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Effect of Aerobic Exercise Program on Blood Glucose Level and Quality of Life in Pre-diabetic Overweight/Obese Adolescents

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KEYWORDS

pre-diabetes, adolescents, aerobic exercises, quality of life, obesity, HbA1C, FBG.

ABSTRACT:

Back ground: Overweight and obesity are considered chronic disorders and are largely responsible for the rise in chronic, non-communicable illnesses worldwide.

Objective: To examine the impact of the diet program with healthy lifestyle awareness sessions and the diet with a designed aerobic exercises program on the blood glucose level, and the quality of life (Qol) in the overweight/ obese pre-diabetic adolescents.

Methods: forty pre-diabetic adolescents of both sexes were equally distributed into group (A) who received only healthy lifestyle awareness sessions, while group (B) who received healthy lifestyle awareness sessions and a program of aerobic exercises for three consecutive months.

Results: A significant change in the mean value of FBG between groups A and B. The mean value of the FBG of group A was 115.59±6.42, and that of group B was 103.38±5.42, post-treatment. A significant drop in HbA1C by 7%, and significant decrease in BM by 2.2%, a significant increase was detected in distance by 6 MWT by 18.6%, a significant reduction in WC was reported by 9.4%, in addition to a significant improvement in general health index by 199% and a statistical significant increase in pain threshold by 154% This demonstrates the effectiveness of the designed aerobic exercise regimen on the blood glucose level of the overweight/obese pre-diabetic adolescents.

Conclusion: Describing and determining the precise forms of exercise programs that can be used to help pre-diabetic patients avoid developing diabetes.This includes aerobic exercises and various treatment approaches that can lower HbA1c, FBG, and BMI, and enhance QoL in general health and pain threshold aspects.

Introduction

The manifestation of overweight and obesity is caused by a person's genetic predisposition to gaining weight as well as environmental variables. The original cause of overweight and obesity, which increases the hazard of negative health consequences, is ectopic or excessive fats that accumulate in different body parts and organs. The avoidance and treatment of these related disorders can now be a key component of weight management programs. It is important to remember that thresholds of excess adiposity may manifest at different body weights and fat distributions, based on the individuals or community consideration. Given that "adiposity" is identified as the characteristic of bodily fat mass, obesity is theoretically defined as the extra risk of negative health outcomes that follows a given level of adiposity that exceeds the size normally observed in the population **(1).**

Childhood central obesity is a global health concern that is associated with cardiovascular risks. A 2019 World Obesity Federation estimate states that 206 million children and adolescents aged 5 to 19 will be obese by 2025, and that proportion will increase to 254 million by 2030 **(2,3).**

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Egypt has the 18th-highest rotundity frequency in the world, according to the World Rotundity Confederation. Fatness was present in 13.2 percent of boys and girls who progress 10-19 in 2016. 17.1 In 2010, 80.6 percent of adolescent boys and 92.9 percent of adolescent girls reported not exerting enough physical effort. Rotundity and obesity in nonage have been related to numerous negative health effects. Based on the prescription of the metabolic pattern, which is steady in adolescents with rotundity and decreases at earlier times, the presence of rotundity in nonage may in the short term signal the start of cardiovascular diseases (CVD), hypertension, disturbed glucose metabolism , and dyslipidemia **(4,5).**

Additionally, stigmatization and bullying by peers are partially to blame for some of the many cognitive effects and comorbidities associated with adolescent rotundity**.** There have been reports linking rotundity in nonage to poor tone, depressive and eating disorders, emotional disorders, attention-deficit hyperactivity disorder, and Internet addictions **(6).** Similar to the rising rates of nonage rotundity, young type 2 diabetes mellitus (T2DM) is becoming more common and prevalent globally, especially among non-white races **(7).**

T2DM is one of the many metabolic variations linked to rotundity. The information that is currently available indicates that a continuous diapason of metabolic changes develops as insulin resistance (IR) progresses to T2DM, passing through pre-diabetes. Early identification of all of the hazards involved is likely to prevent most of these disparities. Rotundity is one of the primary factors that raise the risk of IR in obese children and adolescents. The development of metabolic remodeling in fat patients is significantly impacted by visceral obesity and ectopic accumulation of fat, such as into the muscles and liver **(8).**

