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The comparison between HIIT and Resistance Training in muscle expression of FTO and PPAR-γ in obese diabetic rats

Mahsa Moghadassi [1] ,Boshra Mahmoodi[2] ,Mahmood Ghafari[3], Paria Davari[4] , Fatemeh Asghari ahoii[5], Rozhan Hamzehzadeh[6], Masoumeh Sarreshteh[7]

[1]M.Sc Student of Exercise Physiology, Department of Exercise Physiology, Islamic Azad University Tehran North Branch, Tehran, Iran- ORCID: 0000-0002-5004-2845- Email: – Address: The State University of New Jersey 57 US Highway 1. New Brunswick, NJ 08901-8554- Phone Number: +989122960636

[2] M.Sc Student of Exercise Physiology, Faculty of Sports Sciences, Allameh Tabatabaei University, Tehran, Iran- ORCID: 0009-0009-3996-613X- Email: Boshramahmoudi4@gmail.com

[3] Faculty of Physical Education and Sport Sciences, Allameh Tabataba'i University, Tehran, Iran- ORCID: (https://orcid.org/0000-0002-8585-0957)- Email

[4]Department of Sports Sciences, Faculty of Physical Education and Sports Sciences, Shahid Beheshti University, Tehran, Iran, 0009-0004-9828-8248- Email: Paria76dav@gmail.com

[5]Bachelor student of Physical Education, Faculty of Sports Sciences, Islamic Azad University north Tehran branch- Tehran, Iran- ORCID: 0009-0003-0068-4473- Email: Fatemeh.asghariahoii1995

[6]gBachelor student of Sports Sciences and Physical Education, Faculty of Sports Sciences, Sanandaj Islamic Azad University of Sanandaj, Sanandaj, Iran- ORCID: 0009-0001-9661-874X- Email: rozhanhmz2000@gmail.com

[7] Bachelor Student of Physical Education, Faculty of Sports Sciences, Alzahra University, Tehran, Iran- ORCID: 0009-0005-0881-5081- Email: masoumehsarreshteh@gmail.com

Mahsa Moghadassi

M.Sc Student of Exercise Physiology

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Abstract

Objective: According to the World Health Organization (WHO), the prevalence of obesity among adults aged 18 and above is estimated to be around 2 billion worldwide. The purpose of this study was to investigate the comparison between High Intensity Interval Training and Resistance Training in the expression of FTO and PPAR-γ genes in muscle tissue among type 2 diabetic obese rats.

Methods: This experimental study utilized a sample of 12 male Wistar rats, with an average bodyweight of 220±20 g and an age of 10 weeks. The rats were subjected to a high-fat diet for a duration of six weeks. To induce type 2 diabetes, a single intraperitoneal injection of 30 mg/kg of freshly prepared streptozotocin (STZ) was administered, dissolved in citrate buffer with a pH of 4.5. Rats with diabetes were then randomly divided into three groups: HIIT and Resistance training. Measurements were taken 48 hours after the final training session. The expression level of FTO and PPAR-γ in the muscles were assessed using the real-time PCR method. Statistical analysis was conducted using independent samples t-test and Analysis of Covariance (ANCOVA) to compare the means between the groups.

Results: FTO expression decreased significantly in the HIIT group (P<0.042) while, the RT group faced no significant changes (P<0.452). However, PPAR-γ expression increased only in the HIIT group (P<0.020). The were no significant differences between the changes of FTO and PPAR-γ expression between groups (FTO P<0.243 and PPAR-γ P<0.158).

Conclusion: the findings from this study suggest that short-term and high-intensity aerobic exercises have a more pronounced impact on the expression of FTO and PPAR-γ genes, as well as related factors, in individuals with obesity and type 2 diabetes compared to resistance exercises. The aerobic exercises demonstrated significant alterations in the expression of both the FTO and PPAR-γ genes.

Keywords: Aerobic, T2D, Interval, Mice, Glucose, HIIT, FTO, PPARy

Introduction

Obesity is linked to higher susceptibility to a range of diseases such as hypertension, type 2 diabetes, cardiovascular diseases, osteoarthritis, neurodegenerative diseases, and so on (1–3). According to the report of the World Health Organization, 2 billion adults aged 18 and older are overweight and obese, of which 2 billion 650 million people are obese (4). Recent studies have shown that obesity plays a predominant role in the development of type 2 diabetes among individuals with a genetic susceptibility to this condition (1). However, it is noteworthy that sedentary lifestyles and inadequate dietary patterns, particularly prevalent in developing nations, are also recognized as significant contributing factors to the onset of this disease (5,6).

