The effect of aerobic exercise and diet on selected physical fitness indices and blood glucose hemostasis in patients with diabetes type I

Farkhondeh sadat Abdolrahimi[1], Raziyeh Shoyoie[2*]

(1) MA, Department of Physical Education and Sports Science, Rasht Branch, Islamic Azad University, Rasht, Iran

(2)* Ph.D. Candidate in Exercise Physiology, Department of Physical Education and Sports Science, Rasht Branch, Islamic Azad University, Rasht, Iran. E-mail: soulmaz_sh@yahoo.com

Abstract:

Introduction: This study aimed to examine the impact of aerobic exercise and diet on physical fitness and blood glucose regulation in type I diabetes patients.

Material & Methods: The study aimed to investigate the effects of a 12-week combined exercise program on the blood sugar, glycosylated hemoglobin (HbA1c), and aerobic and anaerobic capacity of 40 eligible volunteer children aged 11-15 years. The participants were randomly divided into two groups: control and experimental. The exercise program included pilates, weight-bearing, and aerobic exercises and was conducted three times a week for one hour. The participant's blood sugar, HbA1c, and aerobic and anaerobic capacity were measured before and after training. The data was analyzed using SPSS software version 26 at a significance level 0.05.

Results: After conducting a paired t-test, it was found that the control group showed a significant increase in body mass index and waist circumference. In contrast, the experimental group showed a significant decrease in fasting blood sugar and hemoglobin levels and an increase in aerobic and anaerobic capacity ($P<0.05$). When comparing the two groups, it was observed that the experimental group had a significant decrease in waist size, FBS, and HbA1c and a significant increase in aerobic and anaerobic power ($P<0.05$). No significant difference was observed in other research variables.

Conclusions: Based on the available evidence, it is likely that engaging in a combination of exercises would lead to improvements in anthropometric indices and glucose homeostasis.

Keywords: diabetes type I, diet, glucose homeostasis, combined exercise training, pilates

1. Introduction

Diabetes mellitus is a group of metabolic diseases that share the common feature of elevated blood glucose levels caused by defects in insulin secretion, insulin function, or both. There are several types of diabetes, including type 1 diabetes. Type 1 diabetes is a metabolic disorder that occurs when there is either a complete absence or an insufficient amount of insulin secretion (1).

Diabetes mellitus (DM) is a rapidly growing health problem worldwide that requires long-term care and treatment, placing a burden on individuals and society. In 2019, according to the International Diabetes Federation (IDF), it was estimated that 463 million adults aged between 20 and 79 suffered from diabetes globally, which is expected to rise to 700 million in 2045 (IDF 2019). The top five countries with the highest diabetes cases in 2019 were China, India, USA, Pakistan, and Brazil. In the Middle East and North Africa (MENA), it was estimated that 55 million people were affected by diabetes in 2019, and this number is expected to rise to 108 million in 2045, necessitating immediate action. The top five countries with the highest diabetes cases in the MENA region in 2019 were Pakistan, Egypt, Iran, Saudi Arabia, and Sudan (2). According to the World Health Organization (WHO), the prevalence of diabetes in Iran is more than 8 percent (3).

