Effects of a Physical Activity Program on Metabolic Control and Cardiovascular Fitness in Children with Insulin-dependent Diabetes Mellitus

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The purpose of this investigation was to determine the effects of a regular vigorous physical activity program on children aged 5–11 yr with insulin-dependent diabetes mellitus (IDDM). The experimental group of children (N = 9) took part in a 30-min vigorous exercise program three times a week for 12 wk; the control group (N = 10) did not. Hemoglobin A_1 (HbA_1) and fasting blood glucose (FBG) were used to determine metabolic control. Oxygen consumption was evaluated by treadmill testing and analyses of expired air. The experimental group significantly ($P < 0.05$) decreased their HbA_1 and FBG while the control group showed no change. The experimental group significantly ($P < 0.05$) increased their peak aerobic capacity (ml/kg·min) when compared with baseline values (47.14 ± 1.94 versus 50.69 ± 1.30). It was concluded that a carefully applied program of regular vigorous physical activity can beneficially influence metabolic control and cardiovascular fitness in young children with IDDM. DIABETES CARE 7: 57–62, JANUARY–FEBRUARY 1984.

Attempts to achieve metabolic control in insulin-dependent diabetes mellitus (IDDM) are based on the fundamental principle of a balance of energy intake, energy expenditure, and insulin action. Successful treatment of diabetes requires careful balance of the three. Although the role of physical exercise as a therapeutically useful tool in diabetes management has been recognized for centuries, the clinical significance of exercise in the metabolic control of diabetes has not been investigated until recently.[1–4] These investigators report an influence of physical activity on blood glucose levels, hemoglobin A_1, insulin dosage, glucosuria, and serum lipid levels; however, these data are limited because of the lack of control and the quantification of the exercise programs.

The purpose of the present study was to determine the effects of a regular physical activity program on metabolic control and cardiovascular fitness in children aged 5–11 yr with IDDM. The activity program was designed to maintain heart rates of greater than 80% maximum heart rate over a 30-min period, three times a week for 12 wk.

METHODS

Subjects. Nineteen children, 12 boys and 7 girls, between the ages of 5 and 11 yr, of similar socioeconomic background and geographic location, were selected based on age from a population of children in regular attendance at the University of Michigan Pediatric Diabetes Clinic Unit (DCU). The children were white with the exception of one child who was black. These children had been diagnosed as having IDDM for at least 6 mo before the study, had no microvascular or other complications that would contraindicate participation in a physical activity program, and had been seen at the pediatric DCU for at least 3 mo. All children were on a mixed split-dose insulin regimen consisting of both regular and long-acting insulin in the morning and evening. All subjects were considered in stable metabolic control in the months before beginning the study based on their hemoglobin A_1 values. Informed consent was obtained according to the Human Research Committee of the University of Michigan Medical Center.

Experimental design. Each child was assigned randomly to either a control (N = 10) or experimental (N = 9) group. The experimental group participated in a physical activity program. All subjects were tested in a similar manner both before (baseline) and after (final) the experimental phase (physical activity program) of the study. The children attended the clinic once before and once after the 12-wk study period. For both groups, contact with the medical team (e.g., physicians, nurse educators) were similar. The children in the experimental group attended the exercise sessions, but the effects of the program on their control and any possible health benefits of the program were not discussed. Both groups were followed from March through May.

Treadmill testing. All subjects participated in a progressive treadmill running test. A modified Balke protocol was used with the treadmill speed remaining constant and the elevation being increased 2% every 3 min. The volume of expired air was collected in Douglas bags, in the fashion described previously.[5] The volume of expired air was measured with a Parkinson-Cowan CD-4 dry gas meter. The use of an indwelling thermister in the dry gas meter allowed for the measurement of the temperature of the expired air. The volume was corrected to Standard Temperature and Pressure Dry (STPD) and for the amount drawn off during sampling. One-half hour after arriving at the laboratory, resting oxygen consumption was measured on each subject while sitting quietly for 2 min before beginning the exercise test. Expired air was collected in Douglas bags every minute during 2 min of rest. Each subject was monitored through the test on a three-lead standard electrocardiographic bipolar CM5 configuration; the last 10 s of every minute were recorded on a Beckman strip chart recorder.

