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Resistance Training and Its Impact on Blood Glucose, Testosterone, FSH, and LH Levels in Men with Type 2 Diabetes

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ABSTRACT

Aims Research has demonstrated a negative association between type 2 diabetes mellitus and male gonadal function, with reductions observed in serum levels of testosterone, follicle-stimulating hormone, and luteinizing hormone. Conversely, resistance training has been shown to positively influence these hormones in healthy men. This study aimed to investigate the effect of resistance training on blood glucose, testosterone, follicle-stimulating hormone, and luteinizing hormone levels in men with type 2 diabetes.

Instrument & Methods This semi-experimental study included 20 men with type 2 diabetes (aged 45-60 years) who were randomly assigned to the resistance training or the control groups (n=10 per group). The training group participated in an eight-week supervised program targeting major muscle groups. Blood samples were collected pre- and post-intervention to measure blood glucose, testosterone, luteinizing hormone, and follicle-stimulating hormone levels. Data were analyzed by SPSS 26 using the mixed ANOVA and an independent t-test.

Findings The resistance training group demonstrated significant improvements ($p<0.05$) in blood glucose, testosterone, and luteinizing hormone levels compared to the control group and baseline measurements. No significant changes were observed in follicle-stimulating hormone ($p>0.05$).

Conclusion Eight weeks of resistance training enhance blood glucose control and gonadal function in men with type 2 diabetes.

Keywords Diabetes; Resistance Training; Testosterone; Follicle Stimulating Hormone; Luteinizing Hormone

CITATION LINKS

[1] Global and regional diabetes prevalence estimates for 2019 and projections for 2030 and 2045... [2] Awareness, treatment, and control of diabetes in Bangladesh... [3] IDF diabetes atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and...[4] Pathophysiology of type 2 diabetes... [5] Obesity and ... [6] Pathophysiology of diabetes... [7] Prevalence and determinants of low testosterone levels in men with type 2 diabetes mellitus... [8] Diabetes-induced male infertility... [9] Effect of testosterone replacement therapy on sexual function and glycemic control among hypogonadal... [10] Testosterone therapy in diabetes... [11] Effects of resistance training on testosterone metabolism in younger and... [12] Effects of aerobic and resistance training on circulating micro-RNA expression profile in... [13] ACSM's guidelines for exercise testing and prescription... [14] Effects of resistance training and nigella sativa on type 2 diabetes: Implications for metabolic markers, low-grade inflammation and liver enzyme prod... [15] Liquid chromatography-tandem mass spectrometry analysis of human adrenal vein 19-carbon steroids before... [16] Liquid chromatography-tandem mass spectrometry analysis of human adrenal vein 19-carbon steroids before and... [17] The role of resistance training in influencing insulin resistance among adults living with obesity/overweight without diabetes: A systematic review... [18] Testosterone is a contraceptive and should not be used in men... [19] Autocrine androgen action is essential for Leydig cell maturation and function, and protects against late-onset Leydig cell apoptosis... [20] Exercise, training, and the hypothalamic-pituitary-gonadal axis in men... [21] Assessing hypothalamic pituitary gonadal function in reproductive... [22] Diabetes mellitus causes male reproductive dysfunction: A review of the evidence... [23] Testosterone level and risk of type 2 diabetes in men: A systematic review... [24] Effects of three type exercise training programs on FBS and HbA1C of elderly men with... [25] Eurycomanone, the major quassinoid in Eurycoma longifolia root extract increases spermatogenesis by inhibiting the activity of phosphodiesterase... [26] Hypogonadism, type-2 diabetes mellitus, and bone health... [27] Effect of nutritional promotion intervention on dietary adherence among type II diabetes patients in North Shoa Zone Amhara Region...

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Introduction

Diabetes mellitus, a chronic metabolic disorder characterized by hyperglycemia (elevated blood glucose), has become a significant public health concern on a global scale [1]. The World Health Organization (WHO) recognizes the rapid rise in diabetes prevalence as a serious threat, with the potential to impact millions of individuals worldwide [2]. This epidemic poses a substantial burden on healthcare systems and carries the risk of severe long-term complications, including cardiovascular disease, blindness, and kidney failure [3]. Diabetes mellitus arises from impairments in the insulin signaling pathway. Insulin, a pancreatic hormone, plays a crucial role in regulating blood glucose homeostasis. Its primary function is to facilitate the uptake of glucose from the bloodstream into cells for energy utilization [4]. In diabetes, either insulin production is insufficient (type 1) or cells become resistant to its effects (type 2). This leads to a buildup of glucose in the bloodstream, resulting in the characteristic hyperglycemia associated with diabetes [5]. Additionally, individuals with diabetes are more susceptible to infertility disorders.

Clinical evidence substantiates a strong association between diabetes mellitus, particularly type 2 diabetes (T2DM), and impairments in male reproductive function [6]. This association is primarily attributed to the disruption of the hypothalamic-pituitary-gonadal (HPG) axis, a complex hormonal pathway responsible for sperm production [7]. This decrease may be due to a decline in the number of Leydig cells, which are responsible for testosterone production. The pituitary gland exerts primary control over testicular function, with follicle-stimulating hormone (FSH) specifically regulating spermatogenesis while luteinizing hormone (LH) primarily influences Leydig cell activity and subsequent testosterone production. Research findings indicate that diabetic men often exhibit lower serum levels of both FSH and LH [8]. Emerging evidence suggests a crucial role for insulin in maintaining male reproductive health.

Serwaa *et al.* [7] demonstrated that there is a strong correlation between insulin resistance and erectile dysfunction, suggesting a potential mechanistic link. Hyperglycemia, a hallmark of diabetes, and decreased levels of sex hormones, particularly testosterone, are proposed mechanisms through which diabetes can contribute to sexual dysfunction. Hypogonadism is common in diabetic men, leading to muscle loss, bone weakness, and sexual problems. It is also associated with heart disease, metabolic issues, and an increased risk of fractures [8]. Shigehara *et al.* [9] observed that hypogonadal men with T2DM who received testosterone treatment for a year exhibit significant improvements in potency, frequency, and libido. Testosterone replacement therapy (TRT) is a complex treatment option for hypogonadism. While it can provide significant benefits, it is essential to consider potential adverse effects. TRT has been associated with a range of complications, including decreased bone mineral density, an increased risk of osteoporosis, lethargy, depression, anxiety, and diminished cognitive function. These factors can substantially impact a patient's quality of life and underscore the importance of careful evaluation and monitoring when considering TRT [10].

However, a potential glimmer of hope emerges in the form of exercise training interventions. According to Ahtiainen *et al.* [11], resistance training may increase serum testosterone levels in men, potentially mitigating some of the detrimental effects of diabetes on male reproductive health. Additionally, regular physical activity offers broader benefits for diabetic patients. Olioso *et al.* [12] suggest that exercise training can significantly reduce diabetic complications, medication needs, and side effects, ultimately improving overall health. Despite these promising findings, the precise effects of resistance training on these serum markers in men with T2DM remain unclear. Therefore, this study investigated the impact of resistance training on blood glucose, testosterone, FSH, and LH levels in men with T2DM.

Materials and Methods

Participants

This quasi-experimental study was carried out in Isfahan in 2020 employing a pre-test post-test design and was conducted on 20 male participants with a documented diagnosis of T2DM selected using convenience sampling and recruited through a call for study participation. Following recruitment (due to budgetary limitations and participant recruitment challenges, a final sample of 20 participants was considered), participants were randomly assigned to the training and control groups (n=10 per group).

Inclusion criteria included male gender, an age range of 45-60 years, a diagnosis of T2DM for at least six months, no current insulin therapy, a body mass index (BMI) within the range of 20-30kg/m^2, no recent use of sports supplements within the past six months, documented abstinence from cigarettes, alcohol, and illicit drugs, and medical clearance for physical activity by a licensed physician. Exclusion criteria included absence from more than two consecutive training sessions without a valid medical excuse, expression of dissatisfaction or unwillingness to continue participation, training-related injuries, and the onset of any new illness or emergence of factors that could significantly interfere with the final results.

Training intervention

This investigation implemented a meticulously designed eight-week resistance training intervention for the assigned training group. The training group participated in three supervised resistance training sessions per week for eight weeks. Each training

session had a structured timeframe of 40 to 50 minutes.

The control group maintained their usual lifestyle habits and did not engage in a structured exercise program throughout the study period. To establish a baseline assessment of muscular strength and guide exercise intensity adjustments throughout the program, a one-repetition maximum (1RM) test was conducted for all participants in the training group before the initiation of the training program. This test was repeated before the commencement of the fifth week to assess strength gains and ensure appropriate program progression, adhering to the established protocols outlined by Ferguson [13].

The training sessions began with a 10-minute warm-up phase designed to prepare the participants for the subsequent resistance training exercises. A comprehensive selection of exercises targeting major muscle groups was employed, including the chest press, lat pulldown, leg press, leg extensions, and hamstring curls. The training regimen followed a progressive order, with upper-body exercises preceding lower-body exercises to optimize workout efficiency. The program adhered to the principle of progressive overload, gradually increasing training intensity throughout the intervention. During weeks 1-4, a moderate intensity range of 40-50% of 1RM was used, with 2-3 sets of 15-20 repetitions. Weeks 6-8 transitioned to a higher intensity range of 75-85% of 1RM, with 2-3 sets of 8-10 repetitions to promote continued strength gains. Following the resistance training exercises, a brief cool-down phase incorporating light static stretching was included to facilitate recovery and reduce post-exercise muscle soreness [13].

