Effect of Strength Training on Glycemic Control and Adiponectin in Diabetic Children

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1Department of Physical Medicine and Rehabilitation, Danube Hospital Vienna, AUSTRIA; 2Department of Pediatric, Danube Hospital, Vienna, AUSTRIA; 3Department of Chemistry, Danube Hospital, Vienna, AUSTRIA; and 4Institute of Sport Science, Department of Prevention—Rehabilitation and Science of Training, University of Vienna, Vienna, AUSTRIA

ABSTRACT

PETSCHNIG, R., T. WAGNER, A. ROBUBI, and R. BARON. Effect of Strength Training on Glycemic Control and Adiponectin in Diabetic Children. Med. Sci. Sports Exerc., Vol. 52, No. 10, pp. 2172–2178, 2020. Purpose: This study aimed to examine the effect of isolated supervised progressive resistance training with duration of more than 32 wk on muscle strength, metabolic control and adiponectin. Method: Twenty-one children with type 1 diabetes mellitus were separated into an intervention group (IG) (n = 11 age 11.0 ± 0.8) and a control group (CG) (n = 10 age 11.30 ± 0.7) without training to control for the effect of progressive resistance training on muscle strength, hemoglobin (HbA1C) and adiponectin. All parameters were assessed before and after a period of 32 wk. No attempt was made to change diet and the daily behaviors during the study in both groups. Results: After a period of 32 wk, upper and lower limb strength increased significantly (P < 0.05) in the IG, whereas no changes occurred in the CG. In the IG, HbA1C decreased significantly after 32 wk but not after 17 wk (P < 0.00), whereas HbA1C increased in the CG (P < 0.007). Adiponectin increased significantly (P < 0.000) only in the IG. Self-monitored blood glucose levels, measured before and after each session, showed a significant reduction (P < 0.00) of 26.5% ± 4.4% after each session. Effect size (ES) for the strength training on limb strength was medium (d = 0.464 to d = 0.661), the ES for strength training on HbA1C (d = −1.292) and the ES for strength training on adiponectin (d = 1.34) was large. There was no hypoglycemia as the result of training. Conclusions: An isolated supervised progressive resistance training two times a week in children with type 1 diabetes mellitus must last at least 32 wk to get a significant decrease in blood glucose level HbA1C. In addition, exercise-induced increase in adiponectin improves insulin sensitivity. Key Words: TYPE 1 DIABETES, METABOLIC CONTROL, INSULIN SENSITIVITY, MUSCLE POWER, ADIPOCYTOKINES, ISOLATED SUPERVISED PROGRESSIVE RESISTANCE TRAINING

The incidence of insulin-dependent diabetes mellitus has increased especially in children and adolescents younger than 15 yr. In children with type 1 diabetes mellitus who had died a natural death, an asymptomatic increase in the intima media thickness (IMT) of the common carotid artery was found (1). Exercise has been accepted to play a key role for the management of type 1 diabetes mellitus. There is evidence that exercise improves physical fitness, lipids, macrovascular risk, and insulin sensitivity in people with type 1 diabetes mellitus (2). Some investigators stated that insulin sensitivity is positively correlated with adiponectin levels (3–6). Kim et al. (3) speculates that exercise-induced improvement in insulin sensitivity is mediated through regulation of plasma adiponectin levels. Fatouros et al. (4) found independent of diet intervention an increase in adiponectin levels due to resistance training and a positive correlation with insulin sensitivity. In his opinion, this may be attributed to an enhancement of insulin sensitivity caused by resistance training. It is not certain whether an increase of insulin sensitivity suggests that in the management of type 1 diabetes mellitus, exercise training would be a valuable adjunct that may improve glycemic control (7). However, the results of studies on exercise and glycemic control are conflicting. Most studies in children with type 1 diabetes mellitus that evaluated the effect of exercise on metabolic control used aerobic training (8–13). There are few studies in children with type 1 diabetes mellitus that evaluated the effect of exercise on metabolic control used aerobic training (8–13). Yardley et al. (16) and Ramalho et al. (17) evaluated the effect of aerobic versus resistance training on metabolic control in adolescents with type 1 diabetes mellitus. Yardley et al. (16) found that resistance exercise causes less initial decline in blood glucose during the activity but is associated with more prolonged reductions in postexercise glycemia than aerobic exercise. In contrast, Ramalho et al. showed that neither resistance training nor aerobic training did improve glycated hemoglobin in type-1 diabetes patients. Durak et al. (18) investigate whether isolated strength training in patients with type 1 diabetes mellitus has a positive effect on metabolism and found that heavy-resistance strength training may be associated with a decrease in glycylated hemoglobin.
in type I diabetic men after training. However, these studies have only evaluated adolescents or adults with type 1 diabetes mellitus. To our best knowledge, this is the first study that investigates the effect of isolated supervised progressive resistance training on metabolic control in children with type 1 diabetes mellitus. In the United States, the number of health club members between the ages of 6 and 17 yr continues to increase (19). Taking into account that young people prefer gyms for resistance training, this evaluation becomes even more important not only for healthy children but also for children with type 1 diabetes mellitus. Unfortunately, there is a lack of information whether isolated strength training has the same acute and long-term effects on the glycemic control and adiponectin in children with type 1 diabetes mellitus as in adults. Therefore, it was obvious to evaluate the effect of isolated supervised resistance training in children with type 1 diabetes mellitus on metabolic control, cardiovascular fitness, muscle strength, and adiponectin and insulin sensitivity.

