Research Article

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Physiological Mechanisms of Acute Resistance Training in Reducing Blood Glucose Levels in Women with a Sedentary Lifestyle: A Randomized Controlled Trial

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Abstract

Background: Women with a sedentary lifestyle are prone to metabolic disorders, including insulin resistance and increased blood glucose levels, which are important risk factors for cardiovascular disease and type 2 diabetes. Acute physical exercise has been shown to increase glucose uptake by skeletal muscle. *Objective*: To determine how resistance training affects aerobic exercise on blood glucose levels in women with a sedentary lifestyle. *Methods*: This study involved thirty-three healthy women with a sedentary lifestyle. Experimental and control groups before and after were used in this experimental study. People were selected through random sampling and allocated to the treatment group (RT), which received resistance exercise intervention, or the aerobic exercise group (AT), while the control group (CO) did not do any activity. Data collection took place over two days, starting with the collection of information regarding the characteristics of the subjects. The volunteers' blood was then taken as pre-test data before going to the activity. The participants were then instructed to warm up. After that, the participants are engaged in group-specific physical activities. Resistance and aerobic activities were among the exercises done. After the exercise intervention, blood samples were taken as post-test data. *Results*: Blood glucose levels in the resistance training group experienced a significant decrease in women with a sedentary lifestyle. *Conclusions*: The results demonstrated that acute resistance training significantly reduced blood glucose levels. Therefore, resistance training is highly recommended, especially for people with a sedentary lifestyle, to prevent various diseases and adverse effects of sedentary lifestyles.

Keywords: Blood glucose, Physical exercise, Resistance training, Sedentary life.

الآليات الفسيولوجية لتدريب المقاومة الحاد في خفض مستويات الجلوكوز في الدم لدى النساء ذوات نمط الحياة المستقرة: تجربة معشاة ذات شواهد

الخلاصة

الخلفية: النساء اللواتي يتبعن نمط حياة خامل معرضات لاضطرابات التمثيل الغذائي، بما في ذلك مقاومة الأنسولين وزيادة مستويات الجلوكوز في الدم، وهي عوامل خطر مهمة لأمراض القلب والأوعية الدموية ومرض السكري من النوع 2. ثبت أن التمارين البدنية الحادة تزيد من امتصاص الجلوكوز بواسطة العضلات الهيكلية. **الهدف**: تحديد كيفية تأثير تدريب المقاومة على التمارين الهوائية على مستويات الجلوكوز في الدم لدى النساء اللواتي يعانين من نمط حياة مستقر. **الطرائق**: شملت هذه الدراسة ثلاث وثلاثين امرأة تتمتع بصحة جيدة بأسلوب حياة مستقر. تم استخدام مجموعات التجارب والضابطين قبل وبعد في هذه الدراسة التجريبية. تم اختيار الأشخاص من خلال أخذ عينات عشوائية وتخصيصهم لمجموعة العلاج (RT)، التي تلقت تدخل تمارين المقاومة، أو مجموعة التمارين الهوائية (AT)، بينما لم تقم المجموعة الضابطة (CO) بأي نشاط. تم جمع البيانات على مدار يومين، بدءا من جمع المعلومات المتعلقة بخصائص الموضوعات. ثم تم أخذ دم المتطوعين كبيانات ما قبل الاختبار قبل الذهاب إلى النشاط. ثم طلب من المشاركين الإحماء. بعد ذلك ، يشارك المشاركون في أنشطة بدنية خاصة بالمجموعة. كانت أنشطة المقاومة والتمارين الهوائية من بين التمارين التي تم إجراؤها. بعد تدخل التمرين، تم أخذ عينات الدم كبيانات بعد الاختبار. **النتائج**: شهدت مستويات الجلوكوز في الدم قلل بشكل كبير من مستويات الجلوكوز في الدم. **الاستنتاجات**: أظهرت النتائج أن تدريب المقاومة الحاد قلل بشكل كبير من مستويات الجلوكوز في الدم. لذلك، يوصى بشدة بتدريب المقاومة، خاصة للأشخاص الذين لديهم نمط حياة مستقر، للوقاية من الأمراض المختلفة والآثار الضارة لأنماط الحياة المستقرة.