The prevalence of Type 1 diabetes mellitus (T1D) in the world ranges from 0.8 to 4.6 per 1000 inhabitants. T1D is a disease that usually begins in childhood where the insulin-producing beta cells of the pancreas are destroyed. Patients require daily administration of exogenous insulin to treat this disease, but its cause is still unknown. The glycosylated hemoglobin (HbA1c) test is used to check patients' blood glucose levels, which shows the accumulated glycemic history from the previous 2-3 months. The HbA1c test result is given in percentages and is a reliable indicator for the diagnosis and prognosis of diabetes. According to the American Diabetes Association (ADA), people with T1D should have an HbA1c level below 7%. Several prospective studies, such as the Diabetes Control and Complications Trial, The UK Prospective Diabetes Study Group (UKPDS), and the Epidemiology of Diabetes Interventions and Complications, have directly linked long-term diabetic complications with the HbA1c index(4). HbA1c is a vital tool used to diagnose, treat, prevent, and monitor the progress of diabetes. Additionally, HbA1c can predict adverse outcomes in GDM, and studies conducted on Caucasian women with GDM have shown a correlation between HbA1c levels and adverse outcomes. However, there is insufficient evidence to draw any conclusions regarding the Asian population (5). Hemoglobin A1c (HbA1c) is a type of hemoglobin that is formed when glucose molecules attach to hemoglobin in red blood cells. This process is non-enzymatic and results in the formation of glycosylated hemoglobin, which is further divided into three subtypes - glycosylated hemoglobin A, B, and C. Out of these subtypes, HbA1c is the most commonly found subtype in the body. The serum level of HbA1c is a valuable indicator of a person's glycemic status over the past 2-3 months. Elevated serum HbA1c levels are closely linked to inflammatory diseases and have been shown to strongly predict the risk of diabetic complications and cardiovascular disease (6). Diabetes can lead to long-term physical complications, including a drop in blood glucose levels below 40 mm/dL or 4 mmol/L. The first signs of this drop are usually related to activation of the sympathetic nervous system. If blood glucose levels fall severely, below 2.5 mmol/L, it can lead to neural activity disturbance, loss of consciousness, unusual behavior, seizures, coma, and even death (7). According to a systematic review conducted by Fernandez et al (2023), adults with type 1 diabetes often face psychological problems, which can lead to poor glycemic control (measured by glycosylated hemoglobin [HbA1c]). Conversely, psychological well-being has been associated with better medical outcomes, including improved HbA1c levels. Selvin et al (2004) found that for every 1% increase in HbA1c, the risk of cardiovascular disease and stroke increased by 18% and 17%, respectively. Additionally, in patients with sepsis, higher HbA1c levels are associated with a greater risk of progression to persistent sepsis and intensive care unit mortality (8). Long-term resistance training improves glucose tolerance, insulin sensitivity, and storage by increasing skeletal muscle mass. Endurance and strength training have a moderate effect on glucose control in diabetic patients (9). Studies have suggested that patients with type 1 diabetes who exercise experience an improvement in their left ventricular function and maximum oxygen consumption. However, people with type 1 diabetes may experience decreased performance due to damage to their endogenous opioid secretion (10). Diet alone can reduce the risk of diabetes by 11 percent, while a combination of sports and diet can reduce it by 10 percent. To prevent diabetes, it is recommended to adopt a low calorie, low fat diet and engage in moderate physical activity, such as rapid walking for 101 minutes per week. For people with type 1 diabetes, it is recommended to increase fiber intake, consume low glycemic index foods with more fruits and vegetables, and decrease saturated fat consumption, according to a study (11).

Most studies have shown that regular physical activity programs are crucial for reducing HbA1c levels. Experimental studies have also confirmed that such programs can lead to an improvement in lipid profiles, blood pressure, and body composition - all factors that increase the risk of cardiovascular disease in diabetic children and adolescents. It is essential to prevent type 1 diabetic children and adolescents from facing the risk of microvascular and cardiovascular disease. Recent studies have shown that signs of diabetic retinopathy and diabetic nephropathy can be recognizable in early childhood. Lack of adequate glycemic control, dyslipidemia, obesity, high blood pressure, and physical inactivity are the primary risk factors for the development of these conditions (12). Different responses to blood glucose concentration can be observed based on the intensity and duration of exercise. For instance, low intensity, speed, and weight training can increase blood glucose levels. In a study of exercise training and cardiovascular risk factors in type 1 diabetic adolescent girls, there was no change in the need for daily insulin or HbA1c in children with type 1 diabetes (13). Balanced diets suitable for type 1 diabetic children and adolescents, along with monitoring glucose levels and maintaining an active lifestyle, can help predict and manage these risk factors. Considering the importance of exercise and diet for type 1 diabetes, especially the significance of combined exercises, this study aims to investigate the effect of diet and physical activity on blood glucose homeostasis and selective physical fitness indexes in children with type 1 diabetes (14).