Blood sampling and analysis

Blood samples were collected at two distinct pre-determined time points, including at baseline and after the intervention. A blood sample was collected precisely 24 hours before the commencement of the first training session. A second blood draw was performed exactly 24 hours after the completion of the final training session. Blood samples were obtained through venipuncture of the antecubital vein in the participants' arms. A standardized volume of 10mL of whole blood was collected from each participant at each time point. Following blood collection, the samples were centrifuged for 10 minutes at 3000g. The extracted serum samples were then aliquoted and stored at a temperature of -80°C until subsequent analyses were performed. Blood glucose levels were quantified using a well-established and reliable enzymatic colorimetric technique. Commercially available enzymatic kits (Pars Azmoon; Iran) were employed for this analysis, adhering to the manufacturer's recommended protocols to ensure assay accuracy. The concentrations of testosterone, LH, and FSH were determined using enzyme-linked immunosorbent assay (ELISA). Commercially available ELISA kits (Monobind Inc; USA) were utilized for these hormone measurements.

Statistical analysis

The Shapiro-Wilk test was used to assess normality. The independent t-test was employed to compare the pre-test means of the two groups. A mixed ANOVA test and t-test were utilized to assess potential changes in blood glucose, testosterone, LH, and FSH levels between the groups. All analyses were conducted using SPSS 26 with a significance level of $p<0.05$.

Findings

A total of 20 men with T2DM participated in this study and their anthropometric data were collected (Table 1).

Table 1. Mean values of participants' anthropometric characteristics

Parameter	Control group	Training group	p-Value
Weight (kg)	77.7±10.8	75.9±9.5	0.75
Body mass index (kg/m²)	25.6±4.2	25.1±3.1	0.72
Body fat percentage (%)	19.3±2.8	20.6±5.1	0.51
Waist-to-hip ratio (WHR)	0.9±0.1	0.9±0.2	0.55

The Shapiro-Wilk test confirmed the normal data distribution for subsequent analyses (p-value>0.05). The independent t-test revealed no significant difference in pre-test means between the two groups. Therefore, the groups were comparable at baseline regarding the measured parameters (Table 2).

Table 2. The levels of measured parameters before and after the training

Parameter		Training group	Control group	p-Value
Blood glucose (mmol/L)	Pre-test	145.4±22.2	159.4±21.3	0.13
	Post-test	125.9±30.5	163.4±21.5	-
Testosterone (µU/mL)	Pre-test	5.1±1.7	4.9±1.1	0.90
	Post-test	7.1±1.6	4.3±0.5	-
Luteinizing hormone (LH; µU/mL)	Pre-test	3.3±1.6	3.5±0.9	0.37
	Post-test	6.7±2.3	3.3±1.0	-
Follicle-stimulating hormone (FSH; µU/mL)	Pre-test	4.6±1.5	4.3±1.5	0.55
	Post-test	5.9±1.2	4.8±1.3	-

Blood glucose levels

The mixed ANOVA revealed a significant main effect of time of blood glucose measurement ($F_{1, 18}=11.82$; $p=0.006$). Subsequent analyses indicated a statistically significant decrease in blood glucose levels within the training group ($p<0.05$). Accordingly, the resistance training demonstrably enhanced glycemic control among participants with T2DM.

Testosterone levels

The mixed ANOVA for testosterone levels yielded statistically significant main effects of both the time of measurement ($F_{1, 18}=12.94$; $p=0.002$) and group allocation ($F_{1, 18}=318.245$; $p=0.001$). There was a

significant elevation in testosterone levels within the training group compared to the control group ($p<0.05$), suggesting a potential positive influence of the intervention on testosterone production.

LH levels

Statistical analyses investigating LH levels revealed a significant main effect of group membership ($F_{1, 18}=154.48$; $p=0.001$). LH levels were significantly higher in the training group compared to the control group ($p<0.05$) following the intervention. These findings suggest a potential effect of the resistance training program on LH levels.

FSH levels

The mixed ANOVA for FSH levels demonstrated a significant main effect of the time of measurement ($F_{1, 18}=7.57$; $p=0.014$). However, the main effect for group allocation and the interaction effect between time and group were not statistically significant ($p>0.05$). These results indicated that FSH levels fluctuated throughout the study, but there was no statistically significant difference between the training and control groups, suggesting a minimal impact of the intervention on FSH levels.

Discussion

This study investigated the impact of resistance training on blood glucose, testosterone, FSH, and LH levels in men with T2DM. It contributes to the growing body of knowledge regarding the efficacy of resistance training interventions for managing T2DM in male populations. The meticulously designed eight-week program produced compelling findings that warrant further exploration.