**Study hypothesis.** We hypothesized that similar to endurance training, regular isolated supervised progressive resistance training adapted to individual performance in children with type 1 diabetes mellitus improves hemoglobin (HbA1c) levels and physical fitness. Additionally, we hypothesized that progressive resistance training has a positive effect on adiponectin levels.

### RESEARCH DESIGN AND METHODS

#### Recruitment of Subjects

The present study was conducted in accordance with the Declaration of Helsinki (as revised in Edinburgh 2000) and was approved by the Ethics Committee of the city of Vienna (Austria). From the invited 65 children between 8 and 12 yr with type 1 diabetes mellitus who are treated regularly at the Department of Pediatric of the Danube Hospital Vienna 46 were assessed for eligibility. Seventeen children were excluded. Of the remaining 29 children, 8 children dropped out during the 32-wk program. This makes a final total of 21 individuals from whom we were able to complete all tests and receive all measured parameters (Fig. 1). They were divided randomly in an intervention group (IG) who performed supervised progressive resistance training (SPRT) twice a week for 32 wk (n = 11) and a control group (CG) without training (n = 10). The children in both groups did not change diet and the daily behaviors during the study. All children had been diagnosed as having type 1 diabetes mellitus for at least 6 months before the study and had no complications that would contraindicate participation in a physical activity program. All children were on a mixed split-dose insulin regimen consisting of both regular and long-acting insulin in the morning and evening. Currently or recently (within the last 3 wk), ill and currently or recently (within the last 6 months) operated or injured subjects were excluded. To be included in the study, subjects had to meet certain criteria. No regular sport more often than once per week and sports lessons in school not more than twice a week, age 8 to 12 yr and no contraindications for training. All participants were informed comprehensively about purpose, procedures, benefits, risks, and discomfort that might result from study participation, as well as the right to terminate participation at will, before they gave written consent to participate in the study. A letter of agreement had to be signed by the participant’s parents or guardians and all participants took part voluntarily. No dietary guidelines were given to make the study practicable.

#### Intervention

A medical preliminary assessment was done by a member of the medical staff to reveal any acute impairment to health. A standardized pediatric, internal, and orthopedic examination included a history questionnaire. Body weight and height were

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**FIGURE 1**—Flowchart of data collection process.
assessed and the body mass index (BMI) calculated. Blood pressure and blood samples were taken. After performing an echocardiogram the left common carotid artery was scanned. All interventions, measurements, and the acquisition of the data took place at the Department of Pediatric, Department of Chemistry and the Institute of Physical Medicine and Rehabilitation at the Danube Hospital Vienna. Blood samples, cardiovascular fitness, muscle strength of the upper and lower extremities, and adiponectin were assessed before and after an intervention period of 32 wk. In addition, after 17 wk, HbA1c was measured again. Our test battery (preintervention and postintervention) included a 6-min run/walk test, strength measurements of the upper and lower extremities, and was guided and closely supervised by a doctor with a sport medical diploma and an appropriately trained and experienced sport scientist to ensure safety and compliance. Tests were conducted at the same time of the day, using the same equipment and subject positioning, as well as standardized instructions. A few days before strength testing all participants were familiarize with the testing procedures and were able to maintain a safe and controlled technique. On a separate visit, all participants were tested in a similar manner both before (baseline) and after (final) the experimental phase of the study.