2. Materials and Methods

Subjects

This study was a quasi-experimental research conducted in a clinical trial. The study population consisted of 484 diabetic patients who were referred to 17 Shahriver hospitals in Rasht, Iran. To be eligible, patients had to meet the following criteria: HbA1c ≥7, a history of illness for at least one year, and an age between 11 and 15 years old. From this population, 44 children with type 1 diabetes were randomly assigned to either an experimental or control group. This sample size was deemed sufficient based on the G-power software version 3-1-9-2. Finally, 20 patients from each group continued the research until the end. At the beginning of the study, parents of the eligible children signed a consent form to participate in the research. To control the diet during the study, a three-day dietary recall was used to evaluate and prescribe the diet. Participants were asked to recall their dietary intake on two working days and one day off. An appropriate diet regimen was provided to patients through lectures and pamphlets.

During the research study, an experimental group underwent training. The exercise protocol involved both resistance training (including Pilates and weight-bearing exercise) and aerobic exercise. The training program consisted of warm-up and cool-down for 10 minutes each, along with 40 minutes of combined exercise. The total duration of the program was 60 minutes, with a 2-minute rest period between each training activity. Pilates exercises such as Plank, Push, Lying Twist Trunk, Deep Squat, Mountain Climber, Crunch, Burpee, Front Plank, Side Plank (right and left), Back Plank, Crunch (Static), Leg Raise (Static), hand stretching exercises, and single leg stretching were performed in 2-3 sets of 8-12 repetitions with a 30-second rest interval between each set. The number of sets and repetitions varied over the course of the program. In the first eight weeks, 1-2 sets and 8-10 repetitions were performed, while in the second eight weeks, 2-3 sets and 10-12 repetitions were completed (15). The lower body weight-bearing activities that were included in the study were double and single multiple-legged hops, countermovement jumps, tuck jumps, jumps with a half turn, drop jumps from a 30cm box, jumps over a 15cm hurdle, and jumping jacks. The upper body weight-bearing activities included front support holds, side support holds on one arm, push-ups, explosive push-ups, burpees, donkey kicks, wheelbarrow walks, and landing on the hands from a knee position. Additionally, we assessed four animal walks that loaded the upper limbs, including the bear walk, inchworm, crab walk, and walrus walk (16). During the first four weeks of the program, the main activity was performed at an intensity level of 60% - 75% of the maximum heart rate, with music set at a pace of 130-135 beats per minute. From the fifth to the eighth week, the intensity level was increased to 75% - 85% of the maximum heart rate, with music set at a faster pace of 140-150 beats per minute. For the following two weeks, the intensity level was reduced to 60% - 70% of the maximum heart rate. This information is based on reference (17).

Diet training

The diet training program for Type 1 Diabetes patients involved consuming foods with a low glycemic index, learning how to consume carbohydrates during and after exercise training, avoiding junk food and reducing intake of salty and fried foods. Patients were also educated on the symptoms of hypoglycemia and hyperglycemia, and taught how to prevent them before and after exercise. During the program, patients filled out the Re-call questionnaire on two working days and one day off, and received appropriate nutritional recommendations.

Measurements

Blood samples were collected from the brachial vein at 8 a.m. following a 12-hour fast. Glucose levels were measured using the enzymatic method of glucosidase/peroxidase with an autoanalyzer device called Hitachi (manufactured in Tokyo, Japan) and with the Full method automation, using a Biosystem kit from Biosystem S.A. in Barcelona, Spain. HbA1c levels were measured with the Biosystem kit using the ion exchange chromatography method. Insulin levels were measured using the insulin kit manufactured by Diametra in Segrate, Italy, utilizing the sandwich method and the diagnostic method of direct immunoenzymatic assay.

Antropometric measurements

Height and weight measurements were taken using the Seca weighing scale with an accuracy of 0.01 kg. Subcutaneous fat was measured with a caliper (SAEHAN, Korea) by measuring the fat under the skin of the leg and upper arm. The amount of subcutaneous fat was determined using Slater's two-point formula.

Aaerobic and anaerobic capacity measurments

The Rockport walk test was used to assess the aerobic endurance of the subjects. The maximum oxygen consumption (vo2max) was calculated using the following formula: For females in diet training: VO2 = 139.168 - (0.388 x age) - (0.077 x weight in lbs) - (3.265 x walk time in minutes) - (0.156 x heart rate). For males, add 6.318 to the above equation for females. The Sargent jump test was used to measure anaerobic power. The Harman equation was used to calculate anaerobic power, which is expressed as peak power (W). The Harman formulas are as follows: Peak power (W) = (61.9 x jump height (cm)) + (36 x body mass (kg)) + 1822.