The established criteria for a peak test included: (1) the oxygen consumption rate showed a leveling off and no further increase occurred, and (2) an R value ≥ 0.95 was reached, and/or (3) a heart rate ≥ 190 beats/min was attained. The peak oxygen consumption test values were used to assess cardiovascular fitness.

Blood chemistry. A 20-cc venous, 12-h fasting blood sample was obtained on each subject by trained personnel. Each sample was analyzed as follows.

1. Glucose: Fasting blood glucose (FBG) was determined by the glucose-oxidase method using a Beckman Analyzer (Beckman Instruments, Inc., Fullerton, California).

2. Hemoglobin A_1: HbA_1 was measured on each serum sample by cation-exchange column chromatography[6] on Bio-Rex 70 resin, as performed by the Diabetes Research and Training Center laboratories (University of Michigan Hospitals). A two-buffer microcolumn method was used (Isolab, Akron, Ohio). The labile fraction of the HbA_1 was removed by incubation of the erythrocytes in isotonic saline for 4 h at 37°C.[7] The resulting stable fraction was then assayed by column chromatography. The removal of the labile or rapidly formed portion of HbA_1 reduces the possible influence of transient changes in blood glucose concentrations.[8]

Dietary assessment. No attempt was made to change diet during the study. All children followed a previously prescribed diet plan as routinely recommended by the DCU dietitian. Twenty-four-hour dietary records (one weekday) were completed by each child and parent twice—once before and once during the study—to determine whether significant changes occurred in each child's diet.

Physical activity program. The physical activity program consisted of three 30-min sessions per week for 12 wk. The children in the experimental group participated in the exercise program, while those in the control group did not.

TABLE 1
Physical characteristics at baseline of experimental (N = 9) and control (N = 10) children*

	Experimental	Control	P†
Age (yr)	9.0 ± 0.47	8.5 ± 0.57	NS
Weight (kg)	33.82 ± 2.13	32.42 ± 3.05	NS
Height (cm)	139.10 ± 2.72	133.04 ± 4.59	NS
Duration of IDDM (yr)	5.11 ± 0.95	3.89 ± 0.70	NS
Insulin (U)	31.1 ± 3.77	24.6 ± 3.81	NS
HbA_1 (%)‡	12.5 ± 0.65	13.9 ± 0.61	NS

*Student's *t* test analysis.
†Statistically significant ($P \leq 0.05$).
‡HbA_1: hemoglobin A_1.

The activity program involved running, games, and movement to music; it was conducted by an activity instructor trained in the implementation of the program. The purpose of the exercise program was to improve metabolic control in young children aged 5–11 yr with IDDM. Because of the uniqueness of design and flexibility of the program, it could serve as a model that is easily adaptable to a variety of settings.

The activity sessions were designed to achieve heart rates of ≥160 beats/min for 30 min. The intensity of activity was measured during each activity session on children selected randomly who either wore a heart rate Exersentry (Respironics, Inc., Ohio) device or by timed palpation of the carotid artery. Heart rates were recorded at 5-min intervals five times during the class. A log of activities was also kept by the instructor. Previous work in this area has shown that it is possible to use heart rate to differentiate work intensity during physical activity.[9] All experimental subjects were required to attend at least 75% of the exercise classes (27 sessions) in order to be included in the final analyses.

Statistical analysis. Appropriate descriptive statistics were performed on all subjects. Paired and nonpaired Student's *t* tests were used based on the assumptions of the statistics, i.e., equality of variances, and normality of distribution to compare overall results (baseline versus final) within the experimental and control groups and between groups, respectively.

Mean values plus or minus the standard error of the mean are presented in the text and in all tables. In all cases, the 0.05 level was used to determine statistical significance.

RESULTS

Physical characteristics. The physical characteristics of the two groups of children before intervention are given in Table 1. As can be observed, there were no significant ($P > 0.05$) differences between the two groups for any of the variables before intervention. There was no significant change ($P > 0.05$) in the mean insulin dosage during the study as evidenced by all statistical analyses performed (experimental group: 31.1 ± 3.77 U versus