Type 2 diabetes is one of the most common complications of obesity, which is associated with cardiovascular diseases, kidney, digestive, vision, skin and nerve damage (1). The escalating prevalence of type 2 diabetes within the population has raised significant public health concerns in recent years, positioning it as one of the foremost global public health challenges. Studies have highlighted a notable rise in the diabetic population, with the number of individuals affected by diabetes increasing from 422 million in 2014 to 463 million in 2019 (4). Furthermore, it is distressing to note that approximately 4.2 million people die annually out of this disease. Moreover, diabetes is correlated with issues such as diminished physical performance and disruptions in daily activities, consequently leading to an escalation in healthcare expenses for individuals affected by this condition (6).

Insulin resistance represents a prominent characteristic among individuals diagnosed with type 2 diabetes (7). In type 2 diabetic patients, a notable disruption occurs in the absorption of glucose by muscle, adipose tissue, and liver cells, resulting in an upregulation of insulin secretion by pancreatic cells. According to reports, obese individuals with type 2 diabetes demonstrate elevated secretion of non-esterified fatty acids, glycerol, and pro-inflammatory cytokines from adipose tissue (8). These factors contribute to insulin resistance and the concurrent occurrence of impaired glucose control.

The fat mass and obesity-associated gene (FTO) serves as one of the principal regulators of fat metabolism (9). Evidence indicates that both overexpression and deletion of the FTO gene in animal cells have resulted in significant alterations in the body mass profile and body composition of the animals. On another note, FTO plays a pivotal role in the pathogenesis of type 2 diabetes by directly interacting with glucose-6-phosphate (GP) (9). The increased expression of the FTO gene in adipose tissue has been associated with the development of type 2 diabetes in obese individuals. Recent research in this field has provided compelling evidence supporting a direct and substantial association between FTO and body mass index, as well as the risk of obesity. Frayling et al. (2007) demonstrated that the FTO gene exhibits widespread expression across various human tissues, particularly in the brain and hypothalamus [10]. Furthermore, Boissel et al. conducted a study on fetal and adult human tissues, revealing that the brain and liver exhibit the highest levels of FTO expression (11). The findings of this study highlight that the mRNA associated with FTO exhibits robust expression levels in the brain, particularly in the hypothalamus, which plays a critical role in regulating hunger and satiety.

Peroxisome proliferator-activated receptor gamma (PPAR-γ) is recognized as the receptor responsible for the inverse regulation of insulin resistance by glitazone, primarily expressed in adipose tissue, PPAR-γ plays a crucial role in regulating the expression of genes associated with fat metabolism (12). The PPAR-γ receptor exerts influence over processes such as cell differentiation and lipid accumulation during adipogenesis. Consequently, it can be regarded as a significant regulator of fat metabolism, insulin sensitivity, and tissue homeostasis as a whole. Additionally, upregulating the expression of peroxisome proliferator-activated receptor gamma (PPAR-γ) has been shown to mitigate hyperlipidemia, hypoglycemia, and arteriosclerosis, which are known risk factors for stroke in individuals with type 2 diabetes [13]. Several studies have reported that enhanced expression of PPAR-γ in diabetic rats is correlated with improved glucose and fat metabolism. Li et al. conducted a study showing that 8 weeks of low-intensity strength training resulted in an upregulation of the expression of the PPAR-γ gene in the adipose tissue of obese mice (14). Kim et al. have reported that 6 weeks of aerobic training (swimming) combined with rosiglitazone administration led to an increase in the expression of PPAR-γ, adiponectin, and Glut4 in the soleus muscle of diabetic rats (15).

