Influence of Resistance Exercise Training on Glucose Control in Women With Type 2 Diabetes

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The objective of the study was to evaluate the effects of acute and chronic resistance training on glucose and insulin responses to a glucose load in women with type 2 diabetes. Subjects consisted of type 2 diabetic women (n = 7) and age-matched controls (n = 8) with normal glucose tolerance. All subjects participated in 3 oral glucose tolerance tests: pretraining, 12 to 24 hours after the first exercise session (acute) and 60 to 72 hours after the final training session (chronic). Exercise training consisted of a whole body resistance exercise program using weight-lifting machines 3 days per week for 6 weeks. Resistance training was effective in increasing strength of all muscle groups in all subjects. Integrated glucose concentration expressed as area under the curve (AUC) was 3,355.0 ± 324.6 mmol/L · min pretraining, improved significantly (*P* < .01) after the acute bout of exercise (2,868 ± 324.0 mmol/L · min), but was not improved with chronic training (3,206.0 ± 337.0 mmol/L · min) in diabetic subjects. A similar pattern of significance was observed with peak glucose concentration (pre: 20.2 ±1.4 mmol/L; acute: 17.2 ± 1.7 mmol/L; chronic: 19.9 ± 1.7 mmol/L). There were no significant changes in insulin concentrations after any exercise bout in the diabetic subjects. There were no changes in glucose or insulin levels in control subjects. An acute bout of resistance exercise was effective in improving integrated glucose concentration, including reducing peak glucose concentrations in women with type 2 diabetes, but not age-matched controls. There were no significant changes in insulin concentrations for either group. Resistance exercise offers an alternative to aerobic exercise for improving glucose control in diabetic patients. To realize optimal glucose control benefits, individuals must follow a regular schedule that includes daily exercise.

IT IS WELL KNOWN that muscle contraction increases glucose uptake in skeletal muscle.[1-5] This, in part, forms the basis for recommending exercise for individuals with type 2 diabetes. Most research studies have investigated the effects of aerobic types of exercise on integrated glucose concentration in diabetic patients, because aerobic exercise utilizes large muscle groups for extended periods of time. However, resistance exercise may provide an equally high, or higher, recruitment of muscle mass over a similar period of time. In fact, a few studies have shown the benefits of resistance exercise on glucose control in individuals with type 2 diabetes or impaired glucose tolerance, and such improvements are of similar magnitude as seen with aerobic exercise.[6,7] Furthermore, it has been shown that a whole body resistance training program involving repeated muscle contractions of the upper and lower body enhances insulin response in healthy individuals.[8-10] A single bout of resistance training can significantly enhance insulin clearance in young type 2 diabetics and controls for up to 18 hours after the exercise session.[11]

There has been some controversy regarding whether the exercise-induced benefits in glucose and insulin control are a result of multiple single bouts of exercise or whether there is a chronic training benefit.[12] Improvements in integrated glucose concentration are greater at 12 hours than 72 hours after a bout of aerobic exercise.[13] Perhaps even more relevant is the finding that improvements in glycosylated hemoglobin in diabetic subjects is not related to initial maximal oxygen consumption or improvement in oxygen consumption and thus is not related to overall aerobic fitness level. Detraining studies also support the notion that improvements in glucose metabolism may be the result of repeated acute effects instead of chronic training as rapid deterioration of glucose tolerance occurs following the cessation of an aerobic training program even though changes in maximal oxygen consumption or muscle enzyme profiles associated with improved fitness persist for weeks.[14] Resistance exercise has not been as thoroughly studied; it is possible that an isolated bout of resistance exercise may be effective at improving integrated glucose concentration in type 2 diabetic subjects even in the absence of sustained effects after a chronic training program. The effects of an acute bout of resistance training compared with the effects of chronic resistance training in women with type 2 diabetes have not been evaluated thus far. Therefore, the purpose of this study was to compare the effects of acute and chronic resistance training on integrated glucose concentration and the insulin response to a glucose load in healthy women and age-matched women with type 2 diabetes.