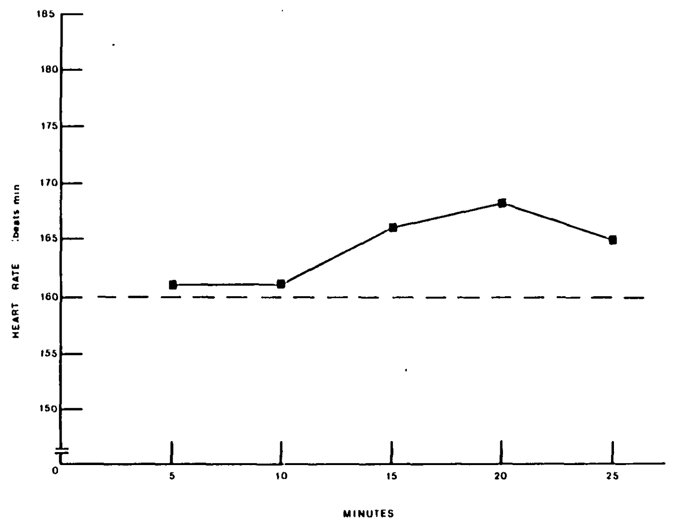

FIG. 1. Mean exercise heart rates during the first 25 min of the physical activity sessions. (Mean of all subjects sampled on four different occasions each, during the 12 wk of the exercise program.)

32.4 ± 3.31 U; control group: 24.6 ± 3.81 U versus 26.9 ± 3.87 U).

According to the National Center for Health Statistics, the girls in the present study were in the 80th and 90th percentiles and the boys were in the 75th and 85th percentiles for height and weight, respectively, compared with children of similar age and sex.[10] The difference in body weight between the two groups was not statistically significant at either baseline or final determinations; however, both groups showed mean increases in body weight (experimental: 33.82 ± 2.13 kg to 35.73 ± 2.27 kg; control: 32.42 ± 3.06 kg to 33.00 ± 3.03 kg). Only the increase in body weight for the experimental group was statistically significant ($P < 0.05$).

Exercise training. The activity program was designed to achieve heart rates of ≥160 beats/min continuously over 30 min. As shown in Figure 1, the exercise program achieved this goal over the 25-min period in which heart rate monitoring took place.

Treadmill testing. The peak treadmill test measurements in the experimental group exhibited a greater change than in the control group. As shown in Table 2, the peak treadmill data revealed the following variables to be significantly ($P < 0.05$) different from baseline values after the exercise program for the experimental group: peak $\dot{V}O_2$ (ml/kg·min) and peak $\dot{V}E$ (L/min). For the control group, peak $\dot{V}E$ showed an increasing trend, though not significantly ($P > 0.05$) different from baseline. All other variables for the control group were not found to be significantly different from baseline values ($P > 0.05$) after the 12-wk study period. Analyses (Table 3) on peak treadmill measurements revealed no statistically significant ($P > 0.05$) differences between the two groups for the baseline or final determinations.

Blood chemistry. The blood chemistry data on the two groups of children revealed improvements in metabolic control in the experimental group when compared with the control group. The results of the paired t analyses for the blood chemistry measurements are presented in Figure 2. After the 12-wk exercise program, HbA_1 and FBG both decreased significantly ($P < 0.05$) in the experimental group (HbA_1: 12.5 ± 0.65 versus 11.3 ± 0.50; FBG: 227 ± 31 versus 190 ± 32). In the control group there was very little change in the measures of metabolic control (HbA_1: 13.9 ± 0.61 versus 13.3 ± 0.54; FBG: 266 ± 39 versus 292 ± 27).

The results showed no significant differences between the two groups at baseline for the blood chemistry measurements. However, the analyses performed on the final values showed both HbA_1 and FBG to be significantly ($P < 0.05$) lower in the experimental group after the 12 wk of study when compared with the control group.

Dietary records. Although the total number of calories increased from 2218 ± 123 to 2514 ± 210 for the experimental group and 2249 ± 185 to 2321 ± 224 for the control group, these were not statistically significant ($P > 0.05$) differences within or between groups.

DISCUSSION

The present study investigated the effects of a well-controlled exercise program on metabolic control and cardiovascular fitness in young children with IDDM. Our results show both HbA_1 and FBG to be significantly ($P < 0.05$) decreased in the experimental group after 12 wk of regular physical activity, while no significant ($P > 0.05$) changes were found in the control group.

TABLE 2
Comparison of the baseline versus final treadmill test data for the experimental (N = 9) and control (N = 10) children*

	Experimental			Control		
Variable	Before ($\bar{X}$ ± SEM)	After ($\bar{X}$ ± SEM)	P†	Before ($\bar{X}$ ± SEM)	After ($\bar{X}$ ± SEM)	P†
Peak $\dot{V}O_2$ (L/min)	1.60 ± 0.12	1.80 ± 0.10	0.01	1.48 ± 0.14	1.57 ± 0.12	NS
Peak $\dot{V}O_2$ (ml/kg·min)	47.14 ± 1.94	50.49 ± 1.30	0.01	45.92 ± 2.48	48.20 ± 1.61	NS
Peak $\dot{V}E$ (L/min)	41.60 ± 2.38	46.65 ± 3.19	0.03	39.24 ± 3.58	42.54 ± 2.58	NS
Peak heart rate (beats/min)	198.11 ± 2.88	198.38 ± 3.70	NS	194.80 ± 1.89	198.60 ± 3.39	NS

*Paired t analysis.
†Statistically significant ($P \leq 0.05$).

TABLE 3
Comparisons of the baseline and final treadmill test measurements between the experimental (N = 9) and control (N = 10) children*

	Baseline			Final		
Variable	Experimental ($\bar{X}$ ± SEM)	Control ($\bar{X}$ ± SEM)	P†	Experimental ($\bar{X}$ ± SEM)	Control ($\bar{X}$ ± SEM)	P†
Peak $\dot{V}O_2$ (L/min)	1.60 ± 0.12	1.48 ± 0.14	NS	1.80 ± 0.10	1.57 ± 0.12	NS
Peak $\dot{V}O_2$ (ml/kg·min)	47.14 ± 1.94	45.92 ± 2.48	NS	50.49 ± 1.30	48.20 ± 1.61	NS
Peak $\dot{V}E$ (L/min)	41.60 ± 2.38	39.24 ± 3.58	NS	46.65 ± 3.19	42.54 ± 2.58	NS
Peak heart rate (beats/min)	198.11 ± 2.88	194.80 ± 1.89	NS	198.38 ± 3.70	198.60 ± 3.39	NS

*Student's *t* test analysis.
†Statistically significant ($P \leq 0.05$).

Exercise was the only variable altered during the study that would effect metabolic control (i.e., insulin dose, dietary intake, self-monitoring of blood glucose). It appears that the decrease in HbA_1 was mediated by the physical activity program in the experimental group (evidenced by increased peak $\dot{V}O_2$), which was not apparent in the control group. Results of this study suggest that improvements in metabolic control are dependent on the frequency, duration, and intensity of exercise, as it has been shown that glucose utilization depends on these factors.[11] In contrast to the present findings, Larsson et al.[4] found no change in metabolic control, determined by the regular measurement of glucosuria, during 5 mo of regular "rigorous" exercise in adolescent boys with IDDM; however, participation in the exercise program was only once a week. In agreement with our findings, Ludvigsson[1] has shown a significant correlation between metabolic control and an index of physical activity. In addition, Struwe[12] found decreases in insulin need in adolescents with IDDM attending summer camp.

Daneman et al.[13] have reported mean values for HbA_1 in 477 individuals of similar age and duration of IDDM to be 11.8 ± 0.2%. It should be noted that our subjects were not in optimal control, and the results may not apply to individuals who are in better metabolic control. Data on regular home glucose monitoring were not obtained on these children. This information would be beneficial, along with the measurement of stable HbA_1 and simultaneous blood glucose obtained, in providing a more precise measure of metabolic control over the duration of the study. While the 1.2% decrease in HbA_1 in the experimental group is statistically significant, the clinical significance of this change is not known.

In the present investigation, the insulin dosage did not change in either group during the study. Weight loss has been shown to improve insulin binding;[14] however, the experimental group significantly increased their mean body weight during the 12 wk of the study. Recently, Wallberg-Henriksson et al.[15] investigated the effects of physical training on insulin sensitivity, determined by the euglycemic clamp technique, in adults with the IDDM. These investigators found increases in insulin sensitivity with no change in metabolic control as determined by HbA_1 and 24-h urine glucose after 16 wk of physical training. The effects of exercise training on metabolic control and the possible mechanisms involved need further investigation.

It is important to note that only one child experienced hypoglycemia during an exercise session. This child was given juice and returned to play soon after. No other adverse reactions were reported during the 12 wk of the exercise program.

