

Dynamics of insulin and glucose changes during early recovery after physical load in elite athletes

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Abstract

During intense physical loads, carbohydrates are the main substrate for working muscles. This process involves increased glucose uptake by muscles, facilitated in part by insulin. This study investigated the impact of intense physical loads on blood glucose and insulin concentrations in elite athletes during the early recovery period.

Methods: Evaluation methods included gas analysis (maximal oxygen consumption), heart rate monitoring, anthropometry, bioimpedance, biochemical analysis and statistical methods. The study was carried out with the participation of 39 elite athletes. The study protocol included three stages: blood sampling to assess the initial glucose and insulin concentrations; the test load; and taking blood samples to estimate glucose and insulin concentrations during the early recovery period 10, 20, 40 and 60 minutes after the test load.

Results and conclusions: It was established that glucose and insulin concentrations increased in response to the physical load performed. The relationship between the increase in insulin concentration after intensive physical load and its initial value was revealed. A lower basal insulin concentration is followed by a higher increase after physical load. Thus, it can be concluded that the severity of changes in insulin depends on its basal level. This is an interesting fact and requires further research to establish the boundaries of the optimal values of its basal level. In addition, the research on changes in insulin and glucose concentrations in the recovery period after being influenced by intense physical loads is a perspective direction for understanding the mechanisms of the recovery process.

Keywords: sports medicine, hormones, exercise, carbohydrate metabolism, resynthesis

Introduction

As a result of adaptation to sports activity, the functioning of various systems and organs of an athlete is improved, including the endocrine system, which is reflected in changes in hormonal responses to load (Cadejani and Kater, 2020; Maidaniuk et al., 2022; Mennitti et al., 2024; Ostapiuk-Karolczuk, et al., 2024).

Fasting insulin should be assessed concurrently with fasting glucose. A normal reference range for insulin concentration is up to 25.0 $\mu\text{U} \cdot \text{ml}^{-1}$ (Muhammad et al., 2019) and for glucose 3.9–5.6 $\text{mmol} \cdot \text{l}^{-1}$ (World Health Organization, 2016; Muhammad et al., 2019). However, the optimal insulin concentration is also used. Studies (Ghasemi et al., 2015) have determined that fasting insulin levels higher than 5.48 $\mu\text{U} \cdot \text{ml}^{-1}$ for men and 7.51 $\mu\text{U} \cdot \text{ml}^{-1}$ for women are considered an independent risk factor for insulin resistance and predictive of type 2 diabetes. Others consider optimal fasting insulin levels to be less than 12.2 $\mu\text{U} \cdot \text{ml}^{-1}$ (McAuley et al., 2001). Another study (Gallois et al., 1996) showed that healthy women (30–49 years) had reference values of insulin concentration on an empty stomach at a median of 5.1 $\mu\text{U} \cdot \text{ml}^{-1}$ (95% CI [4.9–5.3]), and men (30–64 years) and women (50–64 years) at a median of 5.6 $\mu\text{U} \cdot \text{ml}^{-1}$ (95 CI [5.4–5.7]). Some studies claim that insulin levels above the optimal range are associated with hypertension, diabetes and obesity (Ghasemi et al., 2015; Nakrani et al., 2023). Thus, these works showed the perspective and relevance of further studies to establish optimal ranges of insulin concentration on an empty stomach.

During intense physical exertion, the primary substrate for working muscles is carbohydrates, the source of which is glycogen in the muscles and liver, and glucose, which comes from the blood (Marliss and Vranic, 2002). During exercise, there is an increase in muscle glucose uptake both with insulin and through other mechanisms (Cartee, 2015; Šmída et al., 2018; McCarthy et al., 2022; Zumbaugh et al., 2022). This process is provided by specific GLUT4 transporter proteins (DiMenna and Arad, 2020; Flores-Opazo et al., 2020; Zumbaugh et al., 2022). As studies have shown in recent years, physical activity and insulin increase glucose transport in skeletal muscles due to the translocation of GLUT4 into the sarcolemma and transverse tubules. The pool of glucose carrier protein is influenced separately by physical activity and insulin secretion, which has made it possible to identify two distinct glucose utilization pathways: an insulin-independent mechanism and an insulin-dependent mechanism (Cartee, 2015).

