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Marcin Sikora
Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Polan

Anna Zwierzchowska
Department of Special Education, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

Marzena Jaworska
Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Polan

Magdalena Solich Talanda
Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Polan

Rafal Mikolajczyk
Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

See next page for additional authors

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Authors
Marcin Sikora, Anna Zwierzchowska, Marzena Jaworska, Magdalena Solich Talanda, Rafal Mikolajczyk, and Aleksandra Zebrowska

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A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Marcin Sikora[1 ABCEF], Anna Zwierzchowska[2 D], Marzena Jaworska[1 D], Magdalena Solich-Talanda[1 B], Rafał Mikołajczyk[1 B], Aleksandra Żebrowska[1 ADEF]

[1] Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

[2] Department of Special Education, The Jerzy Kukuczka Academy of Physical Education, Katowice, Poland

abstract

Background: Children with type 1 diabetes (T1D) are at high risk of having insufficient physical activity during school days and, thus, the importance of special program in promoting regular physical exercise has been largely emphasized. Therefore, this study examined the levels of physical activity and glycemia control in children with T1D, with particular focus on the relative contributions of regular physical education and physical activity program during the diabetes camp.

Material and methods: Ninety-eight children suffering from T1D for 3.0 ±1.4 years free of diabetic complications participated in the study. Glycemia, insulin doses and diet were monitored, and physical activity was repeatedly measured across school days (GrS) and during the diabetes camp (GrR).

Results: Physical activity of T1D children during the diabetes camp program were significantly higher compared to their regular physical education program GrS ($p < 0.001$). The age of study participants had a significant impact on physical activity, glycemia and daily insulin doses.

Conclusions: Physical activity of children and adolescents with type 1 diabetes is lower compared to reference ranges for healthy population. Our findings highlighted that diabetic camps-based physical activity, in addition to regular physical education classes, could be of heath benefit in children with T1D.

Key words: physical activity, diabetes, health, glucose monitoring.

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Corresponding author: Corresponding author: Prof. nadzw. dr hab. Aleksandra Żebrowska, Department of Physiological and Medical Sciences, The Jerzy Kukuczka Academy of Physical Education, Mikolowska Street 72 A, 40-065 Katowice, Poland; phone no.: +48608418581; e-mail: a.zebrowska@awf.katowice.pl.

INTRODUCTION

Diabetes mellitus is a metabolic disease characterized by high blood glucose caused by the absence or insufficient production of insulin. Type 1 diabetes (T1D) is an autoimmune disease resulting in destruction of β-cells contained in pancreatic islets (islets of Langerhans). Damage to pancreatic β-cells leads to progressive decrease in insulin secretion, and, consequently, to disturbances in carbohydrate, protein and fat metabolism [1–3]. Research has shown T1D has a genetic component increasing the risk of an autoimmune response against β-cells triggered by an inflammatory process [2, 4]. Such an inflammatory response might be modulated by several factors including vitamin D1 deficiency and excess adipose tissue. T1D mainly develops in children and people below the age of 30 [1]. The disease is multifactorial; its pathogenesis is still only partially understood [5].

The majority of findings indicate that children with T1D should participate in regular physical activity as a necessary component of health-related strategies [6, 7]. Regular physical activity may significantly enhance insulin sensitivity [8] and have beneficial effects on metabolism through increases in fatty acid β-oxidation with a simultaneous decrease in their peroxidation [9, 10]. The benefits of physical exercise in T1D children prompt research into physical activity levels and exercise types that regulate glycemic control [11–13]. Evidence suggests that attending a diabetic camp with other youth with T1D may have both psychosocial and medical impacts, largely attributed to sharing active experiences and removing the isolation of those living with diabetes [14–17]. Despite health benefits derived from special program promoting regular physical activity, literature reveals too few children with T1D participate in sport and recreation activities [18, 19]. Therefore, the aim of the present study was to determine the activity levels of children and adolescents with T1D as well as the impact of pre-programmed physical activity during the diabetes camp on glycemic control.

MATERIAL AND METHODS

SUBJECTS

Ninety-eight children with type 1 diabetes were randomly selected from patients of the center of diabetes patients' care and divided into two protocols. The first protocol of the study comprised children attending state schools (GrS) with comparable physical education curricula. The other protocol was performed among children participating in diabetes camps (GrR) organized by the Polish Society for Children and Youth with Diabetes. Medical histories revealed similar duration of the disease with first symptoms approximately 3.0 ±1.4 years prior to the study. All children were treated with recombinant human insulin (NovoRapid Novo Nordisk, Denmark; Lantus SoloStar, Sanofi-Aventis, Germany or Humalog Eli Lilly, Nederland) and were receiving continuous subcutaneous insulin infusion (Medtronic MiniMed Paradigm 715 or 722 insulin pump).