There is substantial evidence supporting the crucial role of exercise and physical activity in both the prevention and management of non-communicable diseases [16–24]. Physical ac

and exercise have been established as the fundamental cornerstones of diabetes care and management for many years (6). Their significance in the field of health is particularly notable due to their low cost and non-pharmacological nature. In a recent study by Silva et al., it was reported that a 16-week intervention consisting of aerobic and strength training resulted in notable improvements in plasma glucose levels, body composition, and high-density lipoprotein (HDL) levels among individuals with type 2 diabetes (25). Also, in a study conducted by Zheng et al., it was reported that performing progressive resistance exercises by people with type 2 diabetes led to an improvement in the glycemic index in people with type 2 diabetes (14). Furthermore, a recent study demonstrated that engaging in 8 weeks of aerobic exercise is associated with improvements in insulin resistance, thyroid hormone function, weight reduction, and reduction in blood lipid levels. Given the beneficial impact of exercise in managing type 2 diabetes and its associated complications, coupled with the insufficient literature on the differential effects of various exercise interventions on the expression of genes related to obesity and metabolic disorders, the objective of this research is to examine the contrasting effects of aerobic and resistance interventions on the expression of FTO and PPARγ genes in diabetic obese rats.

Methods

Animals

This research experiment was conducted on 18 male Wistar rats of 10 weeks old with a body weight of 220±20 g, procured from Iran Pasteur Institute. The rats were first accustomed to the environment in the animal house of Islamic Azad University, Alborz Province, for a week before commencing the study. During this time, the rats were provided with standard high-fat food and drinkable water (Sun et al., 2000), and were kept in a room measuring 1.60×2.20 meters, maintained at a temperature of 22±3 °C, with 30–60 % relative humidity, and a half-day light/ half day dark cycle. The study adhered to the regulations prescribed in the Guide for the Care and Use of Laboratory Animals of Islamic Azad University, Alborz Province, and was approved by the ethics committee under the code 96-8-3788.

Type 2 diabetes induction

In order to induce type 2 diabetes, the animals were fed a high-fat diet for a period of six weeks. Following this, a single intraperitoneal injection of freshly prepared streptozotocin([STZ) at a dosage of 30 mg/kg was administered, dissolved in citrate buffer (pH 4.5), to the animals. The STZ was obtained from Sigma, USA. To prepare the high-fat food, 1% cholesterol powder and 1% pure corn oil were added to the standard food obtained from the Pars Dam company. It is important to note that all three groups of animals were kept on a high-fat diet throughout the study duration. After one week of inducing diabetes, fasting blood glucose levels were measured. Rats with blood glucose levels ranging from 150 to 400 mg/dl were considered to have developed type 2 diabetes, according to the criteria established by Izadi et al. (2017). Subsequently, the diabetic rats were randomly divided into 3 groups, namely the diabetic control group (n=6), the diabetic resistance training group (n=6) and the diabetic HIIT training group (n=6).

Training protocols

The rats in the diabetic resistance training group were trained to climb a ladder for a period of two weeks prior to the commencement of the training protocol. The resistance training involved climbing the ladder with gradually increased resistance, achieved by attaching a load equivalent to varying percentages of the rat's body weight to its tail. The training program involves 5 sessions per week, with each session consisting of 5 sets of 4 repetitions each. Rest intervals of 2 minutes were provided between sets, while a rest interval of 30 seconds was given between repetitions within each set. This exercise regimen lasted for a total of 6 weeks, as detailed in Table 1.

The rats in the high-intensity interval training (HIIT) group were trained to run on a treadmill for a period of two weeks prior to the beginning of the exercise protocol. The HIIT protocol lasted for 6 weeks and involved 5 sessions of 30 minutes per week. The HIIT program consisted of repetitions lasting 40 seconds each, with 8 repetitions in the first week and 10 repetitions in subsequent weeks, at varying speeds and slopes as outlined in Table 2. Active rest periods of 2 minutes at a rate of 10 m/min were provided between each repetition.

Blood and tissue sampling

Forty-eight hours after the final training session, the rats in both groups were anesthetized using a ketamine 10%/xylazine 2% mixture at a dose of 50 mg/kg and 10 mg/kg, respectively. They were then euthanized by cervical dislocation, and blood samples were collected directly from the heart following the opening of the thoracic cavity. Samples of the gastrocnemius muscle from the rats were collected, washed into a saline solution, and then immersed in microtubes containing RNA later TM at a 20% ratio. These samples were then transferred to -70 °C for further genetic testing. The genetic testing was carried out at the Tehran Pasteur Institute in Iran.

