Effects of a short-term circuit weight training program on glycaemic control in NIDDM

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Abstract

This study assessed the effects of short-term circuit weight training (CWT) on glycaemic control in NIDDM. Twenty-seven untrained, sedentary subjects (mean age, 51) with NIDDM participated in an 8-week randomised, controlled study, involving either CWT 3 days/week (n = 15) or no formal exercise (control) (n = 12). All subjects performed regular self-blood glucose monitoring throughout. Fasting serum glucose and insulin were measured following a 12-h fast and during an oral glucose tolerance test (75 g) before and after 8 weeks. Twenty-one subjects completed the study (CWT, n = 11) (Control, n = 10). Strength for all exercises improved significantly after CWT. Pooled time-series analysis, using a random effects model, revealed an overall decrease in self-monitored glucose levels with CWT compared to controls. Significant reductions from baseline values were observed in both the glucose (−213 mmol l⁻¹ per 120 min, P < 0.05) and insulin (−6130 pmol l⁻¹ per 120 min, P < 0.05) area under the curve following CWT relative to controls. After adjustment for body mass changes, the change in self-monitored glucose levels and insulin area under the curve, but not glucose area under the curve, remained significant. Short-term CWT therefore may provide a practical exercise alternative in the lifestyle management of this condition. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Self-blood glucose monitoring; Resistance exercise; One-repetition maximum strength testing

1. Introduction

Regular exercise, combined with diet, has long been recognised as an important component in the management and more recently, the preven-
tion of NIDDM [1]. To understand further the contribution of increased physical activity in the management of this condition, a number of investigators have examined the effects of exercise training in patients with NIDDM [2–5]. So far, all of these studies have focused on aerobic exercise training, which improves glucose tolerance and insulin sensitivity.

The emergence of resistance training programs such as circuit weight training (CWT) as a popular exercise alternative has prompted increased interest concerning its benefits to both physical and metabolic fitness. Circuit weight training refers to a series of weight training exercises with moderate weight loads and frequent repetitions interspersed with short rest periods. Well-designed CWT programs commonly incorporate both upper and lower body muscle group exercises, which may not be readily achievable in many aerobic activities such as walking and cycling. Therefore such programs may contribute to the stimulation of a greater amount of muscle mass compared to these common aerobic-type activities [6]. Although CWT has been reported to improve glucose regulation in normoglycaemic individuals [7–9], its impact on individuals with NIDDM is less well known. Recently however, improved glucose regulation following CWT was reported to be comparable to aerobic training in men with abnormalities in glucose regulation, including some subjects with NIDDM [10,11]. These findings suggest that CWT may provide similar physiological benefits in individuals with NIDDM to aerobic exercise training. The purpose of this study was to evaluate the effects of a short-term CWT program on glycaemic control, utilising self-monitored blood glucose levels and the glucose and insulin response to a glucose load in patients with NIDDM.

2. Materials and methods

2.1. Subjects

Twenty-seven asymptomatic, untrained men \((n = 17)\) and women \((n = 10)\) with established, but controlled (diet and/or medication) NIDDM volunteered for participation in this study. Only those subjects who reported non-participation in regular vigorous exercise \((> 60 \text{ min/week})\) in the previous 6 months on a lifestyle screening questionnaire and who were non-smokers, not taking insulin, and had no previous history or evidence of coronary heart disease were selected for the study. The mean duration of diabetes was 4.8 years. Four were treated with sulphonylureas, 5 with biguanides, 10 a combination of both and 9 through dietary measures. All subjects underwent comprehensive medical screening prior to participation including medical history, physical examination and a resting 12-lead electrocardiogram. Subjects gave their written consent and all methods and procedures were approved by The Human Rights Committee of The University of Western Australia.

2.2. Study design

Following a 4-week baseline period, subjects were randomly assigned using block randomisation to either a CWT program \((n = 15)\) or a non-exercise control group \((n = 12)\) for 8 weeks. To minimise co-intervention bias, all subjects attended the Department of Medicine for fortnightly blood pressure measurement and performed regular self-blood glucose monitoring throughout the intervention period. Subjects were routinely reminded not to alter their physical activity levels and dietary patterns during the study period.

2.3. Methods

2.3.1. Strength testing

Subjects were given two initial familiarisation sessions, where they were shown proper exercise techniques by a trained instructor and given the opportunity to become accustomed to the exercises used in the training program. A week later, one-repetition maximum strength testing \((1RM)\) for each exercise of the training program which involved nine conditioning exercises using preset free weights and Universal machines (Orbit Fitness, Perth, Western Australia, Australia) and one floor exercise (abdominal curls) was performed by
all participants (including controls) under the supervision of the instructor and an experienced physician. The exercise order used for strength testing and training was: leg extension, bench press, leg curl, dumbbell biceps curls, behind neck pulldown, calf raise, dumbbell overhead press, seated rowing, forearm extension using pulley (triceps), and abdominal curls. Each subject was given a brief warm-up using a light workload prior to the testing of strength for each exercise. Following the successful completion of 3–5 repetitions and after a brief rest (1 min), the workload was increased incrementally (2.5 kg) until a maximal load was obtained. The 1RM was considered to be the maximal amount of weight that could be successfully lifted with correct technique for at least one, but not two, complete repetitions. For abdominal curls, the maximum number of curls performed in 30 s was recorded.

Strength testing was repeated after 8 weeks for all participants. To account for training-induced adaptations, 1RM testing was performed in the CWT group after 4 weeks of training and the exercise workload for the remaining exercise period adjusted accordingly.

2.3.2. The training program
Training was performed on three non-consecutive days of the week (Monday, Wednesday and Friday). A brief warm-up and cool-down period consisting of stationary cycling (5 min, no workload) and a series of appropriate flexibility exercises was performed before and after each training session. During the first six exercise sessions, two sets of the circuit were completed using a weight corresponding to 50–55% 1RM for each exercise, and abdominal curls. An additional set was included in the sessions after this initial 2 weeks. The total exercise time, including warm-up and cool-down was approximately 60 min. This format (two sets followed by three sets) was repeated for the remaining 12 sessions after strength testing midway with the adjusted workload. For each exercise, subjects were instructed to perform 10–15 repetitions within a controlled 30 s time period. This was immediately followed by 30 s of active rest. This involved stationary cycling with minimal resistance (< 50 W) placed on the wheel to assist the ease of riding at 60 revolutions per min. This workload (< 50 W) is estimated to yield a MET value of 3.0 [12], which is considered to be a light activity and therefore not expected to contribute to cardiovascular benefits [13]. Each exercise session was supervised to ensure correct technique and to monitor the appropriate amount of exercise and rest intervals. No injuries or complications were reported from the exercise testing and training program.

2.3.3. Self-blood glucose monitoring (SBGM)
Subjects performed SBGM using home monitors at four separate time points (fasting, before lunch, 2 h after lunch and 2 h after main meal) on 4 days of each week. The CWT group was required to include 2 exercise days and the subsequent non-exercise days of each week and performed additional readings immediately after each exercise session and 24 h post-exercise. A standardised recording sheet was submitted at the following visit to the Department of Medicine. Individual instruction was provided during the baseline period on the correct techniques involved in performing SBGM by a nurse trained in diabetes management.

2.3.4. Blood measurements
Following a 10–12 h overnight fast, blood was drawn via an antecubital vein for the analysis of serum glucose, insulin, and glycated haemoglobin. On another visit, 1 week later and after a similar overnight fast, subjects completed a standard (75 g) oral glucose tolerance test (OGTT). In addition to a fasting sample (0 min), blood was drawn at 30, 60, 90 and 120 min following glucose ingestion. Both fasting samples on separate weeks were used to calculate mean fasting serum glucose and insulin levels. Total areas under the OGTT curve for serum glucose and insulin were computed by the trapezoidal method using both fasting concentrations (incremental area) and zero as the baseline. All blood measurements were performed at least 48 h post-exercise.

2.3.5. Dietary analysis
All subjects were provided with instruction on how to complete weighed food records by a
trained nurse during the OGTT and were asked to record their dietary intake for 3 days (2 week days, 1 non-week day) before exercise training and at the completion of the study period. Food records were analysed by a dietitian using the Diet/1 (version 3) Nutrient Analysis software program (Xyris Software, Brisbane, Queensland, Australia). Average daily intakes of kilojoules, protein, carbohydrate and total fat were calculated for both time periods. Throughout the study period subjects were routinely reminded by the research staff to maintain their usual dietary habits.

2.3.6. Blood pressure/anthropometrics

Resting supine blood pressure was assessed using the Dinamap 1846SX automatic blood pressure measuring device (Critikon, Tampa, Florida, USA). The first reading on each occasion was discarded and the mean baseline and post-intervention blood pressure values were calculated from the next 10 readings over a 20-min period on two separate visits.