Measurements

Standardized strength testing provides an opportunity to assess initial strength levels, to develop individualized programs, and to monitor progress. Many of the exercise tests for children and adolescents are similar to those for adults but they must be adapted and interpreted to the child (e.g., selection of devices, age-appropriate explanation of the test). Our test battery included one endurance and three strength tests.

Endurance test: 6-min run test. All participants performed a standardized, self-paced 6-min run test (RUN) in a 30-m-long corridor. They were asked to cover as much distance as possible within 6 min. Participants were allowed to stop at every moment of the test, but were encouraged to restart as soon as possible. The distance covered after 6 min was measured to the nearest meters.

Strength tests. Seated bench press (BP), seated bench pull (BPU), and seated leg press (LP).

Detailed descriptions of strength measurements with reported validity and reliability have been published elsewhere (20). Briefly, we used a dynamometer (Concept 2 Dyno, Vienna), which allows assessment of three common multijoint exercises (BP, BPU, LP). For each exercise, the subjects performed three low-intensity repetitions and, immediately after, three maximal effort repetitions, according to the manufacturer’s guidelines. The best score measured in W·kg⁻¹ from the maximal effort repetitions was recorded and used for subsequent analysis.

Blood Chemistry

Venous blood samples were taken by trained personal before the onset of the 32-wk training program and 48 h after the last exercise session. In addition, after 17 wk, HbA1c was measured again. Blood specimens were collected with subjects in a sitting position in the morning after overnight fasting. Blood was collected in Greiner bio-one Vacutace–EDTA/heparin tubes (Greiner Holding AG, Kremsmünster, Austria). Plasma was frozen (−80°C) immediately until analysis. HbA1c were measured according to standard procedures, adiponectin levels were measured with a commercial ELISA kit (KA0025 and KA0017; Abnova, Taipei, Taiwan). Blood glucose was determined before and after each exercise session using blood drawn by finger sticks. The parents were instructed to register the glycemia control for the next 8 h after the end of the training to avoid hypoglycemia.

Echocardiogram and Left Common Carotid Artery

We performed the examination using a 12-MHz linear array transducer (Vivid S6/GE) after a rest of 10 min in supine position. The image was focused on the posterior wall. Then, a zoom was used to record the images. A moving scan of 5-s duration was taken (from the beginning of the carotid bifurcation and the common carotid artery. From this image, three measurements were taken and the mean distance was calculated. The IMT was defined as the distance between the leading edges of the lumen–intima interface and the media-adventitia interface of the far wall.

Dietary Assessment

In accordance with the recommendation of Fatouros et al. (4), no attempt was made to change diet and the daily behaviors during the study. The experimental design simulated a “real life” situation in which the participants injected their normal dose of insulin and consumed their typical breakfast and lunch before the performance of exercise.

Trainings Protocol

Because there are no recommendations for strength training with children with type 1 diabetes mellitus, we used the recommendations for strength training with healthy children (21). The intervention started with an adaptation phase of 4 wk to familiarize participants with the protocol, the equipment and to learn the effective strength training techniques. All training machines were designed for children (Gym Boy by Teca, Italy). After the adaptation phase, the individualized exercise intervention was designed to train all major muscle groups. Training was performed twice a week separated by at least 48 h for 32 wk. Each training was guided and closely supervised by appropriately trained experts. Before starting exercise according to Riddell (22), participants were required to have blood levels between 6.5 and 15.5 mmol·L⁻¹ (115–280 mg·dL⁻¹). If the level was below 6.5 mmol·L⁻¹ (115 mg·dL⁻¹), the participants were provided with 16 g of glucose and glucose levels were checked again 15 min later. If the level was above 15.5 mmol·L⁻¹ (280 mg·dL⁻¹) training was not permitted. After each training, the blood glucose levels were registered again, and if the level was below 6.5 mmol·L⁻¹
(115 mg·dL⁻¹), the participants were provided with 16 g of glucose and glucose levels were checked again 15 min later. We started with 30% of the one-repetition maximum (1 RPM) on each machine. Proper technique was emphasized at all times over the amount of weight lifted or the number of repetitions achieved. Exercise was stopped when the quality of technical execution starts to break down. The rate of progression was based on individual improvements. Intensity was controlled and changed when necessary on a fortnightly basis. Each session lasted 50 min and consisted of a 10-min warm-up, 20- to 40-min circuit training and was completed by a cool-down routine. According to previous studies (23), the intervention was organized in a circuit program of eight stations. Between two cycles a resting period of 180 s was advised. Each station consisted of an exercise lasting from 25 to 40 s (extended progressively from the first session to the last), and the rest time between them was of 40 to 30 s (gradually reduced during the program). The increase of work time and the decrease of rest time during the intervention were based on the training load progression principle. Applying these repetitions was perceived to provide sufficient stimuli for simultaneous improvements in muscular strength, which was thought necessary to achieve improvements.