Only patients with HbA1c lower than 7.5%, free of diabetic complications were included in the study. Before the start of the study, after assessment of body composition by the bioimpedance method (InBody220, Biospace, Korea), the study participants and their parents/guardians completed a questionnaire on their medical history and signed their consent to participate in the study after being informed about the experimental procedures. The study was approved by the local Bioethical Committee and conducted in accordance with the Declaration of Helsinki of the World Medical Association.

Physical activity measurements

Physical activity (PA) levels of both groups were determined based on the number of steps per day (steps/day). The other indicator of their physical activity was daily energy expenditure of physical activity (kg/day and kcal/kg/day). The triaxial accelerometer used was the ActiGraph® Monitor (Model GT3X; ActiGraph, Pensacola, CA, USA) [20]. The accelerometer measures acceleration and deceleration in 3 spatial dimensions according to a vertical vector, an anteroposterior vector, and a mediolateral vector. According to recommendations, the children wore a device placed firmly on an elastic belt on the right hip [21, 22]. All children were instructed to remove the device during water-based activities (swimming, showering, and bathing) and overnight. According to consensus recommendations for assessing PA in youth, a minimum of 2 or 3 days measured is needed to estimate weekly usual PA behavior in children and adolescents [21, 22]. In our study the accelerometers recorded activity for 7 consecutive days (5 school days and 2 school-free days) in GrS and for 7 consecutive days of the diabetes camp. The devices were collected after the 7-day monitoring and the data were transferred from the device to a computer.

The PA level, glycemia, total daily insulin dose and diet were compared in four age subgroups, ie., below 10 years, 10 to below 12 years, 12 to below 14 years and over 14 years. The characteristics of the GrR and GrS groups are presented in Table 1.

Table 1. Somatic parameters, glycemia, daily insulin dose and physical activity in the study groups

Variables	GrR n = 72	GrS n = 26
Age [years]	13.4 ±2.01	11.36 ±3.08
Body height [m]	1.6 ±0.11	1.51 ±0.15
Body weight [kg]	52.8 ±13	43.7 ±13.5
BMI (kg/m^2)	18.9 ±2.3	19.8 ±1.8
BMI centile	54.5 ±23.2	51.1 ±22.1
Mean glycemia [mg/dl]	134 ±35.1	126.33 ±28.9
Mean total daily insulin dose [U/kg/day]	0.31 ±0.21	0.18 ±0.13
HbA_{1c} before the study	7.02 ±0.4	7.1 ±0.4
Mean number of steps per day	15413 ±6053	9956 ±3995***
Energy expenditure [kcal/day]	498.0 ±196.5	322.0 ±129.5**
Energy expenditure [kcal/kg/day]	9.6 ±3.7	7.4 ±2.9**

*Statistically significant differences GrS vs GrR: **p < 0.01;***p < 0.001*

Blood glucose monitoring

During the study all participants performed self-monitoring of blood glucose levels under glycemic control on a prescribed schedule at least 6 times per day (pre meal, 2 hours postprandial and before retiring to bed) with a glucose meter (ACCU-CHECK Performa, Roche Diagnostics, GMBH, Germany). Subjects recorded results of insulin dosages and consumption of diet. Blood glucose levels were also determined before and after physical effort according to the guidelines on the management of diabetic patients [6]. The frequency and times of additional measurements were individually adjusted. According to the guidelines, insulin doses were individually determined for each study participant [6]. The mean insulin dose (mean of all boluses administered on seven consecutive days of the week) and mean blood glucose (mean of all measurements performed on seven consecutive days of the week) were calculated. The analysis of variance also included the mean total daily insulin and the mean daily blood glucose. In all participants, the concentration of glycated hemoglobin (HbA1c) was analyzed by Ames DCA-2000TM Immunoassay Analyzer at baseline and one week after the both protocols were performed.

Diet assessment

For the entire duration of the experiment, all subjects were asked to list all the foods and drinks consumed. The amount and caloric value of particular nutrients was individually determined for each child with dedicated software (Dietus, B.U.I. InFit. Warsaw, Poland).

All study participants and / or their guardians noted the amount and the type of ingested foods (weight of particular nutrients [g] and corresponding caloric value [kcal]). Based on these records, dietary status was determined. Each child's diet was also compared to the recommended daily nutrient intake.