Seven skinfold (triceps, biceps, subscapular, supraspinale, abdominal, thigh and calf) and nine circumference (relaxed biceps, flexed biceps, forearm, chest, waist, umbilicus, hip, mid-thigh and calf) measurements were performed before and after intervention. All measurements were performed by one trained observer using Slimguide calipers (Creative Health Products, Plymouth, Michigan, USA) and a non-elastic measuring tape. The median of three skinfold measures and the mean of two circumference measures from each site was used. Waist-hip ratio was calculated from the umbilicus and hip circumference measurement sites.

2.3.7. Biochemical analysis

Serum glucose was measured with an automated analyser (Bayer Diagnostics, Sydney, NSW, Australia) using a hexokinase method (between run coefficient of variation 3.1% at 4.9 mmol l\(^{-1}\) and 2.4% at 16.8 mmol l\(^{-1}\)) within 12 h of collection. Serum samples for insulin profiles were snap frozen in liquid nitrogen within 24 h of collection and stored at \(-80^\circ\)C until analysed. Samples obtained at baseline and post-intervention were measured in a single assay to eliminate interassay variation. Serum insulin levels were measured by radioimmunoassay using a Tosoh analyzer (Tosoh, Kyobashi, Chuo-ku, Tokyo, Japan). The intra-assay coefficient of variation for this assay was 14% at 21 pmol l\(^{-1}\) and 7% at 234 pmol l\(^{-1}\). Glycated haemoglobin was measured chromatographically using a cation exchange column and absorbency measurement at 415 nm (BioRad, North Ryde, NSW, Australia).

2.4. Statistical analysis

One-way analysis of variance (ANOVA) was used to assess between group comparisons at pre- and post-intervention testing and the change over the training period. Within-group changes in muscular strength were analysed by paired \(t\)-test.

To evaluate changes in self-monitored glucose readings over the time period, a pooled time series regression analysis using a random effects model was performed according to procedures previously described [14]. The regression model included dummy variables identifying the intervention group, time of sample (a.m. to p.m.), exercise prior to measurement (comparison between samples taken after exercise and other sample times) and day of sample (exercise vs non-exercise) as well as duration of intervention period (week 1 to week 8) as a continuous variable. The model was adjusted for the change in BMI over the intervention period. A probability level of \(\leq 0.05\) was accepted as the maximum value for statistical significance. Data presented are mean \(\pm\) SE of the mean (SEM). The SPSS statistical package was used to analyse all data.

3. Results

Six subjects were unable to continue the study after the baseline period. Of the subjects who commenced the training program, one required non-related surgery, another had a significant alteration in medication, while two had personal concerns and were unable to satisfactorily meet the time commitments of the study. A further two subjects in the control group also were unable to
Table 1
Subject characteristics of both study groups at baseline

<table>
<thead>
<tr>
<th></th>
<th>CWT (n = 11)</th>
<th>Control (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>50.3 (2.0)</td>
<td>51.1 (2.2)</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>8/3</td>
<td>5/5</td>
</tr>
<tr>
<td>Duration of diabetes (years)</td>
<td>5.3 (1.4)</td>
<td>5.1 (1.2)</td>
</tr>
<tr>
<td>Treatment regimen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oral hypoglycaemic medication</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>No medication</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Values expressed are means with standard error of the mean (SEM) in parentheses. There were no significant differences between groups at baseline.

3.1. Strength

The CWT program resulted in significant increases ($P < 0.05$) (paired $t$-test) in strength (1RM) for all exercises. The percentage change in strength for the CWT group from baseline to post-intervention testing ranged between $15 \pm 6\%$ for rowing pulley to $43 \pm 12\%$ for leg extension. The changes from baseline to post-intervention for the CWT group, compared to controls, were significant for all exercises.

3.2. Serum glucose

Mean fasting serum glucose levels did not change significantly from baseline in both groups during the intervention period (Table 2). The CWT group showed a relative decrease ($-22 \pm 62$ mmol $l^{-1}$ per 120 min) in the total serum glucose area under the OGTT curve from baseline to post-intervention values compared to an increase ($191 \pm 84$ mmol $l^{-1}$ per 120 min) in the control group (Fig. 1). This change from baseline was significant between the groups ($P = 0.05$).

Table 2
Physiological changes from baseline to post-intervention in both groups

<table>
<thead>
<tr>
<th></th>
<th>CWT (n = 11)</th>
<th>Control (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body mass (kg)</td>
<td>83.6 (3.7)</td>
<td>83.2 (3.7)</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>28.3 (0.8)</td>
<td>28.1 (0.8)</td>
</tr>
<tr>
<td>Sum of skinfolds (mm)</td>
<td>155.4 (18.8)</td>
<td>158.8 (17.6)</td>
</tr>
<tr>
<td>Waist to hip ratio</td>
<td>0.98 (0.01)</td>
<td>0.98 (0.01)</td>
</tr>
<tr>
<td>Serum glucose and insulin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting glucose (mmol $l^{-1}$)</td>
<td>9.6 (0.9)</td>
<td>9.4 (0.8)</td>
</tr>
<tr>
<td>Fasting insulin (pmol $l^{-1}$)</td>
<td>64.3 (12.7)</td>
<td>63.1 (12.6)</td>
</tr>
<tr>
<td>Glycated haemoglobin (%)</td>
<td>8.2 (0.5)</td>
<td>8.0 (0.5)</td>
</tr>
<tr>
<td>Blood pressure (mmHg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>126 (3.0)</td>
<td>127 (3.0)</td>
</tr>
<tr>
<td>Diastolic</td>
<td>73 (2.0)</td>
<td>73 (2.0)</td>
</tr>
<tr>
<td>Resting heart rate (beats/min)</td>
<td>77 (3.0)</td>
<td>76 (2.5)</td>
</tr>
</tbody>
</table>

Values expressed are means with standard error of the mean (SEM) in parentheses. There were no significant differences between groups at baseline for all variables.

* $P < 0.05$, significance of ANOVA for change from baseline to post-intervention between groups.
3.3. Serum insulin

There was no significant difference in the change in mean fasting serum insulin levels between the two groups from baseline to post-intervention testing (P = 0.09) (Table 2). CWT led to a decrease (\(-2183 \pm 1563\) pmol l\(^{-1}\) per 120 min) in the total serum insulin area under the OGTT curve from baseline to post-intervention compared to an increase (\(3947 \pm 1545\) pmol l\(^{-1}\) per 120 min) in the controls (Fig. 1). This change from baseline values was significant between groups and remained significant after adjustment for change in body mass.

No significant changes were observed in glycated haemoglobin concentration and resting blood pressure (Table 2). There was at least 80% power to detect a 8 mmHg change in systolic blood pressure or a 1% change in glycated haemoglobin at alpha = 0.1.

3.4. Self-blood glucose monitoring

Table 3 presents the results of the pooled time series regression analysis using a random effects model with glucose the dependent variable and adjustment made for the change in body mass. This model reveals that for all subjects there was a trend for self-monitored glucose levels to fall (0.08 mmol l\(^{-1}\)) as the intervention period progressed from the initial (week 1) to final (week 8)
weeks. In addition however, there was a significant reduction, equivalent to 0.28 mmol l\(^{-1}\), in self-monitored glucose levels in the CWT group as the training period progressed, when compared to controls (Fig. 2). Glucose levels were lower (0.66 mmol l\(^{-1}\)) after an exercise session, but when all the other time points were considered, glucose levels were still lower (0.26 mmol l\(^{-1}\)) on the subsequent non-exercise day. This analysis also revealed that self-monitored glucose levels on any chosen day increased (0.61 mmol l\(^{-1}\)) as the day progressed from morning to evening.

3.5. Dietary analysis

Analysis of food records showed that the CWT group had a higher average energy intake (kJ) than controls at baseline (9342 kJ ± 685 vs 6824 kJ ± 730; \(P < 0.05\)) and after training (9711 ± 875 vs 7314 ± 1050; \(P = 0.05\)). However, there were no significant changes in energy intake, average protein, fat and carbohydrate intake observed between the groups from baseline to post-intervention.

4. Discussion

The results of the present study show that CWT can improve glycaemic control in patients with NIDDM. Circuit weight training reduced the plasma insulin response to glucose ingestion during an oral glucose tolerance test and contributed to an improvement in self-monitored glucose levels when compared to deteriorations observed in non-exercising controls. These effects provide evidence that this form of exercise may have merit in lifestyle advice for the management of NIDDM.