MATERIALS AND METHODS

Subjects

Females with type 2 diabetes and age- and height-matched control women were studied; their descriptive statistics are shown in Table 1. Diabetic subjects had significantly greater body mass, fat mass, fat-free mass, percent fat, sagittal diameter, and waist circumference than control women ($p < .05$). Four women were premenopausal. All subjects provided informed written consent, and the study was approved by the Institutional Review Boards of Syracuse University and SUNY Upstate Medical University. Subjects were included if they were not currently and had not participated in resistance training or aerobic exercise for the previous 6 months. Subjects were defined as

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Table 1. Physical Characteristics of the Diabetic and Control Women Before (pre) and After Six Weeks of Training (post)

	Diabetic (n = 7)		Control (n = 8)	
	Pre	Post	Pre	Post
Age (yr)	49.5 ± 2.1		49.1 ± 0.9	
Height (cm)	163.6 ± 3.2		164.1 ± 3.0	
Weight (kg)	100.6 ± 6.3*	99.6 ± 6.0	69.9 ± 4.0	70.4 ± 3.7
BMI (kg/m^2)	37.9 ± 1.9*	37.0 ± 1.8	25.8 ± 1.3	26.0 ± 1.2
Lean body mass (kg)	54.2 ± 2.2†	54.6 ± 2.1	47.0 ± 1.4	48.3 ± 3.6‡
Fat mass (kg)	46.6 ± 4.1*	45.0 ± 4.1‡	21.7 ± 2.8	21.2 ± 2.9
% Fat	45.7 ± 1.3*	44.7 ± 1.3	31.9 ± 2.0	30.8 ± 2.0
Sagittal diameter (cm)	29.4 ± 1.2*		20.4 ± 0.7	
Waist (cm)	104.1 ± 2.6*		78.0 ± 2.7	

NOTE. Data are means ± SE.

*$P < .01$ v control; †$P < .05$ v control; ‡$P < .01$ v pretraining.

having diabetes according to the criteria in the Report of the Expert Committee on the Diagnosis and Classification of Diabetes Mellitus.[15] Subjects were excluded if they took medications known to influence metabolism or total body water (eg, insulin, diuretics, cholesterol-lowering agents, antidepressents, etc) Type 2 diabetes subjects were included if they were taking oral glycemic control medications, but no changes in any medications were made during the study. Two individuals taking glipizide (sulfonylurea), 2 taking troglitazone (thiazolidinedione), and 1 taking metformin HCl enrolled in the study. Self-reported chronic alcohol users or smokers were not included in the study. Additional exclusion criteria for this study were symptomatic coronary artery disease, congestive heart failure, peripheral vascular disease, significant hypertension (>180/100 at rest), renal, hepatic, pulmonary, adrenal or pituitary disease, or untreated hypo- or hyperthyroidism or recent orthopedic injury.

Experimental Design

Females with type 2 diabetes and females with normal glucose tolerance participated in a resistance training program to study the acute and chronic effects of resistance training on changes in integrated glucose concentration and plasma insulin levels after a glucose load. Responses to a single training session were compared with changes after chronic training. The type 2 diabetes subjects and controls underwent the same testing protocol. On the first visit, body composition, height, weight, waist, and sagittal diameter were measured and a pretraining oral glucose tolerance test (OGTT) was administered. On the subsequent 2 visits, subjects were familiarized with the resistance exercises used for the training program. After familiarization, a pretraining 3-repetition maximum strength test (3-RM) was performed for each exercise. The subjects then participated in resistance training 3 times per week for 6 weeks. A second OGTT was performed 12 to 24 hours after the first exercise session (acute) to assess the acute effects of resistance training on integrated glucose concentration and plasma insulin levels. To assess the chronic effects of the training program, the final OGTT was administered 60 to 72 hours after the last training session (chronic) to exclude the acute effects of the last training session. The 3-RM strength test and anthropometric measurements were repeated posttraining to document changes in strength and body composition.