Statistical analysis

The results were presented as mean ± standard deviation (SD), and the normality of the distributions of all variables was assessed. Paired and independent t-tests were used to analyze the data.
Statistical analysis was conducted using SPSS software version 26. The level of significance in all statistical analyses was set at $P < 0.05$.

3. Results

Table 1 presents the Descriptive Statistics of the sample variables.

Table 1: Descriptive Statistics of sample variable in patient with T1D

Index	Group	Mean±SD pre test	Mean±SD Post test
blood glucose (mg/dl)	experimental	163.78±10.09	126.66±05.69
	control	165.52±25.99	168.54±60.47
	experimental	7.1±98.02	7.1±26.51

glycosylated hemoglobin(percent)	control	7.1±83.00	8.1±15.12
aerobic power(ml/kg/min)	experimental	35.86±4.30	38.4±3.26
	control	34.4±4.13	35.1±3.10
anaerobic power	experimental	293.6±6.92	315.6±5.37
	control	274.7±6.18	276.9±6.72

2. The Kolmogorov-Smirnov test indicates normal distribution. Paired t-test results, before and after experimental and control groups, are shown in Table 2.

Table 2. Paired t- test results of blood indices for comparison before and after two groups(n=22 in each groups)

Variable	Group	**pre test Mean±SD**	**Post test Mean±SD**	T	**P**
Blood glucose (mg/dl)	experimental	163.78±10.09	126.66±05.69	2.76	0.012*
	control	165.52±25.99	168.54±60.47	0.957	0.351
glycosylated hemoglobin (percent)	experimental	7.1±98.02	7.1±26.51	-2.80	0.011*
	control	7.1±83.00	8.1±15.12	-1.64	0.117
aerobic power (ml/kg/min)	experimental	35.86±4.30	38.4±3.26	-3.87	0.001*
	Control	34.4±4.13	35.1±3.10	1.24	0.639
anaerobic power	experimental	293.6±6.92	315.6±5.37	-3.87	0.005*
	Control	274.7±6.18	276.9±6.72	-1.50	0.073

The results of the study indicate that there was a significant decrease in the post-test levels of FBS and HbA1c, and an increase in both aerobic and anaerobic power in the experimental group ($P<0.05$). However, there was no significant difference in the control group ($p>0.05$). The independent t-test results showed that there was no significant difference between the groups in the pre-test. However, in the post-test, there was a significant decrease in FBS and HbA1c, and an increase in both aerobic and anaerobic power in the experimental group, as shown in Table 3.

Table 3. Independent t- test results were compared post-test the experimental and control groups

Index	Mean def	F	T	Df	Sig
blood glucose (mg/dl)	40.40	19.62	2.91	38	0.006*
glycosylated hemoglobin(percent)	1.02	4.27	3.22	38	0.003*
aerobic power(ml/kg/min)	28.107	0.031	-3.90	38	0.000*
anaerobic power	20.13	0.008	-2.80	38	0.008*

* significant deference ($P<0.05$)