Data Analysis

All statistical analyses were performed using SPSS (IBM SPSS Statistics, Version 22, Chicago, IL). Data are presented as group mean values ± SD. Baseline measurements were compared between groups using either Student’s unpaired t tests (parametric data) or Mann–Whitney U tests (nonparametric data). To evaluate significant pre–post differences within groups, paired samples t-test or Wilcoxon test was performed. Normality was tested using Kolmogorov–Smirnov tests. Cohen’s d statistics (24) were used for calculating mean effect sizes (ES) as follows: small $d = 0.3$, medium $d = 0.5$, and large $d = 0.8$. The ES is a measure of the effectiveness of a treatment and it helps to determine whether a statistically significant difference is a difference of practical concern. A $P$ value less than 0.05 was considered to be statistically significant.

TABLE 1. Participant characteristic: Intervention group and control group

<table>
<thead>
<tr>
<th>Participants</th>
<th>Intervention Group (n = 11), Mean ± SD</th>
<th>Control Group (n = 10), Mean ± SD</th>
<th>Significance, $P &lt; 0.05$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>11.00 ± 0.8</td>
<td>11.30 ± 0.7</td>
<td>n.s.</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>154.18 ± 3.2</td>
<td>149.70 ± 8.6</td>
<td>n.s.</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>46.23 ± 10.1</td>
<td>44.96 ± 15.8</td>
<td>n.s.</td>
</tr>
<tr>
<td>BMI (kg·m⁻²)</td>
<td>19.26 ± 2.4</td>
<td>19.55 ± 4.2</td>
<td>n.s.</td>
</tr>
<tr>
<td>HbA₁c (%) NGSP</td>
<td>8.75 ± 1.3</td>
<td>7.84 ± 1.3</td>
<td>n.s.</td>
</tr>
<tr>
<td>IFCC (mmol·mol⁻¹)</td>
<td>72.90 ± 14.2</td>
<td>62.90 ± 14.2</td>
<td>n.s.</td>
</tr>
<tr>
<td>Adiponectin/BMI</td>
<td>0.78 ± 0.19</td>
<td>1.00 ± 0.35</td>
<td>n.s.</td>
</tr>
<tr>
<td>Duration (yr)</td>
<td>2.63 ± 1.85</td>
<td>2.80 ± 2.07</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

NGSP, National Glycohemoglobin Standardization Program; IFCC, International Federation of Clinical Chemistry. Adiponectin/BMI, adiponectin adjusted for BMI; Duration, duration of diabetic history; n.s., not significant.

RESULTS

All children completed the tests and exercises without incident. At baseline, there were no significant differences between two groups in all parameters measured. The baseline characteristics of the participants are given in Table 1.

Physical fitness. Fitness data at the baseline of the two groups did not differ when expressed in relative terms (W·kg⁻¹). After the intervention period of 32 wk, upper and lower limb strength increased significantly ($P < 0.05$) in the IG, whereas no changes occurred in the CG. The test results are given in Tables 2 and 3. The ES for the strength training for all three exercises was medium, whereas no effect was found for the run test. The greatest effect was found in the lower limb strength (LP, $d = 0.729$; BP, $d = 0.661$; BPU, $d = 0.464$; RUN, $d = 0.238$).

Metabolic control. In the CG HbA₁c (expressed in % and mmol·mol⁻¹) at the baseline increased significantly after 17 wk as well as after 32 wk follow-up. In the IG, HbA₁c (expressed in percent and millimoles per mole) at baseline did not change after 17 wk of training, but after 32 wk of training the HbA₁c decreased significantly. Test results are given in Table 4. The ES for HbA₁c ($d = -1.292$) was large, indicating a great practical importance of strength training on metabolic control in children with type 1 diabetes mellitus.