INTRODUCTION

Sedentary lifestyles are becoming a more concerning global issue, particularly for teenagers. Over the past ten years, sedentary behaviors, including gaming, watching television, and using electronic devices excessively, have increased due to changes in daily activity patterns and technological improvements [1]. More than 80% of teenagers globally do not meet the recommended levels of physical activity, according to WHO data from 2021. This increases the risk of obesity and other non-communicable diseases [2]. In addition to having an impact on adolescents' physical health, this lifestyle also affects their mental and social well-being [3]. This sedentary lifestyle exacerbates a number of health problems, including obesity, heart disease, type 2 diabetes, and mental disorders [1]. In addition, the impact of sedentary lifestyles on obesity is also very worrying. The condition known as obesity

is characterized by excessive or reckless fat storage, which may be detrimental to one's health. The middle-aged adult (40–59 years old) population has the highest obesity prevalence, at 44.3% [4]. Insulin resistance, which is typified by decreased obese patients, acquires decreased insulin activity in the liver and impaired glucose absorption in muscle and fat [5]. Many metabolic conditions, including poor lipid metabolism, increased blood sugar, and reduced glucose absorption, are indicative of the emergence of insulin resistance. Nearly one-third of people worldwide suffer from obesity and type 2 diabetes mellitus, which are generally believed to be linked to the prevalence of insulin resistance and metabolic syndrome [6]. The rising prevalence of these conditions has made insulin resistance a major cause of death and morbidity globally since it is a key factor in many severe chronic illnesses, including type 2 diabetes, cardiovascular, and cerebrovascular disorders. Globally, an estimated 9.5 million people will be living with T1D by 2025, an increase of 1.1 million people (13%) compared to the previous estimate of 8.4 million in 2021 [7]. Uncomfortably, young people under the age of 20 who are disproportionately present in low- and lower-middle-income countries bear the majority of this burden [8]. In addition to causing patients' physical and mental suffering, these metabolic disorders also put a heavy strain on healthcare systems, with overall costs, including medical bills and perhaps lost productivity, totaling trillions of dollars [9]. In order to keep humans from experiencing this, alternative methods are required. One non-pharmacological strategy to counteract the negative consequences of a sedentary lifestyle is exercise. To lower the chance of acquiring certain illnesses, preventive medicine recommends lifestyle modifications, including consistent exercise [10]. Exercise can improve blood lipid profiles and glycemic control in people with and without type 2 diabetes [11]. Health outcomes may therefore be enhanced by implementing sustainable exercise regimens that enhance cardio-metabolic risk factors. Numerous studies have examined the effects of aerobic exercise on health outcomes [10]. Activities like jogging or walking that require prolonged, repetitive movements of the large muscles for ten minutes or more are referred to as aerobic exercises. Without increasing the size of the fibers, aerobic exercise can change how insulin acts on individual fibers [12]. The American Diabetes Association (ADA) recommends at least 150 minutes of moderate-intensity aerobic physical activity or 90 minutes of vigorous aerobic exercise per week, spread out across at least three days and no more than two days without physical activity [10]. It has been demonstrated that resistance training causes a hypertrophic reaction and a change in the type of muscle fibers in working muscles, which increases the body's overall glucose usage. Resistance training lowers the risk of cardiovascular disease, improves flexibility and body composition, and builds muscle strength and endurance [10]. Resistance training has grown in popularity due to its ability to improve muscle strength and body composition, as well as its involvement in health and illness in more recent times

[13]. These advantages include better bone mineral density, blood lipid profiles, and glycemic management in healthy persons [13]. Specifically, regarding glycemic control, there is limited research examining how aerobic and resistance training can control blood sugar levels. Few studies have examined the acute effects of resistance training in women with a sedentary lifestyle. Furthermore, the underlying physiological mechanisms are still debated among researchers. Therefore, researchers are interested in conducting experimental studies examining the effects of resistance and aerobic training on blood sugar regulation. We want to determine which type of exercise is most effective in lowering blood sugar levels after exercise. This is important for providing practical recommendations regarding the types of exercise that can improve glycemic control in humans.