Statistical analysis

Statistical analysis was carried out with Statistica 13.1 (StatSoft). The results are presented as arithmetic means and standard deviations. The effects of particular factors (number of steps, total daily insulin dosage, mean blood glucose concentration etc.) on the study variables were determined using multifactorial repeated measures ANOVA. Significant differences in glucose homeostasis, insulin doses and physical activity were analyzed with Tukey's post-hoc test. The level of significance was set at $p < 0.05$.

Results

Children from the GrS accumulated an average of 9956 ±3995 steps/day while the average activity-induced energy expenditure was 322.0 ±129.5 kcal/day and the relative energy expenditure was 7.4 ±2.9 kcal/kg/day. The mean number of steps per day during daily PA at school (GrS) was low compared to recommended values (Table 1). Analysis of variance revealed a significant effect of physical activity program during diabetes camp on daily steps and daily energy expenditure ($F = 3.89$; $p < 0.05$). The mean number of steps and the relative energy expenditure in the GrR group (15.413 steps/day ±6.053; 9.6 ±3.7 kcal/kg/day, respectively) were significantly higher compared to that of the GrS group ($p < 0.01$). Physical activity of T1D children met the current recommendations during the diabetes camp program.

ANOVA revealed a significant effect of age on mean steps/day ($F = 1.1$; $p < 0.05$). Significantly higher physical activity was observed in GrR and in the subgroups of >10 years compared to GrS subgroups (Table 2).

Table 2. Glycemia, total daily insulin dose and physical activity (as determined by the number of steps) in the age subgroups

	Age subgroup							
	GrS	GrR	GrS	GrR	GrS	GrR	GrS	GrR
N	8	5	8	19	6	27	3	21
Number of steps	11481 ±3683	14978 ±3054	9375 ±4678*	15571 ±5275	9838 ±2660*	13005 ±6244	7896 ±3341**	13467 ±5105
Glycemia [mg/dl/day]	129 ±26	128 ±26	122 ±35	129 ±28	136 ±28	129 ±32	122 ±20	137 ±39
Insulin dose [U/kg/day]	0.12 ±0.11	0.23 ±0.16	0.17 ±0.11	0.21 ±0.2	0.22 ±0.13	0.33 ±0.13	0.31 ±0.15	0.38 ±0.28

*Statistically significant differences GrS vs GrR: *p < 0.05; **p < 0.01*

The mean blood glucose in the GrS group was 126.33 ±28.9 mg/dl, i.e. lower than in the GrR group (134 ±35.1 mg/dl). ANOVA did not reveal any effect of the group (GrS vs. GrR) or age on blood glucose levels. Despite the lack of statistically significant differences, it can be observed that the oldest GrR participants (> 14 years) had the biggest problem with achieving and maintaining glycemic control. The mean total daily insulin doses increased with age. No significant differences were noted between GrS and GrR; however, the latter group used higher doses. Statistically significant differences in insulin use were revealed between age subgroups in the GrS and GrR groups ($F = 0.51$; $p < 0.05$) as well as between the GrS and GrR groups ($F = 0.78$; $p < 0.05$). The oldest GrR participants (> 14 years) had the highest daily insulin dose (0.38 U/kg/day). It seems important to emphasize differences between age subgroups in GrS and GrR. The mean total insulin dose in the youngest GrR subgroup (< 10 years) was by 0.1 U/kg higher compared to their GrS counterparts. The biggest difference was noted between the subgroups of 12–14 years; total daily insulin doses were higher by 0.12 U/kg than in the GrR.

Diet

No statistically significant differences in the caloric value of nutrients were found between the groups although a tendency towards higher energy intake was noted in the GrS (Table 3).

Table 3. Differences in protein, fat and carbohydrate intake (%) relative to dietary reference intake GrS and GrR

	Recommended daily nutrient intake	
Protein [%]	4.71 ±1.1	2.57 ±1.5
Fat [%]	3.85 ±1.2	8.85 ±2.1**
Carbohydrate [%]	-12.07 ±2.0	-15.03 ±2.1

*Statistically significant differences GrS vs GrR: **p < 0.05*

ANOVA confirmed a significant effect of group and day on the recommended daily protein intake ($F = 2.1$; $p < 0.05$). GrS showed a tendency towards higher protein intake (4.71%) compared to GrR (2.57%). There was a significant difference between the group and recommended daily fat intake ($F = 15.13$; $p < 0.05$). Fat intake in the GrR group was higher than the dietary reference intake; it was also higher compared to the GrS participants ($p < 0.01$). Our findings revealed a significant effect of the day on fat intake, the highest being observed on Sunday (GrR vs GrS; $p < 0.05$). Carbohydrate intake was by 12% (GrS) and 15.28% (GrR) lower compared to the dietary reference intake. No relationship was found between carbohydrate intake and group or day (Table 3).