Table1: Resistance training protocol

week	sets	Repetition in each set	Intensity of exercise	Rest between Rep	Rest between sets	Frequency
1	5	4	30%BW	30 sec	2 min	5 d.w
2	5	4	50%BW	30 sec	2 min	5 d.w
3	5	4	70%BW	30 sec	2 min	5 d.w
4	5	4	90%BW	30 sec	2 min	5 d.w
5	5	4	100% BW	30 sec	2 min	5 d.w
6	5	4	100% BW	30 sec	2 min	5 d.w

Table 2, High Intensity Interval Training Protocol

week	Repetition	Time of exercise	Intensity of exercise	Time of active rest	Intensity of active rest	Gradient
1	8	40 sec	25 m/ min	12. sec	10 m/ min	5%
2	10	40 sec	25 m/ min	12. sec	10 m/ min	10%
3	10	40 sec	28 m/ min	12. sec	10 m/ min	10%
4	10	40 sec	32 m/ min	12. sec	10 m/ min	10%
5	10	40 sec	35 m/ min	12. sec	10 m/ min	10%
6	10	40 sec	35 m/ min	12. sec	10 m/ min	10%

Insulin resistance assay

The blood samples were promptly centrifuged at 1000×g for 2 minutes to separate serum, and the resulting serum was stored at -80°C for later measurement of glucose and insulin levels. Glucose levels were measured using an enzymatic colorimetric procedure with glucose oxidase technology, employing the glucose kit from Pars Azmoon Company (Tehran, Iran). The intra-test and extra-test change coefficients for glucose were 1.74 and 1.19 percent, respectively, and the measurement sensitivity was 5 mg/dl. Insulin levels were measured by the ELISA method using a Demeditec laboratory kit [Germany], with intra-test and extra-test change coefficients of 2.6 and 2.88 percent, respectively, and a sensitivity of 1.76 units. Insulin resistance was then calculated using the following formula:

Insulin resistance = (glucose (mmol/l) × insulin (μU/ml) / 22.5

Real-time polymerase chain reaction [Real-time PCR]

Real-time PCR was used to determine the mRNA expression levels of FTO and PPAR-γ genes in the gastrocnemius muscle tissue. We designed a sequence of primers for these genes and ordered them from Pishgam Biotech Company in Tehran, Iran. We also used RNA-polymerase II gene as an internal control to evaluate the relative quantitation of mRNA expression.

To extract RNA, 20 mg of the tissue was crushed using a scalper and RNA was extracted using the Rneasy protect mini kit from QIAGEN, Germany. The concentration of RNA was determined using a NanoDrop (2000, USA). Then, the cDNA synthesis from RNA was carried out using a cDNA synthesis kit from QIAGEN, Germany, and the obtained product was maintained at -20 °C.

Real-time PCR was performed using the Rotorgen 6000 system and One Step SYBR® Green kit from TaKaRa, Japan, according to the manufacturer's instructions. The thermal cycle protocol included 1 cycle at 42 °C for 20 min, 95 °C for 2 min to activate the enzymes, and 40 cycles at 94 °C for 10 sec and 60 °C for 40 sec. The CT values of the reactions were recorded by the device software, and the fold change was calculated using the following formulas:

ΔCt = Ct target gene – Ct polymerase ll

ΔΔCt = ΔCt training group – ΔCt control group

Fold change = $2^{\wedge[-\Delta\Delta Ct]}$

Statistical Analysis

The normality of data distributions was assessed using the Shapiro-Wilk test, and statistical analyses were performed using SPSS 26 software. Mean values with standard deviations were reported. ANCOVA and independent t-tests were used to compare means, with a significance level set at $p<0.05$.

Results

Statistical analysis in this study has shown a significant increase in insulin in both HIIT ($P<0.001$) and RT ($P<0.000$) following the interventions. Glucose, on the other hand, showed a significant decrease in both groups ($P<0.000$). As it can be seen in table 5, there was no significant difference between the changes of insulin and glucose between two groups after the interventions (Insulin $P<0.611$ and glucose $P<0.207$). The FTO expression in gastrocnemius had a significant decrease in HIIT group ($P<0.042$), while, the RT group faced no significant changes ($P<0.452$). The PPAR-γ expression also was increased just in HIIT group ($P<0.020$). The were no significant differences between the changes of FTO and PPAR-γ expression between groups (FTO $P<0.243$ and PPAR-γ $P<0.158$). Weight had a significant decrease in HIIT group ($P<0.000$), whilst, it increased significantly in RT ($P<0.003$). There was a significant difference between the changes of weight between the groups after the interventions ($P<0.001$).