METHODS

Study Design

In this interventional prospective study, fifty females were evaluated for eligibility, and only thirty-three eligible respondents were randomly selected and divided into three groups: resistance training (RT) group (n=11), aerobic training (AT) group (n=11), and control group (CO) (n=11). The RT group underwent resistance training according to a program determined by the researcher, and the AT group performed aerobic exercise on a treadmill according to a predetermined program, while the control group did nothing (Figure 1).
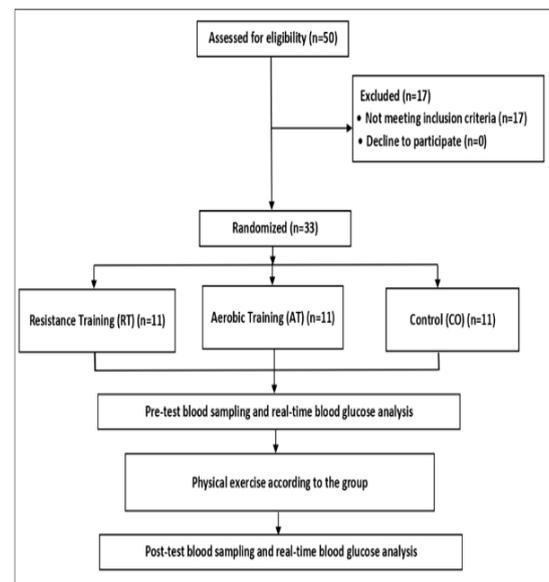
Figure 1: The CONSORT flowchart of the study.

Subjects

The Malang State Polytechnic of Health's ethical committee accepted this study, which was carried out in compliance with the Declaration of Helsinki. This study included thirty-nine healthy women (the subjects' characteristics are shown in Table 1). The researchers created inclusion and exclusion criteria to assess if volunteers met the study requirements. Subjects had to be between the ages of 18 and 26, have

a normal body mass index (BMI), lead a sedentary lifestyle, not smoke, have no history of cancer, cardiovascular disease, or musculoskeletal disorders, not use dietary or ergogenic supplements, and be willing to participate in the study. According to the short form of the International Physical Activity Questionnaire (IPAQ), a sedentary lifestyle is defined as consuming less than 600 MET minutes per week [14]. Additionally, respondents were not required to engage in regular exercise. Participants under the age of eighteen were not permitted to participate in this study. Our study additionally eliminated respondents with hypertension who had abnormal blood pressure before exercise (systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg). Subjects were also eliminated if they were taking nonsteroidal anti-inflammatory medications (NSAIDs).

Exclusion criteria

Exclusion criteria included reluctance to continue the prescribed exercise intervention (not attending the full exercise session), pregnancy, starting a special diet, and taking medication. Each chosen participant read and signed a formal consent form. In this study, 33 female volunteers were split up into three groups: 11 for aerobic training (AT), 11 for resistance training (RT), and 11 for control (CO). The study was conducted at a Fitness Center in Tulungagung City, East Java Province. In addition, all participants were guided by a certified professional fitness trainer during the exercise intervention.

Research Instruments

The following instruments we used include devices for measurement of blood pressure, height, and weight; data collection sheets; stationery; blood drawing equipment; treadmills; and gym equipment used for weight training.

Procedure

The data collection procedure in this study consisted of several steps. Subjects underwent a screening process before beginning the study. This approach was based on specific parameters that allowed information to be included or excluded from the analysis. Furthermore, they provided informed consent to participate in the study after being explained the research procedures. Three groups were randomly selected from the trial participants, divided into a treatment group receiving resistance training and aerobic training interventions and a control group receiving no intervention. Data collection was conducted over two days, beginning with information on the subjects' characteristics. Before the investigation, the subjects were not allowed to eat anything. Subjects were told to follow a typical diet and sleep schedule the day before the research. They were then instructed to warm up before exercising. Afterward, they engaged in physical activity, consisting of resistance training and moderate-intensity aerobic exercise. Before the exercise, blood was drawn for a blood glucose test as real-time pretest data, and after the exercise, blood was

drawn again for a blood glucose test as real-time posttest data. Blood samples were examined directly using blood glucose sticks and an Easy Touch blood glucose tester from the Karya Putra Bangsa Tulungagung Health Sciences College Laboratory. The blood glucose level checkers and blood drawers in this study were professional health analysts at the Karya Putra Bangsa Tulungagung Health Sciences College who had completed professional education in medical laboratory technology. As a form of accountability, after reviewing the data, the researchers compiled a written report of the research results.