Acute glycemia in the intervention group. Self-monitored blood glucose levels, measured before and after each session, showed a significant reduction (169.32 ± 18.39 mg·dL⁻¹ to 123.78 ± 17.18 mg·dL⁻¹ $P < 0.00$) or 26.5% ± 4.4% after each session.

Effects on adiponectin. Adiponectin/BMI did not change significantly during the intervention period in the CG (1.00 ± 0.35 to 1.11 ± 0.324 $P < 0.166$) but increased significantly (0.78 ± 0.19 to 1.02 ± 0.17 $P < 0.000$) in the IG. There is a large ES ($d = 1.34$) for strength training on adiponectin.

Echocardiogram and left common carotid artery.

We could not detect any pathology for IMT. There were no significant differences between the two groups (CG, 0.39 mm; IG, 0.44 mm).

DISCUSSION

To the best of our knowledge, this is the first study that has evaluated the effect of 32 wk of isolated SPRT on physical fitness, blood glucose levels (acute glycemic control), HbA₁c (chronic glycemic control), and adiponectin in children with type 1 diabetes mellitus. Because there are no recommendations for strength training with children with type 1 diabetes mellitus, we used the recommendations for strength training with healthy children (19,25). The National Strength and Conditioning Association recognizes and supports the premise that many of the benefits associated with adult resistance training programs are attainable by children and adolescents who follow age-specific resistance training guidelines (26). Furthermore, there

TABLE 2. Fitness data at the baseline.

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>LP (W·kg⁻¹)</th>
<th>BP (W·kg⁻¹)</th>
<th>BPU (W·kg⁻¹)</th>
<th>RUN (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IG</td>
<td>11</td>
<td>5.26 ± 2.63</td>
<td>1.60 ± 0.61</td>
<td>1.73 ± 0.54</td>
<td>930.90 ± 128</td>
</tr>
<tr>
<td>CG</td>
<td>10</td>
<td>5.46 ± 1.99</td>
<td>1.61 ± 0.27</td>
<td>1.78 ± 0.64</td>
<td>863.40 ± 182</td>
</tr>
</tbody>
</table>

Significance n.s., n.s., n.s., n.s., n.s.
is no evidence to suggest that resistance training will negatively impact growth and maturation during childhood and adolescence (27). In 2007, Benson et al. (28) performed a high-intensity progressive resistance training in obese children and found it safety and health-related benefits. Also, in our study, all children completed the tests and exercises without incident.

**Physical fitness.** Ludvigsson et al. (29) has shown a significant correlation between an index of physical activity in children and adolescents and metabolic control. Benson et al. (30) identified muscular strength as an independent and powerful predictor of better insulin sensitivity in obese children age 10 to 15 yr. Therefore, it was obvious to detect whether children with type 1 diabetes mellitus also have a benefit in metabolic control through resistance training.

According to Faigenbaum et al. (19) gains of roughly 30% are typically observed after short-term resistance training program in healthy children. In accordance with Faigenbaum et al., we also found significantly improvement ($P < 0.05$) of the strength in our collective (given in watts per kilogram) on the upper extremity (9%–16.5%), as well as on the lower extremity (25%), in the training group, whereas no changes occurred in the control group. The difference in strength to Faigenbaum et al. (19) could be explained by the different collectives (healthy children versus children with type 1 diabetes mellitus) and equipment used (training machines were designed for children) and in the different nature of exercise training. In accordance with literature (23,31) improvement in strength could be explained with neural adaptations, for example, changes in motor unit coordination and recruitment, and intrinsic muscle adaptations.

**Acute glycemic control—chronic glycemic control.** The role of physical exercise as a therapeutically useful tool in diabetes management has been recognized for centuries in the metabolic control of diabetes in children (9). But there are still conflicting data from studies dealing with the question whether exercise training can improve glycemic control in children and adolescents with type 1 diabetes mellitus regardless of the type of training. Most studies that evaluated the effect of exercise on metabolic control in type 1 diabetes mellitus used aerobic training (7–10,12,13). There are few studies with mixed exercise in aerobic combined with resistance training (14,15,17) or regular “rigorous” exercise (32).