4. Discussion

The aim of this study was to investigate the impact of diet and exercise training on blood glucose, glycosylated hemoglobin, anaerobic power, and aerobic power of adolescents with type 1 diabetes. The study reported positive effects of regular pilates, weight-bearing, and aerobic exercise training, including improvements in glycemic control and aerobic-anerobic power of type 1 diabetic patients. Several studies have evaluated exercise as a therapeutic intervention, but the type, duration, intensity, and frequency of training varied, and different indicators were evaluated in each study. It is believed that exercise training plays an insulin-like role in muscle contraction, which promotes glucose metabolism by sending energy out to the cells. Muscle contraction increases the permeability of the membrane to glucose by increasing the number of glucose transporter proteins in the plasma membrane. Exercise also increases the amount of GLUT4 in the trained muscles, which improves insulin action on glucose metabolism and can reduce glycosylated hemoglobin levels (18). Exercise can have a positive effect on glucose concentration and blood lipid levels by promoting the uptake of sugar by muscle cells and activating lipid metabolism. As a result, aerobic exercise is considered an important aspect of the treatment for individuals with diabetes (15). Based on the results obtained from several studies, it can be concluded that adding resistance training to aerobic training with a short duration resting period can have a complementary effect. Resistance training involves anaerobic energy production, which means the stored reserves in the body are used without the need for oxygen. This type of exercise has been shown to increase insulin sensitivity and daily energy consumption. There is sufficient evidence to suggest that any type of exercise, or a combination of exercises, can significantly improve blood glucose control in young patients with type 1 diabetes (15). In their 2023 study, Saki et al found that exercise improves blood sugar indices (FBS and c1HbA) and aerobic capacity in boys with type 1 diabetes (15). In a study by Ghalavand (2016), it was found that after eight weeks of training, both aerobic and resistance groups showed a significant decrease in fasting blood sugar levels and an increase in plasma density lipoprotein levels. This suggests that aerobic and resistance training can be effective in controlling blood glucose and improving the lipid profile of diabetic men. Therefore, diabetic patients can benefit from appropriate exercise training to control their blood glucose and lipid profile. Examining the differences between groups revealed that fetuin B and GDF-15 levels significantly increased while pentraxin levels significantly decreased in the healthy group compared to the diabetic group ($p < 0.001$). Furthermore, there was a significant difference between the diabetes control group and the supplement and exercise groups in all indicators ($p < 0.001$). The results of the study showed that aerobic exercise and stevia supplementation can decrease fetuin b and GDF-15 levels while increasing pentraxin 3 levels in type 1 diabetic rats. These improvements were even better in the group that took exercise and supplementation at the same time (17). Tunar et al. (2012) conducted a study titled "The Effects of Pilates Exercise on Metabolic Control in Type 1 Diabetic Adolescents," which was carried out on 31 patients with T1D aged between 12 and 17 years over a period of 12 weeks. The results indicated that there was no significant change in the mean of HbA1c. The difference between this study and the present study could be attributed to the difference in the exercise protocol (pilates exercise only vs. aerobic and pilates training) and the age of subjects. The present study found that after five months of training in children aged 11 with type 1 diabetes, there were no significant changes in blood sugar levels, which is contrary to the study by Tunar et al. (2012) that was referred to earlier (19). Landt et al. (1985) attributed the lack of change in HbA1c to exercise alone, without attention to diet and insulin levels (22). In 1980, Dahl-Jorgensen et al. conducted a study titled "The Effect of Exercise on Glycemic Control," which observed 14 Type 1 diabetic patients with an average age of 11. The participants were enrolled in a monitored sports program for one hour, twice a week, for five months. However, the exercise group did not experience any changes in their HbA1c levels. The difference between our study and previous research lies in the type of exercise protocol, i.e., training alone versus combination exercises, which could impact the intensity and duration of exercises. Our study found that 12 weeks of aerobic and Pilates training, along with a controlled diet, can improve the homeostasis and physical fitness of Type 1 diabetic patients (23).

Our study was limited by a small sample size and strict diet control for patients.

5. Conclusion

Based on the findings of our study, it appears that a combination of aerobic, weight-bearing, and Pilates exercises along with dietary education can significantly improve glucose homeostasis and both the aerobic and anaerobic capacity of individuals with type 1 diabetes. Given the positive impact of this exercise regimen on diabetic patients, we strongly recommend it to sports trainers and healthcare professionals.

6. Acknowledgment

The researchers express gratitude to all study participants and Gil Children's Laboratory staff.

References

1. Sobhi A, Ahadi H, Rajab A, Nafisi K, Hejazi M .(2009). Mental health and coping with stress in parents and child's metabolic control style. Iranian J Diabetes Lipid Disord. 3:327-38.
2. Al Razooqi H, AlNajjar,B, AlShamsi, E, Ibrahim,K. (2023), Correlation between Glycated Hemoglobin Levels and Knowledge, Attitude, and Practice of Type 2 Diabetic Patients Attending Primary Health Care Centers in Dubai Health Authority, Dubai Med J 2023;6:107–114
3. Heidari H, Alhani F, Kazemnejad A, Tol A, Moezi F .(2012). [Assessing the effect of educational program based on empowerment model on HbA1C among adolescents with type 1 diabetes]. Health Syst Res. 7:137683
4. Fernández A, Berrocal P, Gutiérrez M(2023), The relationship between well-being and HbA1c in adults with type 1 diabetes: A systematic review, Journal of Diabetes. 2023; 15: 152–164. Wiley online library.com/ journal/ jdb
5. Muhuza M, Zhang L, Wu Q, Qi L, (2023), The association between maternal HbA1c and adverse outcomes in gestational diabetes, Frontiers in Endocrinology, Endocrinol. 14:1105899.