Exercise intervention

Resistance Training (RT) entails teaching participants proper exercise form while certified professional trainers keep an eye on their performance during group training sessions. Each training session lasts 60 minutes and is delivered acutely. Targeting both the upper and lower body, the 40-minute strength training session consists of three sets of ten exercises, such as the seated row, shoulder press, chest press, lateral pull-down, abdominal crunch, leg press, leg extension, triceps pushdown, and seated bicep curl. Each resistance exercise is carried out in compliance with the National Strength and Conditioning Association's criteria, which have been applied in earlier research [15]. Subjects performed 8-10 repetitions of 3 sets for each exercise and rested for 5-10 minutes between sets. Exercise intensity was 75-80% of 1RM. Participants were assessed using seated leg presses and upper and lower body bicep curls to determine their 1RM. Participants were placed with their knees bent at a 90-degree angle following their leg press warm-up. After applying a conservative load to the machine, participants were told to completely extend their knees and repeat the process until they became tired. The weight was raised for sitting bicep curl participants in a range of 100 degrees, from full extension to fatigue. Due to the participants' inexperience and potential for harm, 1RM was calculated for each participant using a formula rather than being measured directly [14]:

1RM = (Total weight lifted (kg)/(102.78 - (002.78 × number of repetitions)).

Walking briskly for 30 minutes at a pace of 5–6 km/h on a treadmill is known as aerobic exercise (AE). The following formula is used to measure each participant's maximal heart rate (HRmax), which determines the exercise's intensity: $208 - 0.7 \times age = HRmax$ [17].

During a single training session, the exercise's intensity progressively increases from 65% of HRmax to 75% of HRmax. The control group (CO) was asked to just sit and lie down at the designated research location. The only activities allowed were playing with cell phones, sitting, and walking to the bathroom in the designated area. Participants in this group were allowed to play with their cell phones and communicate with their groupmates to overcome boredom while waiting in line to have their blood drawn.

Ethical considerations

Prior to their participation, participants signed a written informed consent form. Prior to the intervention, participants signed a written informed consent form. With reference number DP.04.03/F.XXI.30/00841/2025, the Health Polytechnic's Research Ethics Committee of the Ministry of Health of Malang has approved this study.

Statistical analysis

Following data collection, statistical analysis was performed using SPSS software. The data was subjected to a descriptive analysis in order to ascertain the mean and standard error. As a normalcy test, the Shapiro-Wilk test was also employed in this study. To determine if the data were normally distributed, a difference test was developed using the paired t-test methodology. The data was examined using the Wilcoxon signed-rank test; however, the results showed differently.

RESULTS

Statistics and details regarding the general description of the participants in Table 1 are presented in this section. These statistics provide a better understanding of the characteristics of each group. Mean ± standard deviation is used to display the data. The t-test results from the initial study showed no significant differences between the resistance training, aerobic training, and control groups ($p>0.05$). Based on the normality test in Table 2, the blood glucose data for all groups were normally distributed ($p>0.05$). Therefore, the next test performed was a paired-samples t-test.