IR in young people is most often caused by acquired conditions, such as redundant dysfunctional adipose tissue, dragged consumption of growth hormone or glucocorticoids, and other specifics; decreased physical activity; nutritional imbalance; glucose; and lipid toxin, which are ultimately inferred from the high levels of free adipose acids, ethnicity, and puberty **(8).** In order to overcome IR and compounded insulin stashing, β-cells are under excessive stress from rotundity and IR **(9).** Youth are placed on a path that ranges from IR to pre-diabetes to T2DM due to the inability of β-cells to compensate for IR **(10).**

Estimates of the risk of developing diabetes in the United States vary widely, possibly due to variations in the pre-diabetes description, or the variety of pre-diabetes. Both new incidences of blindness and adult renal failure are mostly caused by diabetes and listed the 7th contributing cause of mortality in the US with raised hazards of CVD, non-alcoholic fatty liver disorders, and non-alcoholic steatohepatitis **(11).**

Glycaemic levels exceeding normal but under the diabetes threshold characterize prediabetes, an intermediate condition of hyperglycemia **(12).** Additionally, the American Diabetes Association advised using Glycosylated Hemoglobin (HbA1c) situations to screen for pre-diabetes in children and teenagers **(13).** HbA1c is a reliable biomarker used to estimate glucose levels every three months **(14,15).**

A large cohort study of 77,107 pre-diabetic individuals indicated that the probability of getting diabetes rose as body mass index (BMI) and HbA1c position were added **(16).** Because pre-diabetes can be reversed with lifestyle changes, certain drugs like metformin, or both, early detection of pre-diabetes is essential to regain normal glucose tolerance (NGT) **(17).**

Wang et al. (18) recommend that at-risk youth be webbed every two years using the fasting plasma glucose (FPG) or oral glucose tolerance test (OGTT) starting at age ten, when puberty begins

Numerous health advantages of physical activity (PA) have been demonstrated, including a longer lifespan and a decreased risk of CVD **(19)**. Furthermore, there are significant financial repercussions of physical inactivity, such as increased healthcare expenses and decreased productivity **(20).**

Physical inactivity has been classified as a "pandemic" by the WHO, and policies and recommendations have been implemented globally to encourage PA, however with little success **(21).** According to a number of observational population studies, practicing particular sports lowers the incidence of CVD and lengthens life expectancy **(22).**

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Overweight children and adolescents frequently display signs of anxiety and sadness, diminished self-worth, and societal judgment. These mental health issues hinder care and have an impact on quality of life (QOL). The overweight and obese groups' overall QoL values were lower than those of the normal-weight groups. Furthermore, the research indicates that the degree of obesity affects the decrease in QoL **(23).**

The study aims to explore the impact of the designed aerobic exercise program and healthy lifestyle awareness sessions on the fasting blood glucose and HbA1C, the BMI, aerobic capacity, and waist circumference, and on the quality of life in general health, and pain threshold sectors of the participants before and after the designed aerobic exercise program in the overweight/ obese pre-diabetic adolescents. Additionally, evaluated the impact of the diet program and health awareness sessions alone versus the diet and sessions combined with a structured aerobic exercise regimen on blood glucose levels (FBG, HbA1C) and the participants' QoL.

Methods

Forty overweight and obese, prediabetes adolescents from both sexes, aged between 14 and 18 years old, participated in this study. They were selected from the nutrition outpatient clinic of the National Nutrition Institute, the outpatient clinics of the nutrition private clinics, and from the Wadi Degla Sportive Club, 6th October branch.

Ethical considerations:

The current study closely followed the guidelines stated in the latest version of the Declaration of Helsinki Code of Ethics. The clinical trial registration number of the current study is (NCT06756425). The study was be carried out only after receiving ethical committee authorization from Cairo University's Faculty of Physical Therapy in Egypt and granted ethical approval with an approval number (P.T.REC/012/005129). Participation was authorized by asking all participants to sign a consent form before baseline assessment.

Inclusive criteria:

The participants were chosen based on the following criteria: They're between the ages of 14 and 18. Based on the CDC's BMI charts, they were overweight and obese: Overweight is recognized as being 85th percentile to less than 95th percentile, while obesity is recognized as being 95th percentile or higher **(24).** They were prediabetic according to CDC, USPSTF: HbA1c level was 5.7% to 6.4%, FPG level was 100 to 125 mg/dL. Their waist circumference percentiles were in the area outside of the normal WC curve according to WHO Normal children and adolescents are in the area under the curve (AUC): 0.69 for boys; 0.63 for girls for normal adolescents **(24).**

Exclusive criteria:

Any adolescent who met the following requirements was promptly excluded from the assessment of the sample's consistency and the statistical findings: Type 1 or type 2 diabetes. Morbid obesity of more than 120% of the 95 percentile or more, or 35 kg/m or more. cardiovascular disorders. Hearing or visual impairments. Any orthopedic deformities in the upper limb or lower limb. Uncontrolled seizures. Receiving any special medication. Participated regularly in sportive activities.