Some clinical trials documented beneficial effects of exercise on glycemic control (8,9,14). On the other side, many studies showed no improvement in glycemic control after physical activity (7,10,12,13,15,17,32). There are a number of potential explanations for these different results. Inadequate reporting of exercise intensity, duration, and frequency in the current type 1 diabetes mellitus studies makes it difficult to compare the results. In addition, often, it is not possible to see from the study design whether the training was supervised and whether the intensity was continuously increased. Literature (11,33) points out that exercise programs must be long enough to achieve a reduction in HbA1c. Kennedy et al. (33) recommends, larger trials lasting at least 6 months. Aouadi et al. (11) showed that aerobic training should last 6 months to improve glycemic control significantly. Also, it has been demonstrated that studies (25,33) need to be supervised and intensity of the exercise program must be increased continuously. We are unaware of previous research examining the effects of a long-term isolated supervised progressive resistance training in children with type 1 diabetes mellitus. In our study, data on regular home glucose monitoring during 32 wk and the blood glucose levels after each training session of isolated SPRT were also obtained as the measurement of HbA1C. Our main finding of this study is that HbA1C did not change after 17 wk of training, but after 32 wk of training HbA1C decreased significantly. This suggests that a period more than 17 wk of regular activity is necessary before any difference in glycemic control can be observed. This is in line with the results of the meta-analysis of Kennedy et al. (33) who recommended a duration of at least 24 wk and a control group of diabetic patients for the design of a study. Based on pooled data from studies (11,33), and assuming that the rate of glycemic benefit persists in a linear fashion, we estimate that studies of greater than 24 wk duration would be needed to obtain an HbA1c reduction because results in our study after 17 wk showed no HbA1c reduction. However, we cannot make the statement whether an improvement could be achieved after a shorter period than 32 wk.

In conclusion, based on our data, strength training with children with type 1 diabetes mellitus should last at least 32 wk twice a week and must be supervised to achieve benefit on health and in metabolic control.

### Table 3. Fitness data at the baseline and follow up 32 wk.

<table>
<thead>
<tr>
<th>Group</th>
<th>LP 1 (W·kg⁻¹)</th>
<th>LP 2 (W·kg⁻¹)</th>
<th>BP 1 (W·kg⁻¹)</th>
<th>BP 2 (W·kg⁻¹)</th>
<th>BPU 1 (W·kg⁻¹)</th>
<th>BPU 2 (W·kg⁻¹)</th>
<th>RUN 1 (m)</th>
<th>RUN 2 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG, n = 10</td>
<td>5.45 ± 1.99</td>
<td>5.72 ± 2.11</td>
<td>1.61 ± 0.37</td>
<td>1.64 ± 0.44</td>
<td>1.79 ± 0.64</td>
<td>1.96 ± 0.60</td>
<td>863.40 ± 182.85</td>
<td>859.80 ± 199.59</td>
</tr>
<tr>
<td>Sign</td>
<td>0.299</td>
<td>0.623</td>
<td>0.00*</td>
<td>0.647</td>
<td>0.00*</td>
<td>0.647</td>
<td>0.00*</td>
<td>0.647</td>
</tr>
<tr>
<td>IG, n = 11</td>
<td>5.26 ± 2.63</td>
<td>7.10 ± 2.41</td>
<td>1.60 ± 0.61</td>
<td>2.00 ± 0.60</td>
<td>1.73 ± 0.54</td>
<td>2.00 ± 0.62</td>
<td>930.90 ± 128</td>
<td>960.45 ± 119.94</td>
</tr>
</tbody>
</table>

*Significant at $P < 0.05$.

LP1, BP1, BPU1, RUN1 = Base line before training; LP2, BP2, BPU2, RUN2 = Follow up 32 wk; W·kg⁻¹ = Watt/kilogram bodyweight.

### Table 4. HbA1C baseline and follow up 17 and 32 wk.

<table>
<thead>
<tr>
<th>Group</th>
<th>HbA1C1</th>
<th>HbA1C2</th>
<th>$P$</th>
<th>HbA1C1</th>
<th>HbA1C2</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG, n = 10</td>
<td>7.84 ± 1.38</td>
<td>8.26 ± 1.26</td>
<td>0.037*</td>
<td>7.84 ± 1.38</td>
<td>8.22 ± 1.33</td>
<td>0.007*</td>
</tr>
<tr>
<td>IG, n = 11</td>
<td>62 ± 14.2</td>
<td>67 ± 13.8</td>
<td>0.37</td>
<td>62 ± 15.1</td>
<td>72 ± 14.5</td>
<td>0.00*</td>
</tr>
</tbody>
</table>