Table 1: Characteristics of research subjects

Variables	Group	Result	*p*-value
Age (year)	RT	20.36±1.12	
	AT	20.63±2.15	
	CO	20.90±1.70	0.759
Height (cm)	RT	157.18±5.61	
	AT	155.82±5.81	
	CO	157.18±7.13	0.840
Weight (kg)	RT	54.19±7.93	
	AT	54.09±7.70	
	CO	51.72±6.73	0.686
BMI (kg/m^2)	RT	21.89±2.77	
	AT	22.27±2.88	
	CO	21.00±2.82	0.563
Systolic (mmHg)	RT	116.36±16.54	
	AT	114.18±8.87	
	CO	108.36±17.06	0.427
Diastolic (mmHg)	RT	77.09±9.75	
	AT	71.36±5.62	
	CO	73.36±9.27	0.285

Values were expressed as mean ± SD. n=11 in each group.

Table 2: Normality test results

Data	Group	Shapiro-Wilk test	
		n	*p*-value
Blood glucose	RT (Pre-test)	11	0.795
	RT (Post-test)		0.286
	AT (Pre-test)	11	0.591
	AT (Post-test)		0.321
	CO (Pre-test)	11	0.570
	CO (Post-test)		0.898

The results of the blood glucose analysis between pre-test and post-test in each group are presented in Figure 2. Figure 2 shows that the RT group given resistance training intervention significantly reduced blood glucose levels in women with a sedentary lifestyle ($p<0.05$).
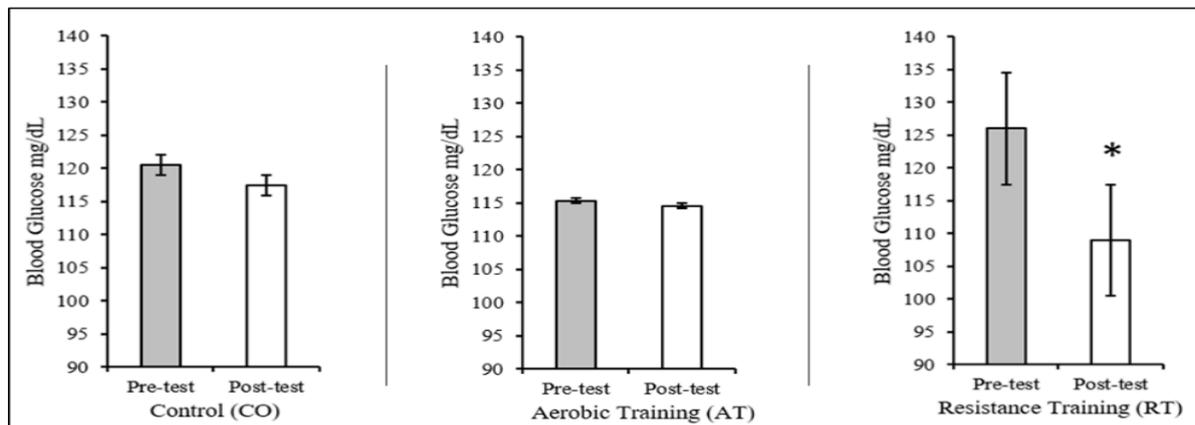

Figure 2: Changes in blood glucose levels pre- and post-intervention in the three studied groups (n=11 in each group).* significantly different compared to pre-intervention ($p<0.05$).

Table 3 shows the results of the paired samples t-test. There was a significant difference in the (RT) group with resistance training intervention ($p<0.05$) and there was no significant difference in the (AT) group with aerobic training intervention or the (CO) control group ($p>0.05$).

DISCUSSION

This study aims to determine the effect of aerobic exercise and resistance training on blood glucose levels. According to the study's findings, resistance training significantly lowers blood glucose levels ($p<0.05$).

Table 3: Results of blood glucose levels

Data	Group	Paired t-test	
		Results	*p*-value
Blood Glucose (mg/dL)	RT (Pretest)	126.0±8.7	<0.0001
	RT (Post-test)	109.55±7.51	
	AT (Pre-test)	115.36±7.94	0.724
	AT (Post-test)	114.55±9.96	
	CO (Pre-test)	120.55±9.48	0.084
	CO (Post-test)	117.45±7.67	

Data are presented as mean ± standard deviation.