DISCUSSION

The main findings in this study are that children with T1D are at high risk of having low physical activity during their regular physical education. Increased activity observed during the diabetes camp confirms good exercise tolerance among T1D children and the need for programmed physical activity performed on a daily basis to prevent diabetes-related complications. A lower mean number of steps and relative energy expenditure were measured in adolescents (>12 years) compared to younger children. This might confirm the greatest importance of conducting additional motor activities in this age group in the prevention of diabetic complications.

In a previous study, Åman et al. [23] emphasized sedentary behavior of children and adolescents with T1D and agreed that time spent watching television and on computer should be limited to no more than 2 hours per day [23]. Other reports on physical activity of children with T1D also accentuate the importance of programmed physical activity during the diabetic camps [24, 25]. Camps for youth with type 1 diabetes (T1D) have grown in size and scope since they first emerged [14, 15]. The medical and motor development outcomes associated with diabetic camp attendance were evidenced in the previous research [24, 25, 26]. However, children participating in the movement games and activities benefited from the supportive and educational camp atmosphere [14, 15].

When comparing our findings to indices proposed by Tudor-Locke et al. [27] for boy and girls of different age groups (Table 4), we found a significantly lower number of steps in the GrS group ($p < 0.05$) whereas the number of steps in the GrR group was significantly higher ($p < 0.05$).

Table 4. Physical activity based on the number of steps per day [27]

Physical activity		
Recommended number of steps	11,000-12,000	13,000-15,000
Recommended energy expenditure (kcal/kg/day)	> 9 kcal/kg/day	>11 kcal/kg/day

Our results showing low physical activity of diabetic children are comparable to those of other authors [24–25]. In a study by O'Neill et al., the mean number of steps per day was by 40–50% lower compared to reference ranges [28]. This study is a sequel to that of Zebrowska et al., which was determined to analyze the energy expenditure associated with the programmed physical activity which is effective for maintaining normoglycemia in children with type 1 diabetes [29]. The main observation made in this study was that programmed physical activity significantly increased daily energy expenditure; however, it may also increase the risk of hyperglycemia. It was also emphasized that greater physical activity seemed to provide more effective control of glucose homeostasis as demonstrated by reductions in HbA1c; however, a more detailed description of the mechanism of glycemia control in response to exercise training in different age groups was not presented.

It was also suggested in the study by Newton et al. that patients with T1D had higher mean daily step counts than those noted in our study, but still did not reach the target of approximately 10,000 steps per day [30]. Newton et al. aimed to motivate their intervention participants with T1D to increase physical activity through using an open pedometer (the number of steps could be monitored) and weekly motivational text messages reminding about the goal number of 10,000 steps to be taken daily. The results were compared with the control group. Pedometers and text messaging did not increase physical activity over a 12-week period [30].

Physical activity, blood glucose level and total daily insulin dose

High levels of physical activity observed in the GrR group confirm the importance and value of diabetes camps as a form of rehabilitation, and especially for children over the age of 14 years. It is this age subgroup whose levels of physical activity were the highest among GrR and the lowest among GrS participants. However, there was also a worrying tendency towards increased insulin use in all age subgroups (GrS vs. GrR). Total daily insulin doses increased with age in both study groups. The increase was more pronounced in GrR although blood glucose levels were comparable in the GrR and GrS groups. This might indicate inability to adjust insulin doses to increased energy expenditure. Hence the conclusion that continued patient education regarding this issue is indispensable [31–33].

The well-documented benefits of physical activity in patients with T1D include improvements in insulin sensitivity, insulin dose reduction, an increase in glucose transport and glucose utilization in energy-requiring processes [13, 32]. Thus, glycemic control is improved and development of diabetes complications delayed.

Training has been shown to enhance processes initiated by a single bout of exercise (9). The efficacy of regular physical exercise as an adjunct to diabetes management was confirmed by a study of Gunasekera and Ambler, who analyzed glycemic control during 10 consecutive diabetes camps held for five consecutive years [24]. At the end of camp, mean insulin doses decreased by 19.2% relative to the day prior to the camp. Mean blood glucose was also significantly decreased. However, there is a discrepancy between the results of Gunasekera and Ambler [24] and ours, as we found an increase in the mean insulin dose while blood glucose levels were comparable in both study groups. The discrepancy may be attributed to a shorter observation period in our study. As already mentioned, they analyzed glycemic control during 10 consecutive diabetes camps held for five consecutive years whereas our data was obtained during three camps held for two years.