The statistically significant reduction in blood glucose levels observed within the training group aligns with well-documented physiological principles and prior research efforts. Jangjo-Borazjani *et al.* [14] reported similar reductions in blood glucose following resistance training interventions in T2DM populations. These collective observations strongly suggest that incorporating resistance training programs into therapeutic regimens presents a potent strategy for enhancing glycemic control in individuals with T2DM. Potential underlying mechanisms for this observed improvement include the recognition that resistance training stimulates skeletal muscle glucose uptake, which is a key mechanism for maintaining blood glucose homeostasis. During exercise, muscle contractions induce the translocation of glucose transporter type 4 (GLUT-4) to the cell membrane, facilitating enhanced glucose uptake from the bloodstream into muscle cells [15]. Resistance training also improves insulin sensitivity, a critical factor in regulating blood glucose levels [16]. Engaging in regular exercise can enhance the body's responsiveness to insulin, enabling more efficient cellular uptake of glucose in response to insulin signaling. Boyer *et al.* [17] emphasize that the increase in the muscle's ability to take up glucose can occur through resistance training even without substantial muscle growth. This indicates that the metabolic benefits of resistance training on glycemic control can be realized even in the early stages of a training program. In conclusion, the findings of this study regarding the effectiveness of resistance training in lowering blood glucose levels in patients with T2DM are well-supported by existing research and established physiological mechanisms.

Previous investigations have consistently demonstrated the detrimental impact of T2DM on hormonal profiles, particularly testosterone and LH levels. Huang *et al.* [8] reported significant reductions in testosterone, LH, and FSH levels in T2DM patients compared to healthy controls. Serwaa *et al.* [7] further corroborated these findings, observing a notable decline in these hormones among diabetic individuals. The reversal of this trend in the resistance training group of the current study highlights the potential of resistance training to counteract the adverse effects of T2DM on the hypothalamus-pituitary-gonadal (HPG) axis. The precise mechanisms underlying the observed elevation of testosterone and LH levels in the resistance training group warrant further investigation. Potential explanations include resistance training might stimulate the pulsatile secretion of gonadotropin-releasing hormone (GnRH) from the hypothalamus, leading to increased LH release from the pituitary gland. This surge in LH could stimulate Leydig cells in the testes to produce more testosterone. Additionally, resistance training might directly enhance the function of Leydig cells, the primary site of testosterone production in the testes [18]. This could be achieved through improved blood flow to the testes, increased expression of androgen receptors, or modulation of signaling pathways within Leydig cells [19]. Resistance training might mitigate the negative feedback exerted by testosterone on the HPG axis, allowing for sustained or even increased testosterone production despite elevated testosterone levels [20]. While the primary focus is on the HPG axis, it is noteworthy that resistance training could also have an indirect effect on testosterone levels by stimulating the adrenal glands within the hypothalamus-pituitary-adrenal (HPA) axis [21]. The adrenal glands produce adrenal androgens, which are precursors to testosterone and can be converted to testosterone in peripheral tissues [8].

The relationship between glycemic control and testosterone production is complex and bidirectional. According to Serwaa *et al.* [7], there is an inverse correlation between fasting blood glucose (FBS) and hemoglobin A1c (HbA1c) levels and testosterone concentrations. This suggests that chronic hyperglycemia can impair Leydig cell function and contribute to testosterone deficiency in patients with T2DM [22, 23]. Resistance training has consistently been shown to improve glycemic control and insulin

sensitivity in individuals with T2DM. Siavoshy and Heidarianpour found that ten weeks of resistance training significantly reduces FBS and HbA1c levels in T2DM patients [24]. Therefore, one potential mechanism underlying the observed elevation in testosterone levels in the resistance training group could be the improvement in glycemic control and insulin sensitivity. By reducing hyperglycemia and enhancing insulin action, resistance training might restore normal Leydig cell function and testosterone production [25, 26].

Diet remains a cornerstone of diabetes management [27]. Future research investigating the effects of exercise interventions would benefit significantly from stricter dietary controls. This would allow for a more precise isolation of exercise's independent contribution to glycemic control in diabetic patients. The proposed exploration of various exercise modalities (strength training, endurance training, and combined approaches) and intensities in future research is highly commendable. This approach would provide valuable insights into tailoring exercise prescriptions for individual diabetic patients, ultimately leading to more effective management strategies.

This study, while providing valuable insights, has limitations. A larger sample size, stricter dietary control, a longer duration, additional hormonal markers, and consideration of individual variability would enhance the generalizability and robustness of the findings.

Conclusion

Eight weeks of resistance training enhance blood glucose control and gonadal function in men with T2DM.

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Ethical Permissions: This study received ethical approval from the Ethics Committee of Arak University of Medical Sciences (IR.ARAKMU.REC.1398.145). All participants were required to provide written informed consent prior to commencing any study procedures. Furthermore, the study was conducted meticulously in accordance with the ethical principles outlined in the Declaration of Helsinki.

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