In the quasi-experimental design, selected adolescents were assigned to two equal-sized groups of eighteen adolescents for each group. Two groups were identified as

- **Group (A):** 20 adolescents received a diet program was tailored specifically for them with healthy lifestyle awareness programs for their parents and them.
- **Group (B):** 20 adolescents underwent the same diet program which was tailored for the group (A) and designed aerobic exercise to treat prediabetes and obesity.

The designed aerobic exercise was applied for 70 minutes, 3 days per week for three successive months for the group (B). In addition, the same healthy lifestyle awareness program was presented for the adolescents in both groups.

Weight and height scale:

Every participant's height and weight were measured using the weight and height scale to determine their BMI, which is calculated by dividing their body weight (kg) by their body height (m) squared **(26; 27).** This scale has a waist-level column, built-in castor wheels, and an easy-to-read LCD screen for convenient clinical use. It has a BMI function; it may be equipped with manual or digital height rod accessories to measure weight and height simultaneously.

Tap measurement for Waist Circumference (WC):

Tap measurement was used for measuring the waist circumference of adolescents in CM. The WC is a commonly used variable of central obesity. It is an established indicator for metabolic disorders. According to WHO, WC is normal when the adolescent's percentile in the area under the curve as in depending on the WC in CM and age of the participant **(28).**

Clover A1c Analyzer device:

According to the US Preventive Services Task, this device detects HbA1C, which is an indicator of long-term blood sugar level that is unaffected by sudden fluctuations in glucose levels (**29**). Clover A1C Features & Options: Just 4µl of blood is a small sample. Fast: test findings in five minutes. The boronate-affinity technique is innovative. Shows the findings in either %, mmol/mol, or both. Memory capacity: results of 200 tests. Simple to use, no need for refrigeration.

Accu-check active blood glucose meter (Glucometer):

The brand's glucometer has fasting and post-meal markings and provides precise readings in just 5 seconds. FPG levels between 100 and 125 mg/dL are considered to be indicative of prediabetes **(30).** The Accu-check active blood glucose meter's benefits include precise blood glucose measurement and simplicity. Blood glucose monitoring is made much simpler with no coding. Display that is easy to read. Handling intuitively with only two buttons.

Health-Related QOL standard questionnaire Short Form–36 (HRQOL SF-36):

The eight subscales of the HRQOLQ SF-36 are: Physical function, role limits resulting from physical health, role limitations resulting from emotional issues, adolescents who are overweight or obese had their QoL evaluated both before and after the intervention based on their energy/fatigue, emotional well-being, social functioning, pain, and general health **(31; 32).**

Tools for the 6 Minute Walk Test (6MWT):

The 6MWT is a practical clinical test for evaluating obese children's and adolescents' physical performance **(33).** Equipment required Stopwatch. Trundle wheel or measuring device to gauge distance travelled. Two cones are used to indicate the necessary distance to be travelled. Pulse oximeter for SpO2 and heart rate measurement. The subjects' aerobic capacity was measured using the 6MWT before and after the trial. We measured how far a child could walk in six minutes at the quickest rate possible **(34).**

Instrumentation for treatment:

The designed aerobic exercise equipment: Apple smartwatch: This smartwatch measured the participants' heart rate during aerobic exercise. Pulse oximeter for participants who didn't have a smartwatch. Stopwatch: For measuring time and speed during the designed aerobic exercise. Sportive mate. Colorful cones. Sportive stepper. Volleyball.

Evaluative procedures:

Assessment of the BMI: It is calculated as body weight (kg) divided by body height (m) squared. While standing barefoot and without bulky outerwear, the participant's height and body weight were recorded. To determine the participants' height, they were instructed to gently press their heels on the wall or the back of the stadiometer. Weight is determined by BMI growth charts. Below the fifth percentile represents underweight. Between the 5th and less than the 85th percentiles is the healthy weight range. From the 85th percentile to less than the 95th percentile represents overweight. 95th percentile or higher being obese. A weight of 35 kg/m2 or above, or 120% of the 95th percentile, is considered severe obesity.