Key mechanisms of carbohydrate metabolism adaptation occurring in skeletal muscles under conditions of regular intense physical exercise include increased glucose uptake, elevated GLUT4 expression and increased glycogen concentration in trained muscles. This is a crucial factor in reducing fatigue during prolonged exertion

and also leads to increased insulin sensitivity (Dela et al., 2019; Arent et al., 2020; DiMenna and Arad, 2020). It is believed that to prevent a disproportionate increase in glucose uptake during intense exercise, insulin concentration in the circulating blood decreases (Arent et al., 2020; Beaudry et al., 2022; McCarthy et al., 2022), and the secretion of counter-regulatory hormones (glucagon, adrenaline, norepinephrine, cortisol) increases, which is necessary to maintain glucose homeostasis and activate enzymes in liver and muscle glycogen oxidation reactions (McCarthy et al., 2022). During intense muscle tension ($> 80\% \text{ VO}_2\text{max}$) and in the first few minutes of recovery, the central regulators of glucose homeostasis, according to scientists, are catecholamines (Marliss and Vranic, 2002; Flockhart et al., 2023), since the response to massive glucose production and glucose utilization occur regardless of whether the plasma insulin remains unchanged, decreases or increases. The levels of catecholamines in this type of load increase markedly, as a result of which glucose production increases seven to eight times, while glucose use increases only three to four times. The rise in blood glucose levels during intense exercise increases immediately upon exhaustion and persists for up to one hour (Kjaer et al., 1990).

After loading, glucose uptake remains elevated due to both insulin-independent (up to 2 hours) and insulin-dependent (up to 48 hours) mechanisms (Colberg et al., 2016). The recovery process is accompanied by an increase in plasma insulin, which persists, according to some authors, for up to 60 minutes of recovery (Marliss et al. 1992; Sigal et al., 1996; Marliss and Vranic, 2002), while other researchers suggest it can last up to 24 hours post-exercise (Colberg et al., 2016).

Hyperglycaemia and hyperinsulinemic response to load during recovery create optimal conditions for muscle glycogen restoration (Marliss and Vranic, 2002; Arent et al., 2020). Additionally, it has been established that insulin exerts an anti-catabolic effect during the post-exercise period, slowing protein breakdown (Everman et al., 2016). During this period, muscle GLUT4 transporters are activated, glycogen synthase activity is increased, and insulin sensitivity is enhanced, leading to increased skeletal muscle nutrient utilization (Beelen et al., 2010; Arent et al., 2020). Such physiological reactions have led scientists to suggest that eating after exercise can reduce the intensity of catabolic processes and increase anabolic (Arent et al., 2020).

Studies have diverse natures with different protocols, so the change in insulin and glucose concentration after loading varies and this depends on its type, so more research is needed to systematize the data on these changes. Thus, the time of intake of nutrients in the period after training becomes an essential aspect in optimizing the training program, as it can improve the recovery process and optimize the athlete's adaptation to physical activity. However, at present, the dynamics of the deployment of the insulin response to intense loads during the recovery period remains an open question since the studies of scientists demonstrate a variety of results and approaches in determining the time of measurement of insulin and glucose after the load (Kraemer et al., 1998; Marliss and Vranic, 2002; Kliszczewicz et al., 2017).

In our previous studies (Maydanyuk and Vdovenko, 2021), we found that individual changes in insulin concentration in response to exposure to intense physical exertion differed significantly. Thus, most athletes recorded a decrease in insulin from insignificant to more than 2.5-fold, while some observed an increase of 50%–300%. The presented data are contradictory, indicating the need for more detailed research on insulin dynamics after intense exercise. Determining the timing of post-exercise insulin levels can help optimize and adjust the timing of nutrient intake to improve recovery and adaptation processes to enhance athletes' training and competition performance. Our work aimed to study the effect of intense physical exercise on glucose and insulin concentrations in elite athletes' blood in early recovery.

Materials and Methods

Participants

Insulin and glucose concentration studies were conducted with 39 qualified male athletes, with an average age of 25.6 ± 3.7 years (from 21 to 32 years old), among whom 9 athletes specialized in rowing (3 honoured masters of sports, 6 masters of sports of international class), 16 athletes specialized in boxing (5 masters of sports of international class, 11 masters of sports), and 14 athletes specialized in Greco-Roman and freestyle wrestling (2 honoured masters of sports, 6 masters of sports of international class, 6 masters of sports). Information on the athletes participating in the studies is given in Table 1.