Previous studies on participants who engaged in high-intensity interval training (HIIT) demonstrated a considerable drop in blood glucose levels, which lends credence to this finding [18]. When blood glucose levels drop, it means that muscles are absorbing more blood glucose as a result of activity [19]. Additional research shows both resistance and aerobic exercise programs lower blood sugar levels in people with type 2 diabetes [20]. Other research findings also support the idea that physical exercise therapies, such as resistance and aerobic exercise, reduce blood sugar in individuals with type 2 diabetes [21]. It has been demonstrated that physical activity significantly improves health status. Indeed, we know that the benefits of resistance training cover various aspects of health, such as strength, bone mass/bone mineral density (BMD), body composition, mental health, and cognitive function [22]. Additionally, resistance training can help prevent negative health outcomes in adolescents, such as type 2 diabetes, cardiovascular disease, and premature death. Furthermore, physical therapy has been shown to improve muscular fitness (i.e., muscle strength, power, and endurance) in adolescents [22]. Additionally, by lowering blood glucose levels, it is a helpful non-pharmacological treatment for individuals with diabetes mellitus. This is in line with other studies' findings that blood glucose levels decreased in individuals with diabetes mellitus after a six-week telerehabilitation intervention that included breathing techniques and exercise sessions conducted three times a week at home via internet-based video conferencing [23]. Results from additional studies revealed that mice treated with physical activity had reduced blood glucose levels [24]. According to a different study, blood glucose levels significantly dropped in 90 diabetes mellitus patients who got aerobic physical activity treatment [25]. Another study indicated that after participating in an aerobic exercise program, blood glucose levels in people with diabetes mellitus decreased, supporting the same findings [26]. In this study, the aerobic intervention group did not show a decrease in blood glucose levels. This may be related to suboptimal exercise intensity. Furthermore, we only examined the acute post-exercise period. Therefore, further investigation is needed to determine why blood glucose levels did not decrease in the aerobic intervention group. Meanwhile, the resistance training group experienced a significant decrease in blood glucose levels. The following are mechanisms by which exercise increases glucose transporter 4 (GLUT4): When we exercise, the body produces more reactive oxygen species (ROS) as a natural reaction [27]. When muscle contraction and ROS levels rise, the action potential moves through the t-tubule, starting muscle contraction and letting calcium ions (Ca^{2+}) out of the sarcoplasmic reticulum. Ca^{2+} ions enter the cytoplasm passively, increasing the amount of Ca^{2+} in the cytosol by ten to twenty times [28]. An increase in intracellular Ca^{2+} activates the calcium/calmodulin-dependent protein kinase (CaMKK) [29]. Research indicates that exercise can enhance this advantage by enhancing muscle function through AMPK regulation. CaMKK activation will boost the activity of adenosine

monophosphate protein kinase (AMPK), which is equally crucial and required for physical fitness [30]. Additionally, physical activity increases the requirement for adenosine triphosphate (ATP) [31]. Therefore, increased phosphorylated AMPK will result in increased production of GLUT4, a protein implicated in glucose transport [19]. Glutamate transporter type 4 (GLUT4) makes it easier for glucose to get into skeletal muscle cells by creating a difference in glucose concentration between the interstitial space (the space outside the muscle cell) and the cytoplasm (the inside of the muscle) [32]. Understanding the molecular mechanisms governing skeletal muscle metabolism is essential for developing better treatment strategies for metabolic diseases such as type 2 diabetes [29]. According to numerous studies conducted on individuals with type 2 diabetes, resistance exercise is the most efficient method of gaining strength and building muscle [30]. After 12 weeks of resistance training, individuals with type 2 diabetes and healthy participants showed similar increases in muscle strength in a randomized controlled trial [31]. Exercise causes muscles to contract more, which uses a lot of energy. Increasing muscle mass is another benefit of resistance training [32]. Because exercise reduces ATP, it can increase AMPK phosphorylation. Muscle contraction energy expenditure increases AMP and decreases intracellular ATP levels, which causes AMPK phosphorylation and activation. Thus, we are aware that HIIT training's high energy expenditure increases the intracellular ADP/ATP and AMP/ATP ratios, which may lead to AMPK [19]. Therefore, during resistance exercise, AMPK will trigger GLUT4 translocation, which may increase blood glucose uptake. Numerous skeletal muscles are used during resistance training, necessitating a large amount of energy to sustain muscle function and complete the training task. Following resistance exercise, blood glucose levels fall as a result of the muscles' increased demand for glucose and their increased muscular mass. We'll also talk about glucose transporters (GLUTs), which are a class of membrane proteins that facilitate the passage of glucose across cell membranes and are similarly elevated during physical activity [33]. Ten weeks of HIIT enhances GLUT4 translocation, according to earlier studies [34]. GLUT4 is the primary and distinct glucose transporter responsible for skeletal muscle glucose absorption [19]. As a result, during resistance training, GLUT4 enables the muscles to rapidly absorb glucose levels. Exercise causes the body's muscles to absorb more glucose, which lowers blood glucose levels [35]. Exercise-induced mechanisms of glucose distribution in muscles include enhanced diffusion, membrane permeability to glucose, and intracellular glucose metabolism [36]. The primary facility in charge of the enormous translocation of tiny GLUT is responsible for transporting molecules across the cell membrane, including metabolites, toxins, and nutrients, which is a part of the glucose transporter [37]. Several glucose transporters, which result in 14 different glucose isoforms in various tissues and species [38], mediate the diffusion. The glucose