Assessment of the waist circumference (WC) percentile:

The participants were standing, without bulky outerwear, with their pockets empty, and breathing out gently while the WC was measured halfway between the lower rib edge and the iliac crest. The WC percentile chart was used to evaluate if the CM-obtained WC readings were inside the AUC.

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Assessment of the Fasting Blood Glucose (FBG) and Glycated Hemoglobin A1C level:

The FBG was tested in the morning before breakfast on every day of aerobic exercise throughout the treatment programs (three months). HbA1C was recorded on the first day of the treatment program and after three months on the last day **(35).**

Assessment the Health-related Quality of Life (HRQoL):

The HRQoL was evaluated by the health-related QOL standard questionnaire Short Form–36 (HRQOL SF-36) as one of the assessed variables in this study for all adolescents in both groups before and after the three months of treatment **(32; 36).**

Assessment of aerobic capacity:

The assessment of aerobic capacity was evaluated by the 6MWT that was being done before and after the designed aerobic exercise program. Cones were positioned at either end of the 30-meter stretch to serve as turning points **(33, 37, 38).** The goal was to walk as many distances as possible without jogging or running in six minutes. To make the instructions more clear, children were advised to move as quickly as they could. Throughout the test, the kids were informed by being told how many minutes they had left to walk or how many minutes they had already walked. Before and after the test, HR was registered with a pulse oximeter.

Treatment procedures:

All participants were randomly allocated into two groups (A), and (B). All of them received tailored diet programs designed for overweight/ obese prediabetes adolescents that provided them with their daily requirements for energy and helped them to lose some fat mass. In addition to that, they received health awareness sessions that concerned about healthy lifestyle education for them and their parents. Additionally, group (B) received a designed aerobic exercise program.

Healthy lifestyle awareness program:

Families of both groups participated in 45-minute sessions of the healthy lifestyle education program once every two weeks for a total of six sessions for 12 weeks. The healthy lifestyle education programs were created concurrently and presented to parents and children individually. The program's objectives are encouraging lifestyle modifications is linked to the risk of obesity and T2DM. Encouraging the consumption of fruits and vegetables on a daily basis, encouraging breakfast and eating five meals a day, and lowering the use of sugar, sweetened drinks, and high-energy foods. Also, boosting consistent amounts of physical exercise, cutting down on sedentary behavior, and encouraging good sleep hygiene and sufficient sleep durations **(39; 40).**

Diet program for overweight/ obese prediabetes adolescents:

There is ongoing debate regarding the best way to control diet in respect to intake. Fruits and vegetables intake has increased. Reducing intake of saturated fats and eliminating all sugar-sweetened beverages. Increased satiety, reduced absorption of carbs, improved insulin sensitivity, and the integration of low-energy foods to the diet are all linked to increasing the intake of foods with a higher fiber content. Consuming foods with a low glycemic index can boost satiety, promote fat burning, and lower postprandial surges in insulin and blood glucose.

The designed aerobic exercise program:

Group B practiced a three-month exercise program that comprised three sessions weekly, each lasting 70 minutes. This amounted to 210 minutes of moderate-intensity exercise per week, which is a proven preventive and treatment strategy for T2DM and pre-diabetic patients **(40).** The participants have never engaged in resistance training before. Participants were introduced to the exercise regimen over the course of two weeks. Activities were planned with 10:12 individuals per group. Cardiovascular exercises lasted 30 minutes per session, followed by 15 minutes of circuit training for aerobic training. Warming up for 10 min walking and increase its speed to slow running.

Indoor activities: (twice a week) Circuits: 2–3 sets; 4–6 exercises; 1:12 minutes of exercise duration, depending on the circuit type; 1:1/2 or 1/4 work-rest ratio between exercises, depending on the duration of the exercise and/or aerobic fitness level; 1–3 minutes of rest in between sets; passive rest recovery. Running lanes: two sets, five exercises, three to four minutes of

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activity time, a 1:1/2 or 1:1/3 work-rest ratio between exercises based on the duration of the exercise and/or aerobic fitness level, two minutes of rest in between sets, and passive rest recovery (slow walking or standing).