HbA1C1 = Hemoglobin (% and mmol·mol⁻¹) at baseline, HbA1C2 Hemoglobin (% and mmol·mol⁻¹) after 17 wk. HbA1C3 Hemoglobin (% and mmol·mol⁻¹) follow up 32 wk.
Adiponectin appears to play a role in the pathophysiology of obesity, diabetes mellitus, and its comorbidities. A lot of investigators stated that adiponectin levels are positively correlated with insulin sensitivity (3–5). For example, Simpson and coworkers (5) examined the relationship between adiponectin and insulin sensitivity in adults with and without type 1 diabetes mellitus and found that adiponectin levels were positively associated with insulin sensitivity. In children, adiponectin is correlated with fat mass and insulin sensitivity in a qualitative similar manner to relationships observed in adults (34). Although the association of adiponectin and insulin sensitivity is undisputed, the results of studies on exercise and adiponectin are conflicting. Some studies have reported no changes in adiponectin levels after exercise (35,36), and others have reported increased adiponectin levels (3–6). Kim et al. (3) showed a 10% increase in plasma adiponectin levels among subjects who underwent 6 wk supervised jump roping exercise five times per week in obese Korean Youth. Fatouros et al. (4) found an increase in adiponectin levels in inactive overweight elderly due to resistance training, independent of diet intervention. As circulating concentrations of adiponectin, besides genetic factors, are partly determined by nutrition, BMI, and by exercise. Fatouros et al. concluded that an increase in adiponectin levels may be attributed to an enhancement of insulin sensitivity caused by resistance training. Also, De Salles et al. (37) reported in his review that the majority of randomized longitudinal clinical interventional controlled trials demonstrated a significant increase in adiponectin levels after resistance training. He summarized that additional studies with longer intervention durations (16 wk or longer) may be necessary to significantly improve adiponectin. As subjects in these studies are healthy or overweight adults, he recommends for different subject populations to address the effects of resistance training on adiponectin. Therefore, it was obvious to evaluate whether an intervention with isolated supervised resistance training of longer intervention durations (16 wk or longer) is able to improve adiponectin significantly in children with normal BMI and type 1 diabetes mellitus. According to Fatouros et al. (4), we do not make changes in diet during the intervention period in our study group. Both groups were asked to continue their usual activities and nutrition for the duration of the study period regardless of group assignment. After 32 wk, adiponectin adjusted for BMI did not change significantly during the intervention period in the control group, but increased significantly in the intervention group. Therefore, it appears reasonable to conclude that SPRT as the sole intervention may increase adiponectin levels in children with type 1 diabetes mellitus.

As a lot of investigators stated that insulin sensitivity is positively correlated with adiponectin levels (3–6), we may speculate that the exercise-induced increase in adiponectin in our study improves insulin sensitivity.

Echocardiogram and left common carotid artery. The thickness of the arterial intima-media layer is a sensitive marker of early vasculopathic processes. Thus, vascular disease should be diagnosed as early as possible to prevent atherosclerotic complications. In our collective, the mean duration of diabetic history was 1.85 to 2.62 yr and, therefore, too short to find vascular changes. The measurements were correlated to the values of normative values for intima-media thickness in healthy adolescents (38), and we could not detect any pathology (0.39 mm, control group; 0.44 mm, intervention group).

CONCLUSIONS

The main findings of this study are that resistance training of a period of 32 wk which needs the important requirements of a supervised and progressive training in children with type 1 diabetes mellitus results in an improvement of physical fitness as well as in a decrease in blood glucose levels (acute glycemic control) and HbA1c (chronic glycemic control) and increase in adiponectin. Because the association of adiponectin and insulin sensitivity in the literature is undisputed, it is very likely that the exercise-induced increase in adiponectin in our study improves insulin sensitivity. In summary, results of this study suggest that improvements in strength, metabolic control, and adiponectin are dependent on the frequency, duration, and intensity of exercise. Based on the results of our study, training should fulfill the following criteria to achieve benefits on metabolic outcomes in the management of type 1 diabetes mellitus: twice a week, 40 to 50 min, supervised, progressive and ideally lifelong (first significant changes of metabolic control after 6 months).

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No potential conflicts of interest relevant to this article were reported for any of the authors. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The authors declare that the results of the present study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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