The present study supports the findings of previous investigators who have also reported reduced glucose-stimulated plasma insulin levels without alteration in glucose tolerance following CWT \([7,8,15]\). A recent study has also reported increased insulin sensitivity using an euglycaemic clamp after CWT \([15]\). However, these earlier observations have been made in normoglycaemic individuals and the results are not necessarily applicable to diabetic subjects. More recently, CWT has been demonstrated to improve glucose-stimulated insulin responses and glucose tolerance to the same extent as aerobic training in men with abnormal glucose regulation, including some subjects with NIDDM \([10,11]\). These studies employed a similar CWT to our study but with a more prolonged intervention (20 weeks). The greater magnitude of improvement in glucose metabolism reported in these studies, compared to our findings, may reflect this longer-term training.

Consistent with the improved insulin response to the OGTT after training, the lower self-monitored glucose levels supported the conclusion of improved glycaemic control with CWT. Furthermore, this observation was independent of the change in body mass over the study period. In addition, the observation of lower self-monitored glucose levels immediately after exercise and its persistence into the subsequent post-exercise period supports the earlier findings of improved insulin responsiveness in individuals with NIDDM 18 h after an acute resistance exercise bout \([6]\). The increased glucose permeability following an acute exercise bout is thought to facilitate the replenishment of depleted hepatic and muscle glycogen stores and may persist for up to 48 h post-exercise \([16]\). To account for this residual effect of the last exercise bout, we assessed our subjects at least 48 h after the last exercise session. This interval may explain the smaller magnitude
of change in glucose and insulin responses to a glucose load relative to previous studies which assessed these effects soon after the last exercise bout [7,10,11,15].

The underlying mechanisms contributing to reduced glucose and insulin responses and insulin sensitivity following resistance exercise are not known. It has been suggested that improvements in glucose metabolism after exercise training are related to decreases in body fat, particularly upper body adiposity [17]. Since neither the waist-hip ratio nor the sum of skinfolds changed in our subjects, it is unlikely that body fat changes account for the improved glycaemic control observed after CWT, consistent with the findings of previous studies [7,8,11]. An increase in lean muscle mass has also been proposed as a mechanism contributing to improved glucose regulation [8], but changes in lean muscle mass were not assessed in the present study.

In the present study there was a small, but significant, increase in body mass in controls compared to a slight decrease in the trained individuals without change in energy intake over the study period. It is possible however, that our recommendation not to alter activity patterns during the 8-week period may have led to reduced activity levels in the control individuals. Thus, the contribution of a relative reduction in energy expenditure towards the increased body mass cannot be excluded.

Although small reductions in glycated haemoglobin have been reported in NIDDM after only 6 weeks of aerobic exercise training [2], larger changes have been associated with longer term programs [4]. Durak et al. [18] however, demonstrated improved glycated haemoglobin levels after 10 weeks of heavy resistance training in patients with Type 1 diabetes. The failure to observe any significant changes in glycated haemoglobin levels in our patient group is possibly the result of the short-term nature of this program. Assessment of long-term changes in glucose control associated with strength training in NIDDM requires further studies with programs of longer duration.

Observations of extreme increases in blood pressure during high-intensity resistance exercise [19] and the suggestion that long-term resistance training may stimulate elevations in blood pressure [20] have previously led to caution in the use of this form of exercise in individuals with an increased cardiovascular risk. Although no changes in resting blood pressure were observed in the present study, our findings support earlier investigations in both normotensive and hypertensive subjects [10,21–23] which suggest that this form of exercise is safe and does not increase resting blood pressure, at least in the short term.

Typically, aerobic-type activities of dynamic nature have been recommended for patients with NIDDM. However, exercises that involve prolonged periods of weight bearing such as walking may be inappropriate for a large proportion of patients with NIDDM [24]. Circuit weight training has the potential to minimise the amount of orthopaedic stress that may be associated with various aerobic activities. It could also be helpful in maintaining interest and adherence to an exercise program since a variety of diverse exercises can be utilised in such programs. It is important to note that the CWT program utilised in the present study was conducted in a supervised gymnasium setting following comprehensive medical screening. The transposition of similar exercise programs to the domestic setting, where adequate supervision may not be readily available, could present various safety concerns in those who may be susceptible to cardiovascular problems. The potential for utilisation of CWT programs conducted outside a controlled community gymnasium setting therefore awaits further investigation.

In conclusion, a short-term CWT program contributed to improved glycaemic control in patients with NIDDM, as evidenced by lower self-monitored glucose levels and an improved serum insulin response to a glucose load, despite only a slight change in glucose tolerance. These findings provide further support for the employment of CWT as a safe and effective adjunct to aerobic exercise in the lifestyle management of glycaemic control in NIDDM.
Acknowledgements

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References