Treadmill testing. The results of the present study indicate an improved peak $\dot{V}O_2$ in the experimental group after the 12 wk of the high-intensity exercise program. The control group did not change their peak $\dot{V}O_2$ significantly during the

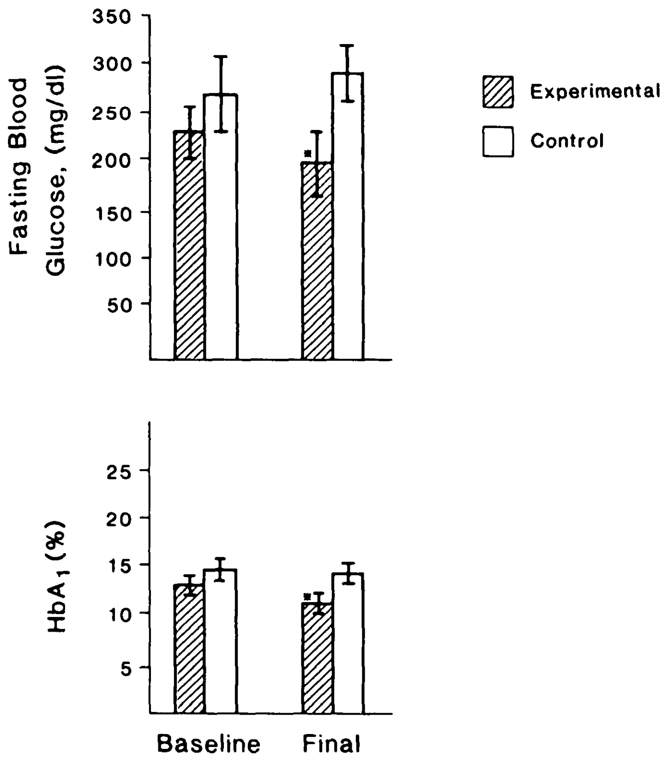

*FIG. 2. Hemoglobin A_1 and fasting blood glucose levels of the experimental and control children before (baseline) and after (final) the 12 wk of the exercise program. *Statistically significant ($P < 0.05$). The final values for the experimental group were significantly different from their own baseline values and from the control group final values.*

study. The peak oxygen consumption values of the diabetic children in the present study were similar to those observed in nondiabetic children of corresponding age.[16,17]

The values for peak $\dot{V}O_2$ in the present study are similar to or slightly lower than those reported by Larsson et al.[4] and Hagan et al.,[18] respectively, for diabetic adolescents. The effects of exercise training on prepubescent children with IDDM have not been investigated previously. The differences between our results and those reported for older individuals could be due to the age-related increase in maximum aerobic power. Similar to our findings, Larsson et al.[4] found significant improvements in peak $\dot{V}O_2$ and physical work capacity (PWC_{170}) in a group of adolescent boys with IDDM after a 5-mo program of regular "rigorous" physical activity. In the present study, that the control group showed some improvement in peak $\dot{V}O_2$ after the study period most likely attenuated the increase in peak aerobic power in the experimental group when the two groups were compared. The increase in aerobic capacity in the control group could be due to the time of year in which the study took place (i.e., an increase in physical activity in the summer months); however, this change is most likely attributable to subjects becoming familiar with the exercise testing equipment.

Previous investigators have found very little change in peak $\dot{V}O_2$ in nondiabetic prepubescent children after exercise training of various types.[16,19-22] In agreement with our results, Brown et al.[23] found a significant increase in peak $\dot{V}O_2$ in a group of prepubescent girls after 12 wk of endurance training; however, there was no control group used to account for possible growth-related changes. Lussier and Buskirk[24] reported a significant increase in peak $\dot{V}O_2$ in a group of prepubescent children after a 12-wk program of regular sustained aerobic activity when compared with an age-matched control group. The differences in the results of these studies could be caused by differences in the physical training programs. The frequency, duration, and intensity of the programs need to be closely monitored in order for comparisons to be made between studies.

Summary and recommendations. Our findings suggest that regular high-intensity physical activity can lead to improvements in metabolic control and cardiovascular fitness in young children with IDDM. Based on these findings, children with IDDM can participate in, enjoy, and benefit from regular vigorous physical activity, with minimal risks.

A similar study on individuals in better control is suggested in order to investigate whether exercise can further improve glycemic control in these individuals. Research is needed to clarify the physiologic mechanisms responsible for improved metabolic control in individuals with IDDM brought about by regular vigorous activity programs.

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