Outdoor activities: (once a week) Sport games: Volleyball. One or two sets of three to four exercises, three to five minutes of exercise time, a 1:1/2 or 1:1/3 work-rest ratio between exercises, depending on the exercise duration and aerobic fitness level, a one to three minute rest interval, and passive rest recovery. Twenty minutes, two teams, and modified rules to guarantee a sufficient and significant aerobic demand characterize volleyball. Then cooling down for 5 min walking then 10 min for stretching.

Measuring the heart rate during the exercise:

A pulse oximeter and an Apple Smart Watch heart rate monitor were used to continually assess HR during the training sessions. Every time the HR drops below the desired training heart rate, the HR monitor instantly alerted the children with a beep, letting them know when they should increase the intensity of their exercises. They were being constantly urged to work out at their predetermined training HR and to accelerate their motion speed whenever the HR monitor signals them to do so. When the intended is reached, the children were being told not to intensify their movements. We want to know how well the participants were achieving the desired HR rates. Thus, we took HR readings at the start, midpoint, and end of the exercise **(39).**

The training program began with an intensity of 50% HRmax to ensure successful participation and address the poor self-esteem typically observed in the pediatric obesity group. The exercises were developed with a low skill level consideration. Later in the exercise program, we switched to more physiologically demanding activities to provide a training effect. We also rose the participants' HR by 5% every six sessions until they reached 70% of their HRmax (moderate intensity of aerobic activity) **(31).**

Statistical analysis:

Data analysis was carried out utilizing the statistical package for the social sciences computer program (SPSS Inc., Chicago, Illinois, USA; version 20 for Windows). The mean± SD was used to express the data. To compare subjects' demographics of both groups, chi square and the unpaired t-test were employed. The data normal distribution was examined utilizing the Shapiro-Wilk test. The effects of the assessed variables (fasting blood glucose and HbA1C, BMI, 6 MWT, waist circumference, general health, and pain) were compared within and between groups using MANOVA. A P value of 0.05 or less was considered significant.

Results

The present displayed the characteristics of the subjects; the mean values for age, weight, height, and sex distribution of both groups did not differ significantly (p>0.05) **(Table 1)**.

Table (1): Demographic data of subjects of both groups

Demographic data	Group A	Group B	t-value	p-value
Age (years)	**16.12±1.62**	**15.53±1.7**	**1.03**	**0.309**
Weight (kg)	**92.76±15.75**	**84.88±12.19**	**1.63**	**0.113**
Height (cm	**164.29±7.02**	**165.94±7.16**	**-0.67**	**0.503**
Sex	**N (%)**	**N (%)**		
Males	**13 (65%)**	**12 (60%)**	**χ2= 0.125**	**0.724**
Females	**7 (35%)**	**8 (40%)**		

Data was expressed as mean±standard deviation, χ2: chi square, p- value: significance

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The check of normality, homogeneity of variance, and the existence of extreme values were analyzed in the data. A two-way mixed design MANOVA was implemented to ascertain how the two groups differed in their scores on the combined values of the parametric variables. The groups' multivariate effect was significant, P= 0.001, η2 = 0.577; for time, P = 0.001, η2 = 0.9517; and for the interaction of groups and time, P =0.001, η2 = 0.866. Between groups comparison indicated a statistical significant variation in the mean values of FBG (p=0.001), HbA1C (p=0.024), BMI percentile (p=0.037), waist circumference (p=0.007) and General health (p= 0.001) after 12 weeks among both groups with the superiority of the study group. While there no statistical significant change in the mean values of 6 MWT (p=0.121) and pain (p=0.053) after 12 weeks between both groups.Within group comparison indicated a statistical significant drop in FBG in control group after 12 weeks in comparison to baseline value (p=0.045) by 2.3%, there was significant increase in distance by 6 MWT (p=0.001) by 4%, there was significant reduction in WC (p=0.001) by 4%, also a significant increase in general health index was detected (p=0.001) by 94% and there was a statistical significant increase in pain threshold (p = 0.001) by 109%. While there was no statistical significant variation in HbA1C and BMI (p= 0.274 and 0.068) respectively.

There was a statistical significant drop in FBG in study group after 12 weeks in comparison to baseline value (p=0.001) by 12.7%, also significant drop in HbA1C (p=0.001) by 7%, and significant decrease in distance by BMI (p=0.001) by 2.2%, a significant increase was detected in distance by 6 MWT (p=0.001) by 18.6%, a significant reduction in WC was reported (p=0.001) by 9.4%, in addition to a significant improvement in general health index (p=0.001) by 199% and a statistical significant increase in pain threshold (p = 0.001) by 154% **(Table 2)**.

Table (2): Clinical characteristics of subjects for FBG and HbA1C, BMI, 6 MWT, waist circumference, general health and pain in both groups.

Measured variables	Control group (n= 18)	Study group (n=18)	MD (95% CI)	P-value1	η2
FBG					
Baseline	**118.37±5.47**	**118.46±4.96**	**-0.09 (-3.74, 3.56)**	**0.961**	**0.001**
12 weeks	**115.59±6.42**	**103.38±5.42**	**2.04 (8.05, 16.36)**	**0.001***	**0.528**
P-value	**0.045***	**0.001***			
HbA1C					
Baseline	**5.71±0.14**	**5.66±0.11**	**0.04 (-0.5, 0.13)**	**0.341**	**0.028**
12 weeks	**5.67±0.16**	**5.26±0.15**	**0.41 (0.3, 0.51)**	**0.001***	**0.660**
P-value	**0.274**	**0.001***			
BMI percentile					
Baseline	**97.08±2.4**	**96.59±1.52**	**0.49 (-0.91, 1.89)**	**0.478**	**0.016**
12 weeks	**96.55±3.05**	**94.43±2.6**	**2.12 (0.13, 4.1)**	**0.037***	**0.129**
P-value	**0.068**	**0.001***			
6 MWT					
Baseline	**524.12±115.27**	**511.76±113.98**	**12.35 (-67.73,92.43)**	**0.755**	**0.003**
12 weeks	**545.29±121.39**	**607.06±104.2**	**-61.77 (-140.8,17.27)**	**0.121**	**0.073**

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P-value	**0.001***	**0.001***			
Waist circumference (cm)					
Baseline	**109.29±11.68**	**104.06±11.74**	**5.23 (-2.95, 13.41)**	**0.202**	**0.050**
12 weeks	**104.82±10.89**	**94.29±104.2**	**10.53 (3.03, 18.03)**	**0.007***	**0.204**
P-value	**0.001***	**0.001***			
General health (%)					
Baseline	**28.7±7.5**	**24.7±12.3**	**4 (-3.12, 11.12)**	**0.262**	**0.039**
12 weeks	**55.6±11.8**	**73.8±8**	**-18.2 (-25, -11.2)**	**0.001***	**0.464**
P-value	**0.001***	**0.001***			
Pain (%)					
Baseline	**33.3±13.2**	**30.1±17**	**3.2 (-7.4, 13.9)**	**0.542**	**0.012**
12 weeks	**69.7±12.9**	**76.5±14.5**	**-6.8 (-16.4, 2.8)**	**0.161**	**0.061**
P-value	**0.001***	**0.001***			

*P-value: significance within groups, P-value1: significance between groups, FBG: fasting blood glucose, η2: partial eta square, *: significant*

Discussion

Childhood obesity is the result of an intricate combination of herediatory, environmental, and social variables that impact children and families. Adversity can alter a person's immune system, metabolism, and genetic makeup, which can alter their energy control and increase their probability of obesity **(2).** This study aimed to examine the effectiveness of an aerobic exercise regimen on FBG level, HbA1c level, BMI, waist circumference, aerobic capacity, and HRQoL in pre-diabetic overweight/obese adolescents. Forty pre-diabetic adolescents of both sexes were randomly allocated into two equal-number groups, group (A) consisted of 20 subjects who were prediabetes overweight/obese adolescents and received healthy lifestyle awareness sessions only, and group (B) comprised 20 subjects who were prediabetes overweight/obese adolescents and received also healthy lifestyle awareness sessions in addition to designed aerobic exercises program for 3 months consecutively.

Learning regular healthy habits that prophylactic from obesity and decrease the overweight all over time as; when eating use a fork for all food types except for soup. This helped them chew their food for a longer period and eat smaller portions than usual. Consequently, they feel full of smaller food amounts than they typically consume and these studies **Hermsen et al., (41) and Bolhuis & Keast, (42)** confirmed that fork users typically have a lower BMI than spoon users and tend to lose weight at a slower rate in the long term.

