)</td>
<td>5.0 ± 1.2</td>
<td>5.0 ± 1.1</td>
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<tr>
<td>High density lipoprotein (mmol/l)</td>
<td>1.4 ± 0.3</td>
<td>1.4 ± 0.4</td>
<td>NS</td>
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<tr>
<td>Low density lipoprotein (mmol/l)</td>
<td>2.8 ± 0.8</td>
<td>2.7 ± 0.9</td>
<td>NS</td>
</tr>
<tr>
<td>Triglycerides (mmol/l)</td>
<td>2.2 ± 3.9</td>
<td>2.2 ± 3.0</td>
<td>NS</td>
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<tr>
<td><strong>Cardiovascular</strong></td>
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<tr>
<td>Resting heart rate (bpm)</td>
<td>85.1 ± 15.5</td>
<td>78.5 ± 13.8\textsuperscript{*}</td>
<td>0.001</td>
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<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>137.7 ± 18.3</td>
<td>133.1 ± 16.1\textsuperscript{1}</td>
<td>0.043</td>
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<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>84.2 ± 10.3</td>
<td>82.4 ± 8.4</td>
<td>NS</td>
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<tr>
<td><strong>Cardiorespiratory fitness</strong></td>
<td>( \text{VO}_{2\text{max}} ) (ml/kg/min)</td>
<td>20.8 ± 5.5</td>
<td>22.4 ± 6.2\textsuperscript{*}</td>
</tr>
</tbody>
</table>

ACE = angiotensin converting enzyme, HbA\textsubscript{1c} = glycated haemoglobin and \( \text{VO}_{2\text{max}} \) = maximal cardiorespiratory fitness.

\* Significantly different to baseline \( (p<0.05) \).

\[ \text{Fig. 1. Percentage improvement (decrease) in acute blood glucose response from pre to post-exercise over the four-week training period (mean ± SEM).} \]

\[ \text{*Significant time effect across the four weeks of training \( (p<0.005) \).} \]
also conducted. In this analysis there was also a significant time effect in the blood glucose decrease (pre to post exercise session) during the exercise session over the four weeks (mean ± SD, week 1: 12.79 ± 18.92%, week 2: 15.3 ± 17.23%, week 3: 15.6 ± 15.79, week 4: 21.43 ± 12.95). Similarly there was a significant (p = 0.02) difference between the percent decrease observed in week 1 compared to week 4.

4. Discussion

The main finding of this study was that the acute blood glucose lowering effect of a single bout of exercise is augmented over a four-week period in patients with T2DM. The percent decrease in blood glucose in response to an exercise session improved from 13.3% in week 1 to 22.8% in week 4. This finding was still evident during analysis excluding patients who were on T2DM medication. The four weeks of exercise training also showed a small but significant decrease in % fat mass, systolic blood pressure and resting heart rate and an increase in cardiorespiratory fitness. Further, there were no significant dietary changes. None of these changes were associated with the changes in the blood glucose response to exercise.

It is uncertain whether the exercise training induced improvement in glycaemic control is due to the effects of each exercise bout individually, their overlapping responses or due to a training effect. The finding that pre-exercise blood glucose did not change over the four weeks suggests the improvement in glucose lowering is the result of a training effect. Small significant decreases in % fat mass, systolic blood pressure and resting heart rate and increases in cardiorespiratory fitness further support a training effect. If correct, this finding would further support current exercise training guidelines for individuals with chronic disease. Further, the lack of significant dietary changes indicate that the changes in glycaemic control seen are likely due to exercise alone. Future studies that manipulate training frequency would be needed to confirm this postulate.

It is well established that the benefits of exercise training in T2DM patients are due to improvements in skeletal muscle blood flow (capillary recruitment) and increases in the translocation and expression of GLUT-4. Although these mechanisms were not assessed, it is unlikely that a training effect would have influenced GLUT-4 given that GLUT-4 protein content decreases rapidly (within 40 h), even after five weeks of training. Therefore, the mechanism responsible for the training effect observed is likely to be related to sustained improvements in skeletal muscle blood flow. This is an exciting area for future research.

Potential limitations of this study include the measuring of blood glucose levels in a non-fasted state and the use of patients’ personal blood glucose monitors. The pre-exercise diet of the patients was not controlled, although patients did exercise at the same time of day for each training session over the four week period. Further, pre-exercise blood glucose measurements did not differ significantly over the training period. Blood glucose monitors have previously been used to assess blood glucose and monitors were verified weekly and the measurement technique was instructed and closely monitored for accuracy. Moreover, while haematocrit has the potential to influence blood glucose readings, the typical ranges for T2DM patients were well with the monitors’ acceptable ranges. However, these findings should be interpreted with caution and warrant replication with more robust measures of glycaemic control. Further, changes in dose of medication were not recorded. However, the medication profile (number of patients taking different types of medication) did not significantly change (data not shown). Further, subsequent analysis excluding patients who were taking insulin, metformin and/or sulfonylureas showed similar results.

5. Conclusion

The acute blood glucose lowering effect of a single bout of exercise is augmented by four weeks of training in patients with T2DM. Findings from this trial could be used to design studies to further investigate the importance of exercise training patients and the relative contribution of the mechanisms involved in the improvement of glycaemic control.

Practical implications

- Patients with type 2 diabetes should exercise because it lowers their blood sugar.
- After four weeks of exercise training the ability of an exercise session to lower blood sugar is improved. Therefore, patients with type 2 diabetes should complete multiple training sessions per week.
- Blood glucose monitors could used to measure the change in blood sugar before to after exercise.

Conflict of interest

The authors declare that they have no conflict of interest.

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