Discussion

The current study aimed to compare the effects of two different types of exercise interventions, namely resistance training (RT) and high-intensity interval training (HIIT), on the expression of FTO and PPARγ genes in the muscles of obese diabetic rats.

Our research findings indicate that engaging in 8 weeks of exercise resulted in significant alterations in insulin hormone levels in both the HIIT group ($p<0.001$) and the RT group ($p<0.000$). Additionally, there was a notable decrease in blood sugar levels in both the HIIT group ($p<0.000$) and the RT group ($p<0.000$). However, we did not observe a significant difference in the levels of the mentioned variables between the HIIT and resistance training groups following the interventions. Specifically, no significant differences were found in insulin levels ($p>0.6110$ and glucose levels $9p>0.207$) between the two groups. Indeed, it is widely recognized that both aerobic and resistance exercise offer extensive benefits in the management and treatment of type 2 diabetes. These types of exercise have been associated with improvements in the function of skeletal muscles, liver, and pancreas, as well as reductions in fat tissue [26,27]. Moreover, exercise offers additional advantages such as enhanced blood sugar control and improved insulin signaling.

It has been reported that immediately following exercise, insulin sensitivity throughout the body

and this heightened sensitivity persists for up to 96 hours [28,29]. Furthermore, studies have demonstrated that aerobic activity results in an elevation in mitochondrial content and oxidative enzymes [30,31]. This leads to notable improvements in various metabolic parameters, including HbA1c levels, insulin resistance, blood sugar control, insulin sensitivity, and oxidative capacity. Additionally, aerobic exercise contributes to the regulation of lipid metabolism and lipoprotein oxidation, involving the oxidation of glucose and fatty acids. Moreover, it has been observed that aerobic exercise increases the expression of proteins involved in insulin signaling, ultimately leading to a decrease in blood sugar levels [32–34]. It has been revealed that achieving a 10 to 15% increase in muscle strength yields several benefits, including improvements in bone mineral density, blood pressure, lipid profile, cardiovascular health, insulin sensitivity, increased glycogen storage, and muscle mass. These findings emphasize the importance of enhancing muscle strength for overall health and well-being. Resistance training offers the advantage of reducing HbA1c levels, thereby facilitating glucose uptake by muscles [26,35,36]. Ronald J. et al. conducted a study demonstrating that 22 weeks of resistance training resulted in improved blood sugar control and reduction in hemoglobin A1c levels among individuals with type 2 diabetes [37]. Furthermore, another study reported that resistance training significantly decreased insulin resistance and blood glucose levels in rats with type 2 diabetes [38]. These findings highlight the beneficial effects of resistance exercise on glycemic control in both human and animal models.