OGTT

All OGTTs were performed following a 12-hour period of fasting and abstention from oral glycemic control medications and during the follicular phase (days 1 to 14) of the menstrual cycle in the premenopausal women, because the menstrual cycle can affect glucose tolerance in women.[16] A catheter with a 3-way stopcock for blood sampling was inserted into the antecubital vein; patency was maintained with a saline flush. The subjects remained seated during the remainder of the test. A 5-mL baseline blood sample was taken and then a 75-g glucose drink (Trutol; Custom Laboratories, Baltimore, MD) was administered. Additional 5-mL blood samples were taken 30, 60, 90, 120, 150, 180, 210, and 240 minutes after consumption of the glucose load.

Familiarization Sessions and 3-RM Strength Testing

During the first 2 visits, subjects were oriented to the 9 resistance exercise machines used for training. The weight pins were removed from the machines to eliminate resistance during this learning experience, and the subjects were asked to complete 2 sets of 10 repetitions on each machine to practice the lifting procedures and breathing techniques. At the end of the second familiarization visit, 3-RM instructions were given,and the 3-RM was estimated on each machine. On the third familiarization visit, 3-RM evaluated and recorded for each of the 9 exercises. The 3-RM was used to establish the starting weight for each exercise during training and to document the effectiveness of training. 3-RM is defined as the heaviest weight that a subject can lift through a full range of motion lift 3 times in a row. It is measured by beginning at a moderate load and increasing the weight in 1 kg increments until the subject cannot complete 3 repetitions.

Resistance Training Program

Subjects performed supervised weight training exercises 3 nonconsecutive days per week for 6 weeks, each session lasting approximately 50 minutes. The weight-training program consisted of 3 sets of 8 to 12 repetitions to failure for 8 resistance-type exercises, as well as 3 sets of 15 abdominal crunches. The 8 exercises performed were chest press, shoulder press, lat pulldown, leg curl, leg extension, leg press, and triceps extension, all performed on Universal equipment and biceps curls performed using free weights. A 1.5-minute rest was given in between sets to keep subjects' heart rates down, avoiding a possible aerobic training effect. The starting weights for each exercise were determined as 80% of the subject's 3-RM. Whenever subjects were able to perform 12 repetitions with proper form, the weight was increased by 5 pounds. Verbal encouragement was given by the exercise supervisor to ensure that the exercises were performed to fatigue while maintaining proper lifting technique.

Body Composition

Body composition analysis was performed both pretraining and following 6 weeks of resistance training to evaluate changes in lean and fat mass. Body composition was measured in the postabsorptive state utilizing a Quantum Bioelectrical Impedance Analysis Machine (BIA101Q; RJL Systems, Clinton Twp, MI).

Serum Analysis

Blood samples were centrifuged for 15 minutes at 2,300 rpm and the serum frozen at −70°C for later analyses of insulin and glucose. Insulin levels were determined using a radioimmunoassay kit (Nichols Diagnostic, San Juan Capistrano, CA), and the glucose content of the blood was measured by the glucose oxidase method (Sigma Diagnostics, St Louis, MO). For both assays, serum samples were analyzed in duplicate. Pretraining, acute, and chronic samples from an individual subject were batched and analyzed using the same assay.

Statistical Analysis

A 2-way analysis of variance (ANOVA) was used to evaluate treatment effects (pretraining, acute, chronic) and group differences

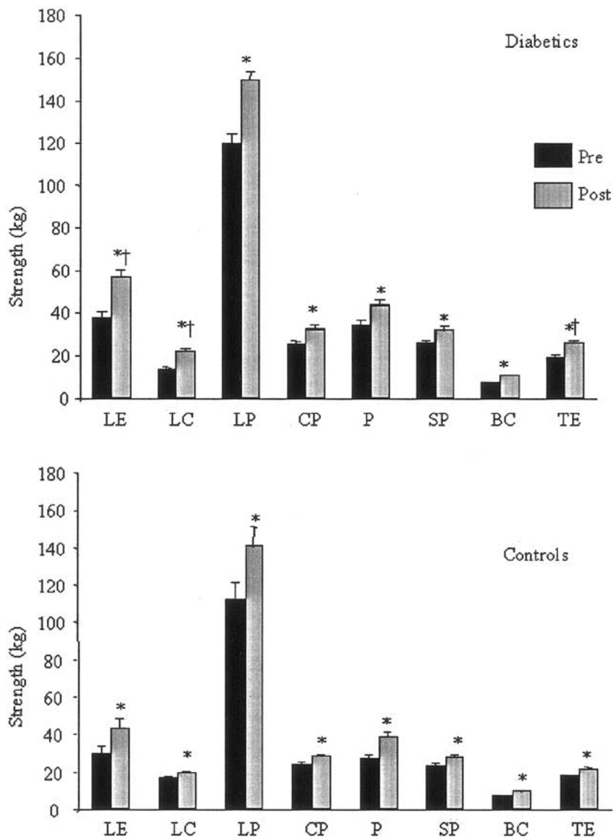

Fig 1. Strength gains for each exercise before and after 6 weeks of training. LE, leg extension; P, pulldown; LC, leg curl; SP, shoulder press; LP, leg press; BC, bicep curl; CP, chest press; TE, tricep extension. Means ± SE. **P* < .01 *v* pretraining, †*P* < .05 diabetics greater improvement than controls, n = 7 diabetics and 8 controls.

(control, diabetic) on fasting glucose and insulin concentrations, peak concentrations, and 4-hour area under the curve (AUC). Group (diabetic, control) and treatment (pretraining, posttraining) differences related to body composition and strength gains were also analyzed with a 2-way ANOVA. Significant differences were analyzed using post hoc analyses. Significance was set at $P < .05$, and data were presented as mean ± SE. All data were analyzed using Super ANOVA statistical software (v 1.11, Abacus Concepts, Berkeley, CA). All variables were examined for the assumption of normal distribution, and all but 2 variables followed a normal distribution (no statistically significant skewness or kurtosis). The fasting values for insulin and glucose followed a relatively normal distribution, but had some skewness and kurtosis due to 1 outlier. Because ANOVA is very robust to the normal distribution assumption, we chose to retain the fasting values of the 1-outlier subject.

RESULTS

Strength

All subjects, control and diabetic, showed significant strength increases ranging from 19% to 57% in all exercises ($P < .01$) (Fig 1). Diabetic subjects showed significantly greater increases than controls on 3 exercises (leg extension, leg curl, and triceps extension) ($P < .05$).

Body Composition

After the 6-week training program, lean body mass increased significantly ($P < .01$) in the control group, while fat mass decreased significantly in the diabetic group ($P < .01$), however, the fat loss was not significantly related to improvements in glucose AUC ($r = .3$, $P > .05$). There were no other significant changes observed, including no changes in total body mass (Table 1).

Glucose Concentrations

The pattern of glucose responses to the 75g-glucose load is shown in Fig 2A. At all time points, the diabetic group had higher glucose concentrations than the control group. The pretraining fasting glucose concentrations were significantly higher in the diabetic group (9.1 ± 1.3 mmol/L) than the control group (5.3 ± 0.7 mmol/L, $P < .05$) (time = 0, Fig 2A). Within each subject group, there were no differences among the fasting glucose values (baseline, acute, chronic). The standard

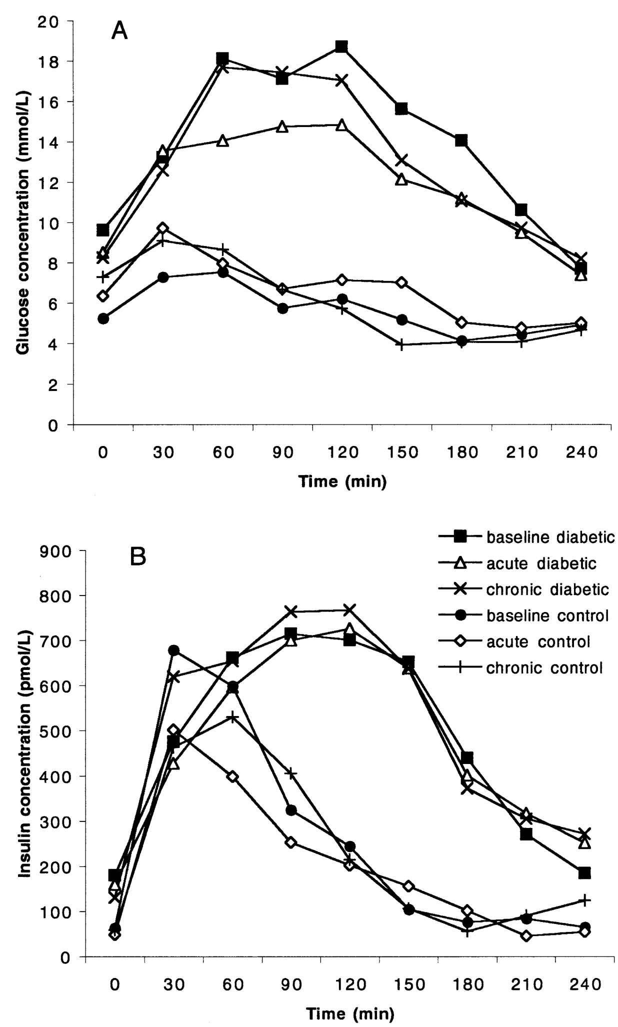

Fig 2. (A) Mean glucose and (B) insulin concentrations over all time points during OGTT for controls and diabetics, n = 7 diabetics and 8 controls.

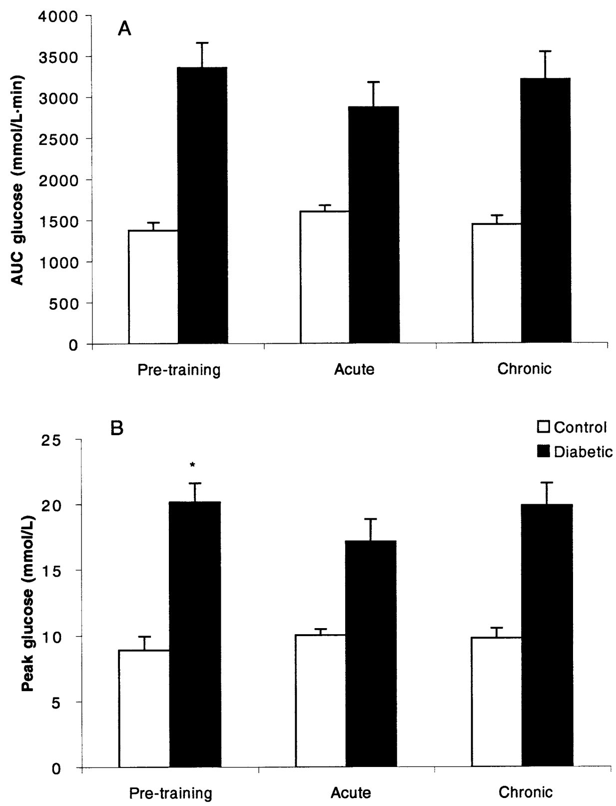

Fig 3. Comparison of effects of pretraining, acute training, and chronic training on glucose concentration (A) 4-hour area under the curve and (B) peak glucose, which is the highest glucose value reported during the OGTT. Means ± SE. **P* < .01 *v* controls, †*P* < .01 *v* pretraining and *P* < .05 *v* chronic, ^*P* < .05 *v* pretraining and chronic, n = 7 diabetics and 8 controls.

glucose load resulted in significantly higher peak glucose concentrations (peak indicates the highest glucose value obtained during the OGTT) ($P < .01$) and 4-hour AUC ($P < .01$) in the diabetic group compared with the control group (Fig 3A). A significantly improved integrated glucose concentration ($P < .01$) was observed in the diabetic group after the acute bout of exercise (AUC: 2,868 ± 324.0 mmol/L · min) compared with pretraining values (3,355.0 ± 324.6 mmol/L · min), but significant changes after the chronic training were not observed (3,206.0 ± 337.0 mmol/L · min). A significant decrease was also shown in mean peak glucose concentration (pre: 20.2 ± 1.4 mmol/L; acute: 17.2 ± 1.7 mmol/L, $P < .05$; chronic: 19.9 ± 1.7 mmol/L, $P < .05$). Glucose concentrations did not change across time with resistance exercise in the control group. The change in integrated glucose concentration induced by a single bout of resistance exercise was related to the initial glucose AUC ($r = .77$, $P < .01$) when the whole population is considered. Upon further analysis, this relationship was strongest among the control subjects ($r = .68$, $P = .06$) compared with the diabetic subjects ($r = .03$, $P = .48$). Generally, the greater the initial hyperglycemia, the greater the improvement with resistance exercises regardless of group (Fig 4). There was no significant relationship between glucose AUC before and after chronic training ($P > .05$).

Insulin Concentrations

Before training, fasting insulin concentrations were significantly higher in the diabetic group than the control group ($P < .01$) (time = 0, Fig 2B). The fasting and postglucose insulin concentrations are shown in Fig 2B. The insulin concentrations began to rapidly decline 30 to 60 minutes postglucose load in the control group, while peak insulin concentrations were delayed and remained elevated for at least 120 minutes in the diabetes group. The peak (highest obtained during the OGTT) values were not significantly different among groups or conditions (Fig 5B). There was a group difference in the 4-hour AUC during the OGTT in the diabetic group ($P < .05$) (Fig 5A). There were no significant changes in insulin concentrations after acute or chronic exercise in either group.

DISCUSSION

The most important finding was that integrated glucose concentration was improved 12 to 24 hours after just 1 session of resistance exercise in the absence of any chronic training effects. This is consistent with what has been observed for aerobic exercise. For example, Schneider et al[13] showed that plasma glucose levels were significantly lower at 12 hours than 72 hours after aerobic exercise in type 2 diabetic men.

Some previous studies involving strength training and glucose control have also shown improved integrated glucose concentration with strength training,[6,7] whereas in other studies, integrated glucose concentration did not change.[8-11] The disparities in effects on glucose tolerance with strength training may relate to the different populations studied. The present study examined middle-aged obese women with type 2 diabetes who had large postglucose load glycemic excursions with delayed inadequate insulin responses. In previous studies involving glucose tolerance and strength or aerobic training, individuals with higher initial glucose levels also showed more

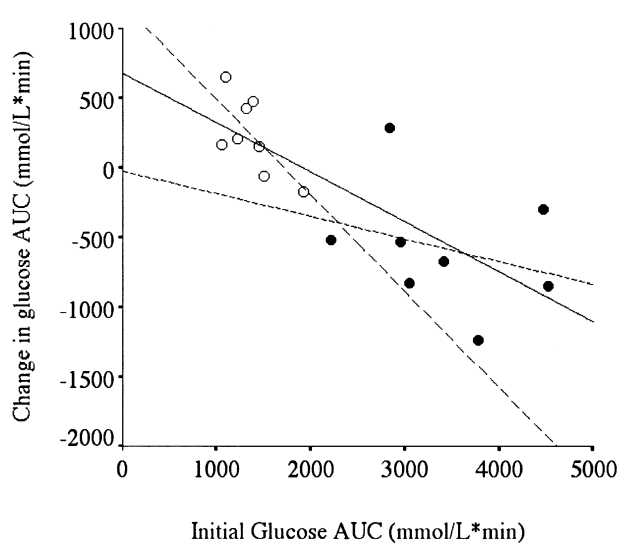

Fig 4. Relationship between initial glucose AUC and change following a single acute bout of resistance exercise. Control subjects, ○ and dashed lines; diabetic subjects, ● and dotted lines; solid line, regression line for the whole population.

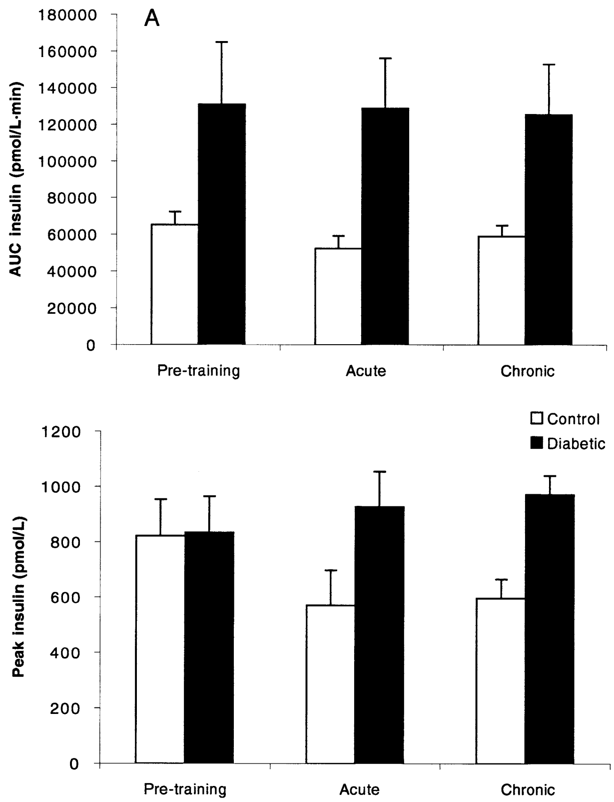

Fig 5. Comparison of effects of pretraining, acute training, and chronic training on insulin concentration (A) 4-hour area under the curve and (B) peak insulin, which is the highest insulin value reported during the OGTT. Means ± SE. *$P < .05$ *v* control, n = 7 diabetics and 8 controls.

dramatic decreases in glucose concentrations with strength training.[6,7] It is reasonable to suspect that normal glucose tolerances in healthy subjects in prior research may preclude finding a decrease in plasma glucose levels with strength training,[8-10,17,18] consistent with Fig 4 in the current study. The current study shows a particularly strong relationship between initial integrated glucose concentration and exercise-derived benefit ($r = .77$), such that subjects with normal initial glucose levels showed little response to exercise, and subjects with high initial glucose levels showed the greatest exercise-induced benefit. In our study, a 6-week training program had no effect on insulin concentrations. Many other studies involving resistance training have shown improved insulin levels.[6-11] In all of these studies except for one,[11] training ranged from 10 to 20 weeks in length, which suggests that longer time periods may be required to impact insulin levels. It is also possible that the effects of both acute and especially chronic exercise may be influenced by the oral hypoglycemic medications of patients. In our study and most exercise studies, medications are heterogeneous for the treatment of diabetes, and because some act peripherally, it is possible that the family of medication used does influence the responses to exercise.

It has been shown that the period after aerobic exercise is characterized by increased insulin sensitivity.[19] Our data suggest this also applies to resistance exercise; although our data preclude identification of the precise mechanism; several mechanisms have been studied by others.[19] These include altered glucose transport,[20] improved glucose disposal to restore muscle glycogen,[21] decreased hepatic glucose output,[22] or the unlikely, but possible, explanation that there is slower intestinal absorption of carbohydrate.

In summary, our data indicate that an acute bout of resistance exercise is sufficient to improve whole body integrated glucose concentration in type 2 diabetic women for at least 24 hours postexercise. Control subjects with normal glucose control showed no exercise-induced changes; in fact, the data show that the greatest exercise-induced benefits in glucose control are observed in the most hyperglycemic subjects (Fig 4). Among diabetic subjects, insulin concentrations did not change in the first 24 hours after exercise, but glucose concentrations decreased; we can infer that insulin sensitivity was transiently improved during the postexercise period. This may have clinical importance, as regular resistance exercise improved glucose control in type 2 diabetics. In addition to improved integrated glucose concentration, resistance training is also known to offer additional benefits, such as increased strength, maintained or increased muscle mass even during hypocaloric dieting, and maintenance of bone density. Furthermore, resistance training may appeal to some patients, particularly the obese, who may have a harder time complying with aerobic exercise prescriptions due to orthopedic or other limitations. The frequency and duration of resistance training needed to have a sustained effect on glycemic control in diabetics will require further study, but our data suggest that exercise should be performed most days of the week.

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