transporter GLUT4, which is activated by muscular contraction during exercise, has been discovered by a number of researchers over the last three decades. Our knowledge of how insulin and exercise affect the movement and absorption of glucose in muscle and fat has improved thanks to earlier studies [39]. How glucose uptake rises so much during exercise is an interesting subject. To guarantee continuous glucose delivery to the muscles, elevated hepatic glucose synthesis and blood flow maintenance of plasma glucose levels are unquestionably essential. But unless the permeability of the muscle membrane to glucose improves, glucose will not be able to enter the muscles [32]. According to research findings [40], athletic exercise can increase GLUT4 in skeletal muscles. Because of the presence of insulin and the GLUT4 translocation mechanism to the muscle fiber membrane surface, skeletal muscle absorbs glucose the most [39]. The benefits of exercise in preventing and treating metabolic illnesses are widely acknowledged [41]. It is still unknown what mechanisms underlie exercise's beneficial effects on metabolic health. Consistent exercise, however, has been demonstrated to have a substantial effect on a person's overall energy metabolism, especially on skeletal muscle substrate consumption [42]. In reality, a 100-fold increase in the legs' glucose uptake would lead to a 100-fold rise in the amount of glucose carried across the muscle membrane [32]. Skeletal muscle is the body's greatest site for quantitative glucose absorption [43]. Thus, it is indeed evident that we need to exercise regularly and consistently to maintain a healthy body. Furthermore, resistance training has a positive effect on increasing glucose uptake through GLUT4, which in turn increases blood glucose absorption in muscles. This underpins the effectiveness of resistance training in lowering blood glucose levels. Indeed, resistance training is highly recommended as a non-pharmacological therapy to lower blood glucose levels in women with a sedentary lifestyle.

Study limitations

The strength of this study lies in its randomized controlled experiment, the most reliable scientific method, which eliminates the possibility of ambiguous cause-and-effect relationships. Furthermore, we discuss the limitations of our study, such as the limited sample size. We acknowledge that a larger sample size would provide a better understanding of the results. Furthermore, we only measured acute effects and did not consider dietary factors, making this a limitation of our study. Furthermore, our intervention focused solely on resistance training and aerobic exercise. Future studies may explore the combined effects of physical exercise on blood glucose levels. Furthermore, the long-term effects of resistance training on glucose control and other metabolic indicators need to be explored. Furthermore, the long-term impact of exercise on patients with high glucose levels or diabetes mellitus is needed to concretely demonstrate the effects of physical exercise on blood glucose levels.

Conclusion

Acute resistance training has been shown to significantly lower blood glucose levels, making it important for women with sedentary lifestyles. Resistance training can be a recommended alternative exercise for lowering blood glucose levels.

Conflict of interests

The authors declared no conflict of interest.

Data sharing statement

Supplementary data can be shared with the corresponding author upon reasonable request.

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