D’hooge et al., on the other hand, evaluated the effect of combined exercise training (aerobic and strength) held twice a week for 20 weeks (each exercise session lasted 70 minutes) [18]. The study group was then compared to the control. Glycemia and HbA1c did not differ significantly between the groups while daily insulin doses decreased significantly in the training group. The authors believe that the lack of intergroup differences regarding glycated hemoglobin could be due to additional carbohydrate intake associated with frequent hypoglycemic episodes, not only during the training but also up to 12 hours following its completion.

Our findings are also not fully consistent. Despite increased physical activity of the GrR group, we did not observe a decrease in the mean blood glucose level while the total daily insulin dose increased significantly. This may have resulted from inadequate dietary adjustments taking into consideration increases in physical activity and difficulty with insulin dose calculation. Hence a need for comprehensive patient education in this respect [7, 31–33].

Importance of diet in the prevention and management of type 1 diabetes

Glycemic response and physical activity of children with T1D should be analyzed in relation to their diet [34–36]. Our study groups were found not to adhere to dietary recommendations for individuals with type 1 diabetes. Relative to reference recommendations, protein intake was higher by 4.71% and 2.57 % in the GrS and GrR groups, respectively, while fat intake was higher by 3.85 % (GrS) and 8.85 % (GrR). Interestingly enough, both groups had a lower carbohydrate intake compared to the reference intake. Despite the generally accepted diabetes nutrition principles, a lot of patients have problems with dietary adherence, and especially children and adolescents.

Our findings show that the intake of particular nutrients in the GrS group differed from dietary recommendations mainly at weekends. Similar results were presented by Helgeson et al., who compared the dietary intake of adolescents with type 1 diabetes with that of their healthy counterparts [36]. They concluded that adolescents with type 1 diabetes consumed more calories from fat than nondiabetic adolescents; furthermore, they exceeded the recommended levels of fat intake. The authors also emphasized that such dietary behaviors increased the risk for cardiovascular disease.

Galli-Tsinopoulou et al. observed that their diabetic participants consumed a diet high in fats and proteins [31]. In healthy people, protein-rich meals do not result in marked increases of blood glucose (11) but stimulate secretion of glucagon, which, in turn, enhances gluconeogenesis [37]. However, in diabetic patients, extra protein may lead to hyperglycemic episodes [38]. Protein does not slow the postprandial absorption of carbohydrates; therefore, adding protein to a meal does not reduce the risk of nocturnal hypoglycemia. It is believed that protein and fat do not directly increase blood glucose; rather, they modify carbohydrate absorption. However, clinical practice seems to indicate that increased protein and fat consumption by patients with absolute insulin deficiency increases their demand for exogenous insulin [35].

Increased fat consumption by diabetic patients causes delayed gastric emptying thus diminishing the early glycemic response. Hence, the type and dose of preprandial insulin may need to be adjusted to excess fat content of the meal to reach postprandial normoglycemia [39]. As already mentioned, compliance with dietary reference intakes tends to be a challenge for many patients with T1D. Mehta et al. pointed out that despite routine nutrition counseling, patients found it difficult to balance the qualitative and quantitative aspects of healthful nutrition [40].

Our findings lead to similar conclusions. High levels of physical activity in the GrR group should cause a decrease in the mean insulin dose and the mean blood glucose level. The lack of such a relationship may indicate that our study participants consumed some extra carbohydrate portions which they did not report to their guardians. Franz et al. also noted that high fat consumption might be a substitute for carbohydrate restriction in patients fearing problems with glycemic control due to high carbohydrate intake [35]. Therefore, some patients try replacement of carbohydrates by healthy fat.

Considering low physical activity of children with T1D, programmed workouts seem a good way to increase motivation for regular exercise. Participation in diabetes camps might positively affect metabolic control in diabetic patients. It also helps develop movement habits and enhance treatment process following camp completion. The present data confirms that in order to minimize a higher risk of glycemia complications associated with exercise, a properly designed exercise program for people with diabetes should include different exercise regimen [11, 41–43]. Education in and emphasis on dietary adherence is indispensable. Diabetes treatment should be based on the patient's response to physical exercise, diet and insulin therapy and balance between these three [44, 45].

A limitation of this research were difficulties in maintaining full control over diet by the examined children and adolescents.

CONCLUSIONS

Physical activity of children and adolescents with type 1 diabetes is lower compared to reference ranges for healthy population although high levels of physical activity noted at diabetes camps seem to evidence good tolerance of physical exercise. The age of study participants had a significant impact on glycemic control. Patients should receive more education about adjusting diet and insulin therapy to increased physical activity and its influence on their body.

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