Studies on food sequencing have demonstrated that initiating with protein, fat, or fiber-rich vegetables meals rather than high-glycemic carbohydrates will slow down the digestive process. This is true for any meal, even light snacks. This slows down the process of gastric emptying, which is the movement of food from your stomach into your small intestine. You consequently eat less food, particularly carbohydrates, and stay fuller for a while**.** People produced a lot of satiety hormones, for example, when they were fed chicken, veggies, and white rice. In contrast to when they had these mixed items or in various combinations, they reported lower and more gradual increases in blood sugar**.** Furthermore, consuming vegetables firstly at a meal was linked to consuming more vegetables overall **(43-45).** The American Heart Association (AHA), the American Academy of Pediatrics (AAP), and the World Health Organization

(WHO) advocate the following as the main nutritional strategies for children and adolescents: (**46; 47).**

Our study's findings revealed no significant variations across groups A and B's mean values for height, weight, and age, as well as their sex distribution. The age and sex distributions of both groups were comparable to guarantee full randomization and minimize any potential biases in the outcomes. There is a significant change in the mean value of FBG between both groups A and B. the mean value of the FBG of group A was 115.59±6.42 and that of group (B) was 103.38±5.42, post-treatment. This demonstrates the effect of the designed aerobic training regimen on FBG level of the overweight/obese adolescents with prediabetes. The designed aerobic exercise program was conducted according to the protocols of **(46-50).** Exercise raises energy intake, lowers body adiposity, increases muscular mass, and has a significant impact on the endocrine system **(51; 52; 18).**

In a systematic review and meta-analysis of RCTs, **Jiang et al. (53)** adopted aerobic exercise regimens for those with pre-diabetes and concurred with our findings. According to the results, those with pre-diabetes who practice aerobic exercise can successfully lower their chance of acquiring diabetes. In particular, it was proven that aerobic exercise significantly improves hemoglobin A1C, 2-hour postprandial plasma glucose, and fasting blood glucose, all of which contribute to blood glucose regulations. Subgroup findings also showed that increased aerobic exercise volume and duration over a particular timeframe can result in a higher improvement in blood glucose levels in pre-diabetic individuals. Therefore, aerobic exercise can help lower the risk of diabetes and act as a therapeutic strategy for pre-diabetes. In contrast to those with normoglycemia, pre-diabetic adolescents typically have impaired FBG, impaired glucose tolerance, or both. Additionally, they are often identified by increased or "inappropriately" elevated endogenous glucose synthesis **(53).** Anomalies in glucose control that lead to this condition include hepatic insulin resistance (IR), poor glucose uptake responses, and diminished hepatic glucose elimination **(54).**

Prediabetes is characterized by β-cell malfunction, varied levels of IR, and delayed glucose absorption by skeletal muscle. Our research showed that aerobic training protects pre-diabetic people by efficiently lowering FBG and HbA1c levels primarily via changing the translocation of glucose transporter 4 (GLUT4), skeletal muscle contraction, and oxidation of fatty acids. GLUT-4 is a member of the glucose transporter family, which is mostly found in cardiac, skeletal, and adipose tissue **(54).** Particularly, aerobic training can increase muscle cell GLUT4 expression and improve glucose absorption **(55,56).** Skeletal muscle contraction also encourages glucose intake, which helps control blood sugar levels. Aerobic exercise reduces IR, fat formation, and fatty acid oxidation **(57).** Aerobic exercise is a viable approach for the treatment of prediabetes because it protects individuals by enhancing insulin sensitivity and metabolic processes.

Nevertheless, current information indicates that aerobic training, or exercise overall, may possess restricted effectiveness in regulating blood glucose levels. **Jiang et al. (53)** indicated that the exercise had no discernible effect on FBG. According to **Zheng et al. (58),** exercise alone may not be very successful in reducing FBG in pre-diabetic people. On the other hand, FPG levels can be considerably decreased by exercise in conjunction with dietary intervention. Based on the American College of Sports Medicine (ACSM) consensus statement, therapies that combine weight training and aerobic exercise may be better than either one as a separate **(57).**

Walking, jogging, running, and cycling are all supported by the large muscle groups involved in aerobic activity, which is rhythmic in nature. Aerobic training enhances vascular function and insulin sensitivity along with improving aerobic fitness and reducing body adiposity **(48).**

According to ADA and ACSM standards, a minimum of 150 minutes of moderate-to-intense aerobic exercise should be planned for at least three days a week, with no more than two days between. The main argument in favor of this frequency guideline is that aerobic exercise enhances insulin sensitivity for about 48 hours **(59).** These studies imply that a single aerobic activity is not very effective at controlling blood sugar levels, and a combination of treatments, such as dietary changes, lifestyle changes, and medication, is necessary for improved outcomes.

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Aerobic exercises such as running, swimming, and cycling depend on the energy production by adenosine triphosphate (ATP), which is produced in the mitochondria during oxidative phosphorylation. In response to elevated cardio-respiratory and metabolic needs, exercise triggers the sympathetic nervous system, which aids in preserving homeostasis **(60).** Exercise raises the plasma cortisol levels, epinephrine, and dopamine, which then drop to their baseline values when exercise is stopped. Long-term aerobic exercise improves insulin sensitivity, which can influence HBA1c levels through several processes **(61).**

There are two primary routes that improve the glucose absorption in skeletal muscle: insulin-dependent and insulin-independent. During aerobic activity, skeletal muscle helps GLUT-4, an essential transporter, move to the cell membrane, enhancing insulin-free glucose uptake. After 3-6 hours, these negative effects of exercise go away, and the muscle recovers sensitivity to insulin **(62).** Depending on intensity, food, and other variables (such as sleep), this insulin-sensitizing effect may persist for up to 48 hours **(63).** Thus, prior weight reduction or increases in aerobic fitness, it is well known that one exercise session improves insulin sensitivity and blood glucose control. Importantly, exercise reduces the hazard of hypoglycemia in T2DM individuals who do not use insulin **(57).**

Therefore, increasing aerobic fitness and improving insulin sensitivity regardless of body weight will reduce CVD and all-cause mortality in T2DM individuals. The advantages of exercise for glycemic control are well established. In overweight individuals with T2DM, for instance, 6-month aerobic training consisting of four weekly sessions at 45–60 minutes each at 50–75% VO2peak reduced FPG (-18.58 mg/dl) and insulin levels (-2.91 mU/l) in comparison to a non-exercise control group **(64).**

The burden of chronic diseases like T2DM can be reduced by exercise, which also improves HbA1c and reduces stress and anxiety. Additionally, exercise reduces body fat percentage and cardiovascular disease risk **(61).** The efficacy of aerobic exercise on blood glucose levels in pre-diabetic patients was investigated in this meta-analysis and comprehensive review. Analyzing 16 randomized controlled trials with 2518 records that focused on HbA1c, 2-hour postprandial plasma glucose (2hPG), and FBG showed that aerobic exercise effectively lowers these glucose markers. The findings demonstrated that aerobic exercise is an beneficial approach for controlling pre-diabetes, with longer intervention durations (≥48 weeks) and greater weekly exercise volumes (≥180 minutes) correlating with larger decreases in glycemic indices. These results suggest that aerobic exercise is a good way to treat prediabetes and may even stop it from developing into T2DM **(53).**

In other studies resistance training also has beneficial effects, particularly when combined with aerobic exercise. But the most effective modality for glycemic control was an integration of aerobic with resistive training, suggesting that a multifaceted approach may yield the best results. Longer intervention durations and higher exercise volumes were associated with greater improvements in controlling glucose levels **(65).**

Chou et al., (66) explored how body fat distribution, particularly the waist-hip ratio (WHR), influenced the effectiveness of the exercise interventions. It was found that individuals with a higher WHR benefitted more from aerobic exercise in terms of HbA1c reduction compared to those with a lower WHR. This underscores the importance of assessing body composition in tailoring exercise programs for optimal outcomes.

Conclusion

Aerobic exercise provides a substantial metabolic and psychosocial benefit for adolescents at a threat of developing T2DM, making it a key component of early intervention strategies. The data support the integration of aerobic programs in preventive care plans for this demographic.

Interventions can focus on both clinical treatment of T2DM and support for emotional and social well-being, suggesting a more holistic approach is necessary in managing adolescents at risk for or diagnosed with T2DM. These findings have significant clinical implications for overweight/obesity prediabetes adolescents and their families.

AUTHOR CONTRIBUTIONS

The authors refer to their contributions to the following areas of the article: The study's idea and design were carried out by Marina N. Meseha, while Amira El-Tohamy and Marina N. Meseha prepared the draft paper and collected, analyzed, and interpreted the data. Each author examined the findings and gave their approval to the manuscript's final version.

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CONFLICT OF INTEREST STATEMENT

The authors state that they have no financial conflicts of interest with respect to the topics included in the work.

DATA AVAILABILITY STATEMENT

Upon request, the corresponding author provided the data that support the study's findings. The data are not publicly available due to privacy and ethical considerations.

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