Table 1. Age and anthropometric measures of qualified athletes ($n = 39$)

Parameter	$\bar{X} \pm m$
Age, years	25.6 ± 3.7
Height, cm	175.8 ± 7.7
Body weight, kg	75.1 ± 2.1
Body fat percentage, %	10.8 ± 0.4
Fat mass, kg	8.3 ± 0.5
Fat-free mass, kg	66.8 ± 1.8

Notes. $\bar{X}$ = average value; m = standard error

Procedures

The study protocol consisted of three stages (see Fig. 1). The first stage (I) involved blood sampling to assess the initial concentration of glucose and insulin. Blood was taken before exercise at seven o'clock in the morning on an empty stomach. The second stage (II) involved an exercise test. The third stage (III) involved blood sampling to assess glucose and insulin concentrations during rapid recovery at 10, 20, 40 and 60 minutes after the exercise test.

Participants were instructed to fast for two hours before the exercise test and for one hour after the exercise test until the blood draw.

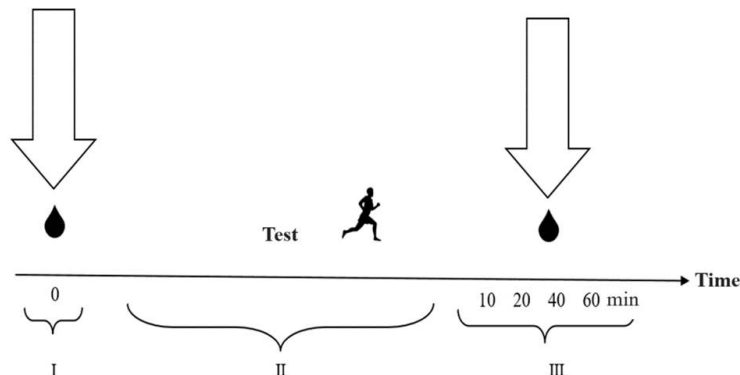


Figure 1. Study protocol (Stages I–III)

Measures

Laboratory research

Insulin and glucose concentrations were determined in serum using a ChemWell automated chemistry analyser (Awareness Technology, Palm City, FL, USA), with the aid of AccuBind ELISA test systems (Monobind Inc., Lake Forest, CA, USA) and reagents from Pointe Scientific (Canton, MI, USA). Blood samples were collected from the ulnar vein. Subsequent sample processing was performed according to the manufacturer's instructions.

Load test

The test to determine maximal oxygen consumption ($\text{VO}_{2\text{max}}$, $\text{ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$) involved performing an incremental exercise test on either a Concept2 rowing machine (Concept2, Morrisville, VT, USA) for rowing participants or a LE 500 treadmill (Vyaire Medical GmbH, Hoechberg, Germany) for the boxing participants and wrestlers, and continued until the subjects reached $\text{VO}_{2\text{max}}$. A sign of achieving $\text{VO}_{2\text{max}}$ was the absence of an increase in oxygen consumption with an increase in power or its fluctuation within $100 \text{ ml} \cdot \text{min}^{-1}$. Respiratory system parameters were recorded using an Oxycon Mobile gas analyser (CareFusion, Hoechberg, Germany). The system was calibrated according to the manufacturer's recommendations. Before performing the test load, a 6-minute warm-up was carried out, and after the test was completed, there was a 3-minute cool down, during which the speed of recovery processes was evaluated according to the heart rate and blood lactate concentration.

The initial workload on the Concept2 rowing ergometer was set at $1.5 \text{ W} \cdot \text{kg}^{-1}$ of body mass, with an increase of 30 W at each subsequent stage. The initial workload on the treadmill was $2.0 \text{ W} \cdot \text{kg}^{-1}$ of body mass (running speed of $10 \text{ km} \cdot \text{h}^{-1}$). The timing for the stages of the incremental exercise test was 2 minutes for the treadmill and 3 minutes for the rowing ergometer.

Ethics

The study was conducted in accordance with the fundamental bioethical principles of the World Medical Association Declaration of Helsinki—Ethical Principles for Medical Research Involving Human Participants (2000, as amended in 2008), the Universal Declaration on Bioethics and Human Rights (1997), and the Council of Europe Convention on Human Rights and Biomedicine (1997). All study participants were informed about the protocols and conditions of the study and provided written informed consent to participate.

Statistical analysis

All statistical analyses were performed using Statistica 12 with a significance level set at 0.05, unless stated to the contrary. One-way ANOVA, cluster analysis (k -means) and correlation analysis (Spearman rank correlation) were used to assess insulin level changes due to physical loads. Duncan's post hoc analysis was used to estimate group differences. The correspondence of the sample to the normal distribution was checked for asymmetries and excesses, which indicated the proximity of the distribution to the normal curve.

Results

Analysis of the dynamics of glucose and insulin concentration in the blood of qualified athletes under the influence of physical activity is presented in Table 2.

Table 2. Effect of exercise on blood glucose and insulin concentrations of qualified athletes (n = 39)

Blood collection	Insulin, $\mu\text{MO} \cdot \text{ml}^{-1}$		Glucose, $\text{mmol} \cdot \text{l}^{-1}$	
	X $\pm$ m	CI 95%	X $\pm$ m	CI 95%
Baseline	3.9 $\pm$ 0.4	3.1 – 4.6	4.3 $\pm$ 0.1	4.1 – 4.5
10 min post-load	7.1 $\pm$ 1.1*	4.9 – 9.3	5.7 $\pm$ 0.3*	5.1 – 6.3
20 min post-load	8.9 $\pm$ 1.1*	6.6 – 11.3	6.0 $\pm$ 0.3*	5.5 – 6.6
40 min post-load	8.2 $\pm$ 0.8*	6.6 – 9.8	5.0 $\pm$ 0.2*	4.7 – 5.4
60 min post-load	5.8 $\pm$ 0.7*	4.4 – 7.3	4.3 $\pm$ 0.1	4.1 – 4.5

Notes. X = average value; m = standard error; post-load = after physical activity; * = $p \leq 0.05$ compared to the baseline; CI = confidence interval.

For a more detailed analysis of the significance of fasting insulin concentration, we divided the athletes into two groups using a 95% confidence interval. The first group included athletes with fasting insulin concentrations below the upper limit of the mean confidence interval ($\leq 4.5 \mu\text{U} \cdot \text{ml}^{-1}$); the second group included athletes with fasting insulin concentrations above the upper limit of the mean confidence interval ($\geq 4.6 \mu\text{U} \cdot \text{ml}^{-1}$) (see Table 3).

Table 3. The effect of exercise on the concentration of glucose and insulin in the blood of qualified athletes (X $\pm$ m; n = 39)

Blood collection	Group 1 (n = 19)		Group 2 (n = 20)	
	Insulin, $\mu\text{U} \cdot \text{ml}^{-1}$	Glucose, $\text{mmol} \cdot \text{l}^{-1}$	Insulin, $\mu\text{U} \cdot \text{ml}^{-1}$	Glucose, $\text{mmol} \cdot \text{l}^{-1}$
Input data	2.56 $\pm$ 0.28	4.34 $\pm$ 0.09	6.20 $\pm$ 0.40	4.22 $\pm$ 0.15
10 min post-load	6.87 $\pm$ 1.27	5.65 $\pm$ 0.34	7.56 $\pm$ 2.08	5.70 $\pm$ 0.59
20 min post-load	8.30 $\pm$ 1.41*	6.37 $\pm$ 0.35	10.04 $\pm$ 1.87	5.50 $\pm$ 0.36
40 min post-load	7.10 $\pm$ 1.02*	5.06 $\pm$ 0.21	10.00 $\pm$ 0.76	5.01 $\pm$ 0.34
60 min post-load	4.58 $\pm$ 0.74	4.21 $\pm$ 0.13	7.99 $\pm$ 1.39*	4.50 $\pm$ 0.16

Notes. X = average value; m = standard error; post-load = after physical activity; * = $p \leq 0.05$ compared to the original data.

Discussion

Our study aimed to determine the impact of intense exercise on the dynamics of insulin and glucose concentrations in the blood of athletes during early recovery. Basal glucose and insulin concentrations in the blood, measured in the morning at rest before exercise, were within the reference range for all athletes studied (World Health Organization, 2016; Muhammad et al., 2019).

Analysis of the dynamics of glucose and insulin concentrations during early recovery did not reveal any significant differences from the test load. However, a sharp increase in glucose and insulin concentrations is typical in response to exercise and is consistent with data from other authors (Kraemer et al., 1998; Kliszczewicz et al., 2017; