Strength and endurance training lead to different post exercise glucose profiles in diabetic participants using a continuous subcutaneous glucose monitoring system

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Abstract

Background Although both strength training (ST) and endurance training (ET) seem to be beneficial in type 2 diabetes mellitus (T2D), little is known about post-exercise glucose profiles. The objective of the study was to report changes in blood glucose (BG) values after a 4-month ET and ST programme now that a device for continuous glucose monitoring has become available.

Materials and methods Fifteen participants, comprising four men age 56.5 ± 0.9 years and 11 women age 57.4 ± 0.9 years with T2D, were monitored with the MiniMed (Northridge, CA, USA) continuous glucose monitoring system (CGMS) for 48 h before and after 4 months of ET or ST. The ST consisted of three sets at the beginning, increasing to six sets per week at the end of the training period, including all major muscle groups and ET performed with an intensity of maximal oxygen uptake of 60% and a volume beginning at 15 min and advancing to a maximum of 30 min three times a week.

Results A total of 17 549 single BG measurements pretraining $(619 \cdot 7 \pm 39 \cdot 8)$ and posttraining $(550 \cdot 3 \pm 30 \cdot 1)$ were recorded, correlating to an average of $585 \pm 25 \cdot 3$ potential measurements per participant at the beginning and at the end of the study. The change in BG-value between the beginning (132 mg dL^{-1}) and the end (118 mg dL^{-1}) for all participants was significant (P = 0.028). The improvement in BG-value for the ST programme was significant (P = 0.02) but for the ET no significant change was measured (P = 0.48). Glycaemic control improved in the ST group and the mean BG was reduced by 15.6% (Cl 3–25%).

Conclusion In conclusion, the CGMS may be a useful tool in monitoring improvements in glycaemic control after different exercise programmes. Additionally, the CGMS may help to identify asymptomatic hypoglycaemia or hyperglycaemia after training programmes.

Keywords Continuous subcutaneous glucose monitoring system, strength and endurance training, type 2 diabetes mellitus. *Eur J Clin Invest 2005; 35 (12): 745–751*

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Introduction

Type 2 diabetes mellitus (T2D) is a serious chronic disease associated with hyperglycaemia, obesity and the metabolic syndrome [1,2]. The effectiveness of physical exercise has long been recognized for the treatment of T2D [3,4]. Endurance training (ET) has been advocated as the most suitable form of exercise mode [5,6] with many positive metabolic effects, such as decreased blood glucose (BG) levels and reduced body fat (BF), but also undetected hypoglycaemic episodes during and after training. In comparison, only limited information on the effect of strength training (ST) on T2D is available [7–10]. Measurement of HbA1C is the standard test for assessment of glycaemic control in diabetic subjects. As glycosylated haemoglobin (HbA1C) reflects an average of all blood glucose values for a duration of 3 months and HbA1C is negatively influenced by hypoglycaemic episodes, it therefore does not give good information on post exercise glucose profiles.

Continuous glucose monitoring system (CGMS) has now been added to the repertoire of technological devices useful in the management of patients with diabetes. Specifically, such monitoring enables clinicians to detect occult hypoglycaemia or hyperglycaemia not otherwise discernable with intermittent testing of blood glucose. Therefore, CGMS may provide us with new and important information on glucose profiles over a longer period of time which will give a more accurate picture of daily blood glucose excursions than can be determined by HbA1C or finger-stick methods and allow identification of the glycaemic effect after training.

The main aim of the present study was to investigate continuous blood glucose profiles over 48 h at the beginning and at the end of a 4-month ET and ST programme. Secondary aims were to evaluate whether it is possible to detect hypoglycaemic and hyperglycaemic episodes before and after ET or ST programmes.

Materials and methods

Study population

The study randomized 15 patients, four men (mean age \pm SE: 56.5 ± 0.9 , range: 51–69 years) and 11 women (mean age \pm SE: 57.4 ± 0.9 , range: 50–70 years), attending the Endocrinology and Metabolism Department between September 2000 and May 2002. The participants were divided into two groups (ST vs. ET) and none of the participants from either group was involved in organized exercise training programmes. All participants fulfilled the diagnosis of T2D, according the WHO criteria, with a fasting glucose concentration of 7.0 mmol L^{-1} (126 mg d L^{-1}). Eight participants (mean age \pm SE: 55·1 \pm 1·7) undertook ST for 4 months and seven participants (mean age \pm SE: 60·3 \pm 3·1) undertook ET. A physician performed a medical history and physical examination on each subject. The participants were excluded if they had rapidly progressive or terminal illness, myocardial infarction, uncontrolled arrhythmias, third-degree heart block, elevated blood pressure (> 200/100 under therapy), valvular heart disease, nephropathy (microalbuminuria > $50 \ \mu g \ min^{-1}$ albumin excretion), severe peripheral or autonomic neuropathy or diabetic proliferative retinopathy. All participants were on antidiabetic drug treatment [Sulphonylureas (SU) in one case, Metformin in three cases and combination SU/Metformin in eight cases] and three participants were on Metformin in combination with insulin therapy which was commenced within 6 months before the study.

All participants were advised to maintain their current medications unaltered during the entire study period and no new medication was started during the exercise period. Medications (especially Sulphonylureas) were modified to avoid hypoglycaemia only. The participants received specific recommendations to maintain their energy intake unchanged during the 4-month training period.

The study was approved by a local Ethics Committee. The purpose, nature and potential risks of the study were explained in detail to the participants before obtaining their written consent

Training programme and study design

Training programme

The study tried to define comparable training units for both groups. A unit was defined as an organizational unit for both training groups where training occurred. This was facilitated by taking comparable training units of top athletes of each training group. A top weight-lift body-builder for example does 30 units per muscle group per week, whereas a top endurance athlete trains for 10-12 h per week. This study decided that 15-20% of these training units for each group reflected an achievable workload for the study participants.

Endurance training

Systematic ET was performed on a cycle ergometer on three nonconsecutive days of the week. In the first 4 weeks, seven ET participants trained for a duration of 15 min per session three times per week. The duration of exercise was increased every 4 weeks by 5 min per session. The total exercise time per week, excluding warm-up and cool-down, was 90 min during the last 4 weeks.

Heart rate (HR) was monitored continuously throughout the training period using a Polar[®] continuous heart rate monitor (Polar Electro Oy, Kempere, Finland). Based on the linear correlation between oxygen consumption (VO₂) and HR the training was controlled by a HR reflecting 60% of VO₂ max, which was derived from ergometry using the following formula:

HR = HRrest + (HRmax – HRrest) $\times 0.6 \pm 5$ beats min⁻¹,

where HRrest is the HR after a break of 5 min in supine position.

Strength training

Eight subjects participated in a 4-month systematic ST programme on three nonconsecutive days of the week. A brief warm-up period, which involved 10 min of moderate cycling with very low intensity, was performed before each training session. Instructions in correct exercise techniques and supervision of the participants throughout the entire training period were performed by a professional instructor and an experienced physician. During the first 2 weeks, the weight was kept to a minimal level in order for the participants to learn the exercise techniques, adapt their muscles to training and prevent muscle soreness. From the third week, the training aimed for hypertrophy and started with three sets per muscle group per week. One set consisted of 10–15 repetitions, without interruption, until severe fatigue occurred



Figure 1 Study flow chart.

and completion of further repetitions was impossible. The training load was systematically adapted to keep the maximal possible repetition per set between 10-15 repetitions. When more than 15 repetitions were successfully performed at a given weight, the weight was increased by an amount that allowed approximately 10 repetitions to be performed. The number of sets for each muscle group were systematically increased from three, at commencement of the programme, to four, five and finally six sets per week at the end of the programme. The ST programme consisted of exercises for all major muscle groups. Exercises to strengthen the upper body included bench press (pectoralis), chest cross (horizontal flexion of the shoulder joint), shoulder press (trapezius and latissimus dorsi), pull downs (back muscles), bicep curls, triceps extensions and exercises for abdominal muscles (situps). Lower body exercises included leg press (quadriceps femoris), calf raises and leg extensions (biceps femoris).

Study design

The CGMS was inserted at baseline and after the 4-month period of ET, or ST, in the abdominal tissue and calibrated over a 60-min period and operated for 48 h (Fig. 1). The CGMS was inserted in all participants within 1 week of completing their training programmes.

Testing

Continuous glucose monitoring system measurements

This is a Holter-style sensor system designed to continuously monitor interstitial fluid glucose levels within a range of $40-400 \text{ mg dL}^{-1}$. The glucose sensor is a microelectrode that is inserted into the subcutaneous tissue and generates an electronic signal proportional to the amount of glucose present in the surrounding interstitial fluid. Each participant arrived at the office before the first training unit started and the catheter of the CGMS device was inserted horizontally into the abdominal subcutaneous tissue. The signal was sent to a portable monitor that recorded sensor signals every 5 min and converted them into blood glucose readings. After 2 days the data were downloaded via the Com-Station using the MiniMed Solutions Software version $2 \cdot 0b$ (MiniMed).

All participants were instructed in the use of the CGMS device and asked to enter at least four daily self-obtained

capillary blood glucose measurements into the CGMS for calibration.

Laboratory measurements

Routine HbA1C levels were measured using standard techniques. Commercially available standard kits were used for all measurements and were performed in quality certified labs.

Spiroergometry

Cardiorespiratory fitness was measured by an exercise stress test. All subjects performed a cycling test to exhaustion on an electrically braked cycle ergometer (Ergo-metrics 900, Ergoline, Germany). Heart rate was continuously monitored via an electrocardiogram and blood pressure measured in the final minute of each work level. The exercise was started with a work load of 50 W and increased stepwise by 25 W every 2 min until exhaustion.

Dynamometry

Maximal strength of a muscle was determined by one repetition maximum (1 RM in kgf) using the Concept 2 Dyno[®] (Concept 2 Ltd, Wilford, UK), where 1 RM is the maximal strength that a muscle group is able to generate with a single contraction. A maximum of three tests were allowed to avoid muscle fatigue. The representative exercise for determination of 1 RM, as measured by the Concept 2 Dyno, included a bench press performed in a seated position.

Statistical analysis

Data analysis was performed using the Statistical Package for Social Sciences (SPSS 10.0). All parameters were described by mean values \pm standard error of the mean (SE). A Student's paired t-test was used to assess significant differences of the same variables within the participants before and after the training period. Any values of $P \le 0.05$ were considered statistically significant and 95% confidence limits (CL) were calculated. To estimate change in BG-values between the beginning and the end of the training programme, multiple regression models and t-tests were applied. As dependent variable log (bzvalue) was used as this resulted in approximately normally distributed residuals. Owing to different intervals being measured per participant and period (pre/post) the analysis included 'time of day' and 'day-off' period effects into the model. The final regression model included sine and cosine components of 'time of day' as well as a linear 'day-off' period effect to account for systematic variation in observations. Mean values of the resulting residuals were then analyzed by *t*-tests.

Results

A summary of the participants demographic and clinical characteristics at baseline and after 4 months' strength or ET are shown in Table 1.

	Baseline		After 4 months			
	ST	ET	ST	ET	P^1 ST	P^1 ET
Age, years (mean ± SE)	55.1 ± 1.7	60.3 ± 3.1				
Sex (female/male)	5/3	6/1				
Duration of diabetes (a)	9 ± 4	9 ± 4				
Mean BG	$138 \cdot 1 \pm 13 \cdot 1$	124.4 ± 13.5	116.6 ± 12.1	117.7 ± 7.2	0.02	NS
HbA1C (%mean ± SE)	7.5 ± 0.5	8 ± 0.4	7.0 ± 0.3	7.6 ± 0.5	NS	NS
BMI (kg m^{-2})	29.9 ± 0.8	$36 \cdot 3 \pm 4 \cdot 7$	29.9 ± 1.0	36.3 ± 2.6	NS	NS
Lean body mass (kg)	$46\cdot3\pm2\cdot6$	56 ± 3.9	51.9 ± 3.2	$58 \cdot 2 \pm 4 \cdot 2$	< 0.01	0.03
Fat mass (kg)	38.9 ± 2.3	46.9 ± 4.0	33.5 ± 2.8	44.4 ± 3.9	< 0.01	< 0.01
Peak VO2 $(ml \times kg^{-1} \times min^{-1})$	1.66 ± 0.2	1.36 ± 0.1	1.67 ± 0.2	1.47 ± 0.2	NS	NS
Bench press (kg)	$47{\cdot}4\pm5{\cdot}3$	$31 \cdot 8 \pm 4 \cdot 0$	59.65 ± 6.5	31.7 ± 4.0	0.01	NS

Table 1 Summary of participants demographic and clinical characteristics at baseline and after 4 months of strength or endurance training

ST, strength training; ET, endurance training; HbA1C, glycosylated haemoglobin; mean BG; average of blood glucose value measured in CGMS.

PeakVo2 max. maximal oxygen uptake; mean \pm SE; NS = not significant; BMI, body mass index; P^1 value, difference in each group before and after 4 months of strength or endurance training.

At study entry, participants who undertook ST had higher average BG baseline levels [$(138 \pm 13 \cdot 1 \text{ vs. } 124 \cdot 4 \pm 13 \cdot 5) \text{ mg}\% \pm \text{SE}$], lower body mass index (BMI) ($29 \cdot 9 \pm 0 \cdot 8$ vs. $36 \cdot 3 \pm 4 \cdot 7$, $P = 0 \cdot 03$) and lower fat mass (FM) ($38 \cdot 9 \pm 2 \cdot 3$ vs. $46 \cdot 9 \pm 4 \cdot 0$, $P = 0 \cdot 04$) kg than the ET group. The HbA1C was not significantly different in either group.

After the ST/ET period there were significant differences for BMI (29.9 ± 1 vs. 36.3 ± 2.6 , P = 0.03), for FM (33.5 ± 2.9 vs. $44.4 \pm$, P = 0.04) kg and a significant increase in bench press weights (59.65 ± 6.5 vs. 31.7 ± 4.0 , $P \le 0.01$) between groups.

A total of 17 549 single BG measurements comprising pretraining (619.7 ± 39.8) and post training (550.3 ± 30.1), corresponding to an average (585 ± 25.3) potential measurement per participant at the beginning and end, were evaluated.

The change in BG-value between the beginning (132 mg dL⁻¹) and the end (118 mg dL⁻¹) for all participants was significant (P = 0.028). Also, the change in BG-value was significant for the ST programme (P = 0.02), but for the ET programme no significant change was measured (P = 0.48). Glycaemic control improved significantly in the ST group where the mean BG was reduced significantly by 15.6% (Cl 3–25%), while in ET group only a trend in mean BG decrease of 5.5% was measured. Two summary figures containing the mean values for the respective time points for ET and ST are shown in Fig. 2 and Fig. 3.

Asymptomatic nocturnal hypoglycaemic episodes with glucose values 40 mg dL⁻¹ were recorded in 1/0 participants before and 1/1 participants after ET/ST.

Prolonged hyperglycaemic periods with values \geq 300 mg dL⁻¹ were found in 2/1 participants before and no participants after ET/ST.

In one participant (NG) an interesting glucose sensor profile with frequent hypoglycaemic and hyperglycaemic episodes before and after ET was measured. In another participant, female, (SG) an example of a prolonged unrecognised hypoglycaemic period during the night after ST was noteworthy.

Changes in medications

After 4 months of training, the antidiabetic medication in ST participants was reduced by 3.3% for SU and was unchanged for Metformin, and for the two ST participants receiving insulin therapy the insulin dose was unchanged. For ET participants, SU therapy was reduced by 1.6% from baseline, and Metformin therapy and the insulin dose was unchanged. None of these changes was statistically significant.

Discussion

This study observed significant improvements in glycaemic control, as shown by reduced BG-profiles, in participants with diabetes on ST, while the effects of ET on the respective parameters were only moderate. As expected, maximum strength (1 RM) of bench press (24·2%) increased after 4 months of ST in contrast to no improvements after 4 months of ET. Not surprisingly, improvements were observed in peak VO₂ after ET (7·5%), while no such changes were seen in ST. The later findings were predictable from the specificity of the training stimulus and demonstrated that the training was adequate in both groups, which showed that the specific training stimulus was sufficient for both training groups.

Medications, especially Sulphonylureas, were reduced only to avoid hypoglycaemia. Reduction of Sulphonylureas was greater during ST $(-3\cdot3\%)$ than during ET $(-1\cdot6\%)$ even though this did not reach statistical significance. Insulin dose and Metformin therapy were unchanged during ST and ET. More importantly, the observations were made in the presumed absence of dietary changes during the training period.

The positive change in the glycaemic profiles of the participants after training are therefore presumably owing to the effectiveness of the training programme.

The use of CGMS has opened a new window through which it is possible to observe directly *in vivo* what happens to



Figure 2 Mean glucose values of all participant before and after ST.



Figure 3 Mean glucose values of all participant before and after ET.

participants with diabetes. The first noticeable observation in our participants after strength or ET was the improvement of the glycaemic profile (estimated from 17 549 single BG measurements), even in the absence of significant changes in the usual daily schedule (oral antidiabetic medication and dose of insulin and diet). This new device showed that it is possible to obtain exact information on glycaemic profiles after ET or ST programmes while HbA1C values only showed trends in improvements during the same time period. It was also understandable that numerous glucose elevations during the day and not a single glucose value are an important determinant of the overall glycaemic control.

The CGMS sensor measured the amount of glucose in the interstitial fluid and then calculated the expected corresponding blood glucose level. During physical exercise, the interstitial fluid glucose levels may decrease more quickly than the plasma glucose level because the cells are consuming glucose rapidly. In general, differences between plasma glucose and interstitial fluid glucose have been reported to be relatively minor with the lag time between them usually being < 10 min [11]. As the study determined whole daily glucose profiles before and after the training periods and not only single glucose values this limitation of the device was compensated.

Extensive large studies have validated the agreement and accuracy of sensor readings and shown a significant correlation between capillary glucose determinations and simultaneous sensor readings [12–15].

Reports on the sensitivity of detecting hypoglycemia have been controversial. In a recently published paper [16] the reliability and sensitivity of a CGMS in detecting hypoglycaemia was weak and in other papers the CGMS often failed in detecting hypoglycaemia [17–19]. In contrast to these results are the outcomes of other studies [20,21]. In the recently published paper of the Diabetes Research in Children Network study group [16], the authors speculated that the greatest value of a CGMS may be for detecting trends and not for serving as a sentinel for single hypoglycaemia. In this study asymptomatic nocturnal hypoglycaemic episodes with glucose values 40 mg dL⁻¹ were recorded in one participant before training and two participants after the training programme. In these two cases after the training programme, the episodes of hypoglycemia were foreseeable because of slowly lowering BG over a longer time period before hypoglycemia appeared, and the accuracy of sensor readings showed significant correlations with the capillary glucose determinations of the participants.

Prolonged hyperglycaemic periods with values > 300 mg dL^{-1} were found in three participants before training and none after training. CGMS is an accurate device in sensing higher glucose levels, which has also been confirmed in other studies [22,23].

A limitation of this study was that participants randomized for the ST group had higher baseline levels for BG than participants randomized for the ET group. It should be mentioned that values that are high and outside a normal physiological range can be reduced more easily than values that lie closer to the normal range. Although BGs in the ST group were higher and outside the physiological range at study entry, after the 4-month training period the values were closer, or nearly equal, to normal values than those in the ET group.

Another limitation of this study was that it is a comparative type study without a control group (as there was no nonexercise control group) and it is uncertain as to what extent the changes following ST, or ET, are on top of the changes that could possibly be expected if no exercise training was undertaken. However, as the improvement in maximum strength (1 RM) of the ST subjects was highly significant (25% of initial levels) and this finding was predictable from the specificity of the training stimulus, the authors believe that the specific training stimulus was sufficient and probably responsible for the changes in BG-values after 4 months. The authors were aware that the improvements from training would be more impressive when compared with participants without training, but the Ethics Committee had reservations about a group where exercise was withheld from the participants.

Other points to be discussed are training intensity and volume in ST and ET programmes. The ET with an intensity of VO2 max 60% and a volume (starting at 15 min and increasing to a maximum of 30 min/three times a week) is at the lower end of an endurance training programme; this was selected because of the poor training status of the participants at the start of the study. As all the participants were new to physical training the study had to start with low intensity and low volume.

In conclusion, the CGMS is considered a useful tool in monitoring improvements in glycaemic control after a ST or ET programme. Additionally, the CGMS is of clinical utility in routine clinical practice because the glucose profile is representative of the overall control of the participants, similar to a self-control of blood glucose. Furthermore, the CGMS may help to identify asymptomatic hypoglycaemia or hyperglycaemia after physical training programmes.

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