6. Han,F, Shi,X, Pan,J, Wu, K, Zhu,Q. (2023), Elevated serum HbA1c level, rather than previous history of diabetes, predicts the disease severity and clinical outcomes of acute pancreatitis, BMJ Open Diab Res Care 2023;11:e003070
7. Christie et al ., (2014), Using motivational interviewing to engage adolescents and young adults with diabetes, Volume31, Issue6 July/August 2014, Pages 252-256.
8. Selvin E, Marinopoulos S, Berkenblit G, et al. Meta-Analysis: glycosylated hemoglobin and cardiovascular disease in diabetes mellitus. Ann Intern Med 2004;141:421–31.
9. Albright A, Franz M, Hornsby G, Kriska A, Marrero D, Ullrich I, et al.(2000). American College of Sports Medicine position stand. Exercise and type 2 diabetes. Medicine and science in sports and exercise. 32(7):1345.11
10. Peirce N.(1999). Diabetes and exercise .British journal of sports medicine. 33(3):161- 72.
11. Nelson KM, Reiber G, Boyko EJ.(2002). Diet and exercise among adults with type 2 diabetes findings from the third national health and nutrition examination survey (NHANES III .) Diabetes care. 25(10):1722-8.
12. Hancox RJ, Milne BJ, Poulton R .(2004). Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. Lancet. 364:257-62
13. O'Hagan C, De Vito G, Boreham CA.(2013). Exercise prescription in the treatment of type 2 diabetes mellitus. Sports Med. 43(1):39-49.
14. Heyman E, Toutain C, Delamarche P, Berthon P, Briard D, Youssef H, Dekerdanet M, Gratas-Delamarche A .(2007). Exercise training and cardiovascular risk factors in type 1 diabetic adolescent girls. Pediatr Exerc Sci. 19:408-19.
15. Boyaci, A., Tutar, M., & Biyikli, T. (2018). The Effect of Dynamic and Static Core Exercises on Physical Performance in Children. Online Submission, 4(7), 50-61.
16. Erlandson MC, Hounjet S, Treen T, Lanovaz JL(2018 Jul 18). Upper and lower limb loading during weightbearing activity in children: reaction forces and influence of body weight. Journal of sports sciences.36(14):1640-7.
17. Rokka S, Kouli O, Bebetsos E, Goulimaris D, Mavridis G .(2019). Effect of Dance Aerobic Programs on Intrinsic Motivation and Perceived Task Climate in Secondary School Students. International Journal of Instruction. 12(1):641-54.
18. Forbes JM, Cooper ME .(2013). Mechanisms of diabetic complications. Physiological reviews. 93(1):137-88.
19. Saki H, Nazem F, Fariba F. Effect of Combined Exercise Training on Heart Rate Variability and Aerobic Capacity of Boys with Type 1 Diabetes. Avicenna J Clin Med 2023; 29 (4) :232-239.
20. Ghalavand A, Delaramnasab M, Afshounpour M, Zare A. Effects of continuous aerobic exercise and circuit resistance training on fasting blood glucose control and plasma lipid profile in male patients with type II diabetes mellitus. J Diabetes Nurs 2016; 4 (1) :8-19.
21. Tunar et al (2012) The effects of Pilates on metabolic control and physical performance in adolescents with type 1 diabetes mellitus. Journal of diabetes and its complications.;26 (4) , 348-51.

22. Landt, KW, Campaigne, BN., James, FW. Sperling, MA .(1985). Effects of Exercise Training on Insulin Sensitivity in Adolescents with Type I Diabetes. Diabetes Care. 8: 461-465.
23. Dahl-Jorgensen, K., Meen, H.D., Hanssen, K.F. and Aagenaes, O. (1980) The Effect of Exercise on Diabetic Control and Hemoglobin A1 (HbA1) in Children. Acta Paediatrica, 69, 53-56.