Our findings indicate that HIIT is associated with significant changes in the expression of the FTO gene ($p>0.042$). However, the expression of this gene did not demonstrate any significant changes in the Resistance training group ($p<0.452$). Moreover, no significant difference was observed in the expression of this gene between the aerobic and resistance interventions after 6 weeks ($p<0.243$).
Yazdan Pazhooh et al., in alignment with the present study, conducted research on the effect of resistance training on the expression of the FTO gene in type 2 diabetic rats and found that 6 weeks of resistance training did not alter the expression of the FTO gene in adipose tissue [38]. Additionally, consistent with these findings, Mohammadian et al. reported that 12 weeks of exercise, specifically high-intensity interval training (HIIT), resulted in a decrease in FTO gene expression in type 2 diabetic rats [39]. These studies support the notion that the effects of exercise on FTO gene expression may vary depending on the type and duration of the exercise intervention [9]. Indeed, there is limited research available regarding the effects of exercise on FTO gene expression in individuals with diabetes. It has been reported that only resistance training led to a significant reduction in FTO gene expression in the muscle tissue of obese women with type 2 diabetes. However, due to the scarcity of studies in this area, particularly focusing on the effect of exercise on FTO gene expression in muscle tissues of individuals with diabetes, there is a lack of substantial evidence regarding the specific impact of these exercises on FTO gene expression in this particular population. Further investigations are needed to better understand the relationship between exercise interventions and FTO gene expression in diabetic individuals, particularly in muscle tissue. Based on the previous literature and the findings of this study, it can be concluded that the intensity of physical activity is a crucial factor influencing the expression of the FTO gene. A study conducted by Danaher et al. examined the acute effects of two aerobic activities with different intensities on FTO mRNA expression in muscle tissue among healthy individuals.
The results of this study revealed that a session of high-intensity aerobic activity [at 80% of VO2 peak] led to a significant decrease in FTO mRNA gene expression in both healthy men and women. Conversely, there were no significant changes observed in FTO gene expression following aerobic activity with low intensity (at 40% of VO2 peak). These findings highlight the impact of exercise intensity on FTO gene expression, suggesting that higher intensity activities may have a more pronounced effect on regulating FTO gene expression [39]. Based on the findings of the mentioned study, the lack of significant changes in FTO gene expression in the resistance training group of the present study could potentially be attributed to the inadequate intensity and the relatively short duration of the exercise protocol. Researchers should consider these factors in their investigations to ensure optimal effects on FTO gene expression. However, it is important to note that the underlying mechanisms linking exercise and physical activity to FTO gene expression have not been fully elucidated. Nonetheless, some studies have suggested the involvement of AMPK-activated protein kinase (AMPK) in mediating these effects. AMPK is known to play a role in cellular energy metabolism and may contribute to the regulation of FTO gene expression in response to exercise stimuli [27,39]. Further research is needed to better understand the precise mechanisms underlying the impact of exercise on FTO gene expression and its association with AMPK activation.

Table3: The primer sequences of FTO and PPAR-γ in this study

Genes	Primer sequence	Product size	Tm	Gene Bank
FTO	**For**:TACACAGAGGCCGAGATTGC **Rev**:AAGGTCCACTTCATCATCGCAG	159 bp	60	NM_001191052.1
PPAR-y	**For**: ACAACAGGCCACATGAA-GAGC **Rev**:AAGCTTCAATCGGATGGTTCTTCG	159 bp	60	NM_001191052.1
RNA Polym-raseII	**For**: ACTTTGATGACGTG-GAGGAGGAC **Rev**:GTTGGCCTGCGGTCGTTC	164 bp	60	XM_008759265.1

Table 4, Metabolic differences between interventions in post-test

Variables Time	**HIIT [mean±SD]**	**Resistance training [mean±SD]**	**Time effects p-value**	**Interaction effect [time*group] P-value**
Insulin **Pre:** **Post:**	5.22±0.44 6.52±0.58	5.22±0.44 6.37±0.34	P<0.001 Eta-squared=0.788	P=0.611 Eta-squared=0.027
Glucose **Pre:** **Post:**	293±13.04 194±14.25	293±13.04 184.5±12.34	P<0.001 Eta-squared=0.989	P=0.207 Eta-squared=0.154
Weight3 **Pre:** **Post:**	397.33±5.35 335.50±16.48	397.33±5.35 417.67±11.38	P=0.028 Eta-squared=0.409	P<0.001 Eta-squared=0.852
FTO **Pre:** **Post:**	1.00±0.00 0.71±0.30	1.00±0.00 0.92±0.27	P=0.046 Eta-squared=0.340	P=0.243 Eta-squared=0.134
PPAR-γ **Pre:** **Post:**	1.00±0.00 1.69±0.61	1.00±0.00 1.26±0.32	P=0.007 Eta-squared=0.531	P=0.158 Eta-squared=0.189

Table 5, Differences in metabolic factors after two interventions

Variables	HIIT Group			Resistance Training Group		
	Pre	Post	P	Pre	Post	P
Insulin [μIU/ml]	5.22	6.58	0.001**	5.22	6.37	0.000**
Glucose [mg/dL]	293	194	0.000**	293	184.5	0.000**
Weight [g]	397.33	355.50	0.000**	397.33	417.67	0.003**
Gastrocnemius FTO	1.00	0.71	0.042*	1.00	0.92	0.452
Gastrocnemius PPAR-γ	1.00	1.69	0.020*	1.00	1.26	0.077

Indeed, AMPK is recognized as a crucial regulator of energy metabolism in various tissues, including skeletal muscle, adipose tissue, and the heart. Its role in modulating the expression of FTO has been observed in both muscle and adipose tissue, where AMPK activation has been shown to decrease FTO expression. Exercise, being a potent physiological activator of the AMPK pathway, is implicated in this context. Studies have reported an increase in AMPK protein levels in diabetic rats following exercise, indicating the involvement of the AMPK pathway in mediating the effects of exercise. These findings provide insights into the potential mechanisms underlying the reduction of FTO expression through exercise-induced AMPK activation. However, further research is necessary to fully understand the intricate molecular pathways involved and their precise impact on FTO regulation [11,40].

The findings of the present study demonstrated significant changes in PPARγ gene expression associated with HIIT exercises ($p<0.020$). However, no significant difference in PPARγ gene expression was observed in the resistance training group ($P>0.077$). Additionally, there were no significant differences in the expression of PPARγ and FTO genes following 6 weeks of resistance and aerobic training ($P<0.158$). It is worth noting that previous research has reported an increase in PPARγ gene expression following 6 months of combined aerobic and strength training [41]. These observations suggest that the duration and type of exercise interventions, as well as the study population, may play a role in influencing the expression of PPARγ gene. Further investigations are required to elucidate the underlying mechanisms and the potential long-term effects of exercise on PPARγ gene expression. The findings of Lee et al. demonstrated a significant increase in PPARγ gene expression in subcutaneous fat tissue of male Sprague-Dawley rats following 8 weeks of low, moderate, and intense resistance training, which contrasts somewhat with the results of the present study [14].

It is important to consider two points in relation to the resistance training group in the present study: 1) The limited sample size [n=6] may have influenced the statistical significance, as indicated by the p-value of $P>0.077$, suggesting that with a larger sample size, significant changes may have been observed. 2) The duration of the current protocol was shorter than the average duration of the other studies, and it is possible that changes in PPARγ expression would have been observed if the exercises were continued beyond 8 weeks in the resistance group. Furthermore, Pala et al. reported a decrease in PPARγ expression in the liver and the muscle tissue of red albino rats after 30 minutes of single-phase exercise at a speed of 30 m/min,

, but the continuation of this exercise for 6 weeks resulted in a significant increase in PPARγ, GLUT4, and GLUT2 in liver and muscle tissue [15]. The studies conducted by Kim et al., Yang et al., and Dunstan et al. provide further evidence supporting the positive effects of exercise on PPARγ expression and its related metabolic outcomes [15,42,43]. Kim et al. showed that swimming exercise for 6 weeks increased the expression of PPARγ, PGC-1α, GLUT4, insulin sensitivity, and muscle glucose uptake in the soleus muscle of diabetic rats [15]. Yang et al. demonstrated that resistance training increased the expression of PPARγ in skeletal the muscle and adipose tissue of type 2 diabetic rats [42]. Similarly, Dunstan et al. reported that resistance training has improved insulin sensitivity and increased PPARγ expression in muscle tissue of elderly subjects with impaired glucose tolerance [43]. The increase in PPARγ expression is thought to be a result of improved insulin sensitivity and the direct effect of PPARγ on genes involved in glucose transport and glycolysis, ultimately leading to improved insulin sensitivity and blood glucose levels [44]. The genetic components of FOXO1, PPARγ, and FTO are known to play a role in energy homeostasis, glucose metabolism, and fat metabolism in target tissues such as skeletal muscles and adipose tissue. Increased expression of PPARγ generally leads to the expression of GLUT4, IRS-1, and P85 (PI3K regulatory subunit), as well as increased expression of proteins involved in glucose metabolism and insulin sensitivity. Taken together, these findings suggest that the expression of PPARγ in skeletal muscles and adipose tissue plays a significant role in the prevention and control of type 2 diabetes [15,45]. Exercise-induced increases in PPARγ expression contribute to improved glucose metabolism, insulin sensitivity, and overall metabolic health.

Conclusion

Based on the results of the present study, it appears that short-term and high-intensity aerobic exercises have a greater effect on the expression of FTO and PPARγ genes and related factors in obesity and type 2 diabetes compared to resistance exercises. These exercises were associated with significant changes in the FTO gene expression and PPARγ gene expression.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the authors.

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