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Original Article

The Effects of Resistance Training and Chromium Picolinate Supplementation on Glycemic Control and Hormonal Profiles in Men with Type 2 Diabetes

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Abstract

Background: Research has demonstrated a negative association between type 2 diabetes mellitus (T2DM) and male gonadal function, with reductions observed in serum levels of testosterone, follicle-stimulating hormone (FSH), and luteinizing hormone (LH). Conversely, resistance training and chromium picolinate supplementation in healthy men have been shown to influence these hormones positively. This study aimed to investigate the effects of resistance training and chromium picolinate supplementation on glycemic control and hormonal profiles in men with type 2 diabetes.

Methods: Twenty-five men with type 2 diabetes were enrolled and randomly assigned to three groups: resistance training with chromium picolinate ($n=9$), resistance training with placebo ($n=8$), and control ($n=8$). The training groups participated in an 8-week supervised training program targeting major muscle groups. Blood samples were collected pre- and post-intervention to measure blood glucose, testosterone, LH, and FSH. A mixed ANOVA (group × time; $\alpha=0.05$) was used for data analysis using SPSS version 26.

Results: The resistance training and resistance training with chromium picolinate groups showed a significant decrease ($P<0.05$) in blood glucose and an increase in testosterone, LH, and FSH levels compared to controls and baseline. No significant differences were observed between training groups ($P>0.05$).

Conclusion: The combined application of resistance training and chromium picolinate supplementation in individuals with type 2 diabetes may offer a potential strategy for ameliorating glycemic dysfunction while mitigating potential adverse hormonal effects.

Keywords: Chromium picolinate, Resistance training, Diabetes, Testosterone, Follicle-stimulating hormone, Luteinizing hormone

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Introduction

Diabetes mellitus is a chronic disorder that impacts the body's ability to manage blood sugar levels. This metabolic disorder has become a major global health concern, with millions of people impacted worldwide (1). The World Health Organization has warned about the rapidly increasing prevalence of diabetes and its devastating consequences (2). Diabetes not only presents immediate health challenges but also imposes a significant strain on healthcare systems. It significantly increases the risk of serious long-term complications such as heart disease, kidney damage, and eye problems. At the core of diabetes is a disruption in the body's ability to produce or effectively use insulin, a hormone essential for regulating blood sugar levels. In type 1 diabetes, the pancreas produces little to no insulin, while in type 2 diabetes (T2DM), the body becomes resistant to insulin's effects (3). Both conditions lead to elevated blood sugar levels. These impairments lead to hyperglycemia, which, in turn, increases susceptibility to infertility disorders (3).

Comprehensive reviews of fertility rates in contemporary societies have established a significant correlation between the prevalence of diabetes mellitus and the decline in fertility and birth rates (4). Emerging evidence underscores the role of diabetes as a primary contributor to male infertility, with research demonstrating its adverse effects on oocyte maturation, estrous behavior, and overall reproductive and sexual function (5). The deleterious impact of type 2 diabetes on multiple organ systems, including the reproductive system, is attributed to the generation of free radicals and subsequent lipid peroxidation. Oxidative stress disrupts hormonal balance

and reproductive function, ultimately compromising fertility (6).

Diabetes mellitus has been extensively studied in animal models and is associated with significant impairments to the endocrine regulation of sexual function (5,6). These impairments lead to decreased fertility, diminished sexual performance, and changes in hormonal profiles (7). Specifically, diabetic individuals often exhibit decreased serum concentrations of testosterone, follicle-stimulating hormone (FSH), and luteinizing hormone (LH). These hormonal imbalances are correlated with structural changes in testicular tissue, resulting in diminished sperm count, impaired sperm quality, and atrophy of accessory reproductive glands (8,9). Hence, diabetes exerts a multifaceted negative impact on male reproductive health, affecting hormone production, testicular function, and sexual performance. A comprehensive understanding of these mechanisms is essential for developing effective therapeutic strategies.

Lifestyle interventions, such as physical activity and dietary modifications, are the cornerstones of diabetes management. Exercise has demonstrated efficacy in improving glycemic control, reducing cardiovascular risk, and enhancing overall well-being (10). Moreover, emerging research suggests that physical activity may positively influence male reproductive health by modulating hormonal profiles and mitigating oxidative stress (11).

Chromium picolinate, a popular dietary supplement, has emerged as a potential candidate for improving glucose homeostasis and preventing T2DM onset. Chromium is a trace mineral with potential implications for insulin sensitivity and glucose metabolism. Chromium picolinate is a specific form widely marketed for its purported benefits in diabetes prevention, weight management, and muscle building (12). Experimental studies have shown that chromium supplementation can ameliorate glucose intolerance by enhancing insulin sensitivity. Furthermore, chromium has been shown to reduce inflammatory markers and improve lipid profiles, suggesting potential benefits beyond glucose control (13, 14). Despite its popularity, the efficacy and safety of chromium picolinate for T2DM prevention remain unclear. Well-designed clinical trials are needed to definitively assess its impact on insulin resistance, glycemic control, and T2DM risk reduction. Given the potential benefits of both resistance training and chromium picolinate, this study aims to investigate their combined effects on glycemic control and hormonal profiles in men with T2DM.

Methods

The study employed a quasi-experimental design with a pre-test and post-test structure. Given its timeframe, the research was classified as applied and cross-sectional. Subjects were selected based on predefined inclusion and exclusion criteria and randomly assigned to three groups: exercise and supplement, exercise and placebo, and control. The study population comprised men with type 2 diabetes residing in the city of Arak. Following coordination with local clinics and dissemination of recruitment information, 25 men with type 2 diabetes who met the eligibility criteria were enrolled. The subjects were randomly assigned to three groups: resistance training with chromium picolinate ($n=9$), resistance training with placebo ($n=8$), and control ($n=8$) (Table 1). The inclusion criteria were male participants aged 30 to 70 years with non-insulin-dependent type 2 diabetes, body mass index (BMI) within the range of 20 to 30 kg/m², diabetes diagnosis for a minimum of six months, absence of chromium supplement use within the past four months, and HbA1c level greater than or equal to 7% who were non-smokers, tobacco-free, and physically capable of performing exercise. The exclusion criteria were history of cancer, anemia, cardiovascular disease, uncontrolled hypertension, infection, any diabetes-related complications, consumption of supplements beyond recommended dosages, regular physical activity in the previous six months, and presence of any condition or factor potentially influencing study outcomes.

Ethical conduct was a primary concern in this research. To ensure participant autonomy and well-being, informed consent was obtained from all individuals prior to study initiation. The study process adhered to the rigorous ethical standards outlined in the Declaration of Helsinki. Participants were provided with comprehensive information regarding the study's objectives, procedures,

Table 1. Anthropometric data, including age, height, weight, and BMI, for participants in the three groups are shown in the table below

Variables	Stages	Groups			*P*
		Con Mean ± SD	RT + Plc Mean ± SD	RT + ChP Mean ± SD	
Age (year)	Pre-test	49.1 ± 5.11	53.25 ± 12.38	51.89 ± 10.52	0.63
Hight (cm)	Pre-test	173.88 ± 5.80	173.5 ± 14.1	170.5 ± 5.22	0.47
Weight (Kg)	Pre-test Post-test	74.59 ± 8.14 75.06 ± 8.99	75.26 ± 4.98 74.82 ± 4.34	71.13 ± 9.85 70.97 ± 9.99	0.07
Body Mass Index (Kg/m²)	Pre-test Post-test	24.78 ± 3.50 24.94 ± 3.76	25.47 ± 4.80 25.35 ± 4.85	24.63 ± 3.40 24.59 ± 3.55	0.11

Con: control; RT + Plc: resistance training with placebo; RT + ChP: resistance training with chromium picolinate

potential risks, and benefits. Importantly, they were explicitly informed of their absolute right to withdraw from the study at any point without justification. This provision underscores the commitment to safeguarding participant interests and maintaining their trust. This study was granted ethical approval by the Ethics Committee of Arak University of Medical Sciences, Islamic Republic of Iran (approval reference number: IR.Arakmu.rec.1397.172).

Exercise intervention

The subjects in the training groups engaged in a resistance training program consisting of three sessions per week, each lasting 40–50 minutes, for eight weeks. The control group maintained their usual lifestyle without dietary or medication modifications. The training protocol comprised a ten-minute warm-up with dynamic stretching, followed by six resistance training exercises for upper and lower body muscle groups: shoulder press, chest press, lat pulldown, leg press, leg extension, and standing leg curl. A cool-down period with light stretching concluded each session. To progressively increase exercise intensity, participants began with 50–60% of their one-repetition maximum (1RM) for three sets of 12–15 repetitions during the first four weeks. This was increased to 70–80% of 1RM for three sets of 8–10 repetitions in weeks five to eight. The initial 1RM assessments were conducted in the first week, followed by a reassessment before the fifth week (15).

Supplement and placebo preparation

The participants assigned to the exercise training and supplement group received a daily chromium picolinate supplementation of 400 mcg (21st Century, USA), divided into two capsules for consumption post-breakfast and post-dinner. This regimen was maintained for eight weeks. A visually indistinguishable placebo, composed of starch, was prepared by Shiraz University of Medical Sciences. This placebo was administered to the exercise training and placebo group to ensure experimental control.

Blood sample collection and processing

The participants underwent a two-phase blood collection protocol. A baseline blood sample was drawn precisely 24 hours before the commencement of the training program. Subsequently, a post-intervention sample was acquired exactly 24 hours after the conclusion of the final training session. Both blood draws were conducted via venipuncture of the antecubital vein, yielding 10 mL of whole blood from each participant. To isolate the serum component, the collected blood samples were subjected to centrifugation at 3000 × g for a duration of 10 minutes. The resulting serum was then divided into aliquots and preserved at a temperature of -80 °C until further analysis.

Biochemical and hormonal assays

Blood glucose levels were quantified using a commercially available enzymatic colorimetric assay kit procured from Pars Azmoon Co. Adherence to the manufacturer's guidelines ensured optimal assay precision. Concurrently, the concentrations of testosterone, LH, and FSH were determined through the implementation of enzyme-linked immunosorbent assays (ELISAs). These assays were facilitated by commercial ELISA kits supplied by Monobind Inc. (USA).

Statistical analysis

Data normality was assessed using the Shapiro-Wilk test. Between-group comparisons of pre-treatment means were conducted via one-way analysis of variance (ANOVA). To evaluate changes over time and between groups, a mixed-model ANOVA was employed. Post hoc comparisons were performed using Bonferroni corrections. All statistical analyses were executed using SPSS version 26, with statistical significance defined as a P value less than 0.05.

Results

Table 2 presents data on blood glucose, testosterone, LH, and FSH levels among training and control groups assessed pre- and post-intervention. Shapiro-Wilk tests indicated normal distribution for all variables ($P > 0.05$),

Table 2. The descriptive statistics (mean ± SD) for key variables measured pre- and post-training in three groups are shown in the table below.

Variables	Stages	Groups			*P*
		Con Mean ± SD	RT + Plc Mean ± SD	RT + ChP Mean ± SD	
Testosterone (T) (nmol/L)	Pre-test Post-test	9.88 ± 1.49 9.75 ± 1.92	9.96 ± 1.36 13.11 ± 1.09	10.21 ± 1.05 12.94 ± 1.19	0.89 -----
Lutein hormone (LH) (IU/mL)	Pre-test Post-test	4.22 ± 0.90 4.18 ± 0.68	4.92 ± 1.21 6.36 ± 1.73	5.05 ± 0.82 6.83 ± 0.75	0.20 -----
Follicle-stimulating hormone (FSH) (IU/mL)	Pre-test Post-test	4.7 ± 1.19 4.88 ± 2.26	4.25 ± 1.09 8.05 ± 1.31	3.81 ± 1.02 7.63 ± 1.56	0.21 -----
Fasting blood glucose (mg/dL)	Pre-test Post-test	155.38 ± 5.68 149.25 ± 18.8	149.63 ± 20.1 118.13 ± 5.9	155.78 ± 11.93 116.44 ± 5.4	0.69 -----

Con: control; RT + Plc: resistance training with placebo; RT + ChP: resistance training with chromium picolinate.

justifying the use of parametric statistical tests. One-way ANOVA revealed no significant differences in pre-intervention means across the three groups, suggesting comparable baseline conditions for the measured parameters ($P > 0.05$).

Blood glucose levels

The mixed-model analysis of variance (ANOVA) revealed a statistically significant interaction between time and group on blood glucose levels (F (2, 22) = 14.635, $P < 0.001$). Pairwise comparisons indicated significant differences between the control group and both training groups ($P < 0.05$) in terms of mean blood glucose levels, as determined by Bonferroni post hoc tests. However, no significant difference was found between the two training groups ($P > 0.05$).

These findings suggest that both training groups (RT + Plc and RT + ChP) were effective in reducing blood glucose levels compared to the control condition. The absence of a significant difference between the two training groups implies that they might be equally efficacious in managing blood glucose.

Testosterone levels

The mixed-model analysis of variance (ANOVA) yielded a significant interaction between time and group on testosterone levels (F (2, 22) = 14.970, $P < 0.001$). Post hoc Bonferroni comparisons revealed significant differences in mean blood glucose levels between the control group and both training groups ($P < 0.05$). No significant difference was observed between the two training groups ($P > 0.05$).

Luteinizing hormone (LH) levels

The mixed-model analysis of variance (ANOVA) revealed a significant interaction between time and group on LH levels (F (2, 22) = 3.567, $P < 0.01$). Subsequent Bonferroni post hoc tests indicated significant differences in mean LH levels between the control group and both training groups ($P < 0.05$). No significant difference in LH levels was observed between the two training groups ($P > 0.05$).

Follicle-stimulating hormone (FSH) levels

The mixed-model analysis of variance (ANOVA) demonstrated a significant interaction between time and group on FSH levels (F (2, 22) = 36.692, $P < 0.001$). Subsequent Bonferroni post hoc tests revealed statistically significant differences in mean FSH levels between the control group and both training groups ($P < 0.05$). No significant differences in FSH levels were observed between the two training groups ($P > 0.05$).

These findings suggest that both training groups (RT + Plc and RT + ChP) were effective in increasing testosterone, LH, and FSH levels compared to the control group. The absence of a significant difference between the two training groups suggests comparable efficacy in elevating testosterone, LH, and FSH levels.

Discussion

This study contributes to the expanding body of knowledge concerning the effects of resistance training and chromium picolinate supplementation on glycemic control and hormonal profiles in men with type 2 diabetes mellitus (T2DM). The observed statistically significant reduction in blood glucose levels within both the resistance training with chromium picolinate and resistance training alone groups is consistent with established physiological principles and previous research findings. These results align with those reported by Jangjo-Barazjani et al in a similar T2DM population, collectively supporting the integration of resistance training into the therapeutic management of T2DM to improve glycemic control (16). Moreover, consistent with the present study, Arslan et al demonstrated that chromium supplementation combined with increased physical activity in individuals with metabolic syndrome can lead to a reduction in adipose tissue, an increase in body mass, and improved carbohydrate metabolism (17). Additionally, Pala et al reported that a regimen combining chromium picolinate supplementation and exercise in rats led to a significant decrease in blood glucose, cholesterol, and triglyceride levels. Furthermore, they demonstrated upregulation of GLUT-2 and GLUT-4 gene expression within both hepatic and muscular tissues (13).

In contrast with our findings, Joseph et al examined the impact of a 12-week resistance training program, with or without chromium picolinate supplementation, on glucose metabolism in overweight individuals. Their study indicated that strength training positively influenced glucose metabolism, while chromium picolinate supplementation had no significant effect (18). Given that Joseph et al's study involved overweight participants. However, our study focused on individuals with a BMI between 24 and 25, the discrepancy in findings may be attributed to differences in body composition (18). Overweight and obesity are known to impact blood sugar and lipid profiles, which could potentially influence the response to exercise interventions (10).

Resistance training is recognized for its ability to stimulate skeletal muscle glucose uptake, a critical component of blood glucose homeostasis. This effect is mediated by the exercise-induced translocation of glucose transporter type 4 (GLUT-4) to the sarcolemma, facilitating increased glucose transport from the bloodstream (19). Furthermore, resistance training has been shown to improve insulin sensitivity, a key factor in regulating blood glucose levels. Regular exercise enhances the body's responsiveness to insulin, resulting in more efficient cellular glucose uptake (20).

Chromium, an essential trace mineral, plays a role

in carbohydrate, protein, and lipid metabolism (12). Its association with glucose homeostasis has been extensively studied (12-14). Epidemiological research consistently reports lower serum chromium levels in individuals with impaired glucose tolerance and type 2 diabetes mellitus (T2DM) compared to healthy controls. Experimental studies have demonstrated that chromium supplementation can ameliorate glucose intolerance by enhancing insulin sensitivity (21). Chromium picolinate may synergistically potentiate these effects. The proposed mechanisms of action include improved insulin receptor binding and activation of insulin signaling pathways (22,23). A combined approach of resistance training and chromium supplementation may offer a synergistic effect, leading to more pronounced improvements in glycemic control compared to either intervention alone.

Testosterone, a key hormone in male reproductive health, is primarily produced by Leydig cells through testicular steroidogenesis. Disruptions to this process, often caused by endocrine-disrupting chemicals, can impair fertility (24). While chromium picolinate is a common dietary supplement with purported health benefits, its impact on male reproductive function remains controversial. Studies have indicated that chromium picolinate may adversely affect male fertility by inhibiting enzymes crucial for steroidogenesis, inducing cellular damage, and altering oxidative stress (21, 25). Consequently, it has been associated with decreased testosterone levels, impaired sperm quality, and reduced fertility (26). However, our findings suggest a more nuanced picture. Resistance training, with or without chromium picolinate supplementation, has been shown to elevate testosterone, LH, and FSH levels in type 2 diabetic men. Intriguingly, while both groups experienced increases in these hormones, the magnitude of the rise was slightly but not significantly greater in the resistance training-only group. The precise mechanisms underlying the observed elevation of testosterone, LH, and FSH levels in the resistance training group necessitate further investigation. Potential explanations encompass direct stimulation of the hypothalamic-pituitary-gonadal (HPG) axis through increased gonadotropin-releasing hormone (GnRH) secretion and augmented Leydig cell function or an indirect influence mediated by the hypothalamic-pituitary-adrenal (HPA) axis (27). Additionally, the possibility of attenuated negative feedback within the HPG axis cannot be dismissed (28).

A complex bidirectional relationship exists between glycemic control and testosterone production. While hyperglycemia has been implicated in impaired Leydig cell function and subsequent testosterone deficiency (29, 30), the improvements in glycemic control and insulin sensitivity induced by resistance training offer a plausible mechanistic explanation for the observed increase in testosterone levels. By attenuating hyperglycemia and enhancing insulin action, resistance training may restore normal Leydig cell function and testosterone production (31, 32). These findings contribute to the growing body of evidence supporting the beneficial effects of resistance training on hormonal health in individuals with T2DM (33). The observed elevation of testosterone, FSH, and LH levels in response to resistance training and chromium picolinate underscores the intervention's potential to mitigate the adverse hormonal consequences of T2DM. To elucidate the specific mechanisms underlying these effects, future research should prioritize large-scale randomized controlled trials to confirm the findings and assess the long-term impact of resistance training on hormonal profiles, metabolic health, and other relevant outcomes in T2DM patients. Furthermore, investigating potential interactions between resistance training, pharmacotherapy, and lifestyle interventions on hormonal outcomes would provide valuable insights. Ultimately, a comprehensive understanding of the mechanisms by which resistance training influences the HPG axis in the context of T2DM is essential for developing effective therapeutic strategies to address hormonal dysfunction and improve the overall health and well-being of individuals with this metabolic disorder.

The study's limitations include the small sample size, which may compromise the generalizability of the findings to a broader population. Additionally, the relatively short study duration limits the assessment of long-term effects, potentially obscuring delayed adverse reactions or sustained benefits. The study population was predominantly male, which may restrict the applicability of the results to women or individuals with other health conditions. Moreover, potential confounding factors, such as dietary intake or lifestyle variables, could have influenced the outcomes, potentially introducing bias into the findings.

Conclusion

The results of our study indicate a potential beneficial effect of a combined resistance training and chromium picolinate supplementation regimen on blood glucose levels and reproductive hormones, specifically testosterone, LH, and FSH. Therefore, the combined application of resistance training and chromium picolinate supplementation in individuals with type 2 diabetes may offer a potential strategy for ameliorating glycemic dysfunction while mitigating potential adverse hormonal effects. Further research is warranted to elucidate the underlying mechanisms and optimize intervention parameters.

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Authors' Contribution

Conceptualization: Mohammad Parastesh, Behzad Aria.

Data curation: Ali Hamed Abdul Ali, Zahra Yusuf Vand.
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Competing Interests
The authors declare no competing or conflicting interests regarding this study.

Ethical Approval
This study was granted ethical approval by the Ethics Committee of Arak University of Medical Sciences, Islamic Republic of Iran (approval reference number: IR.Arakmu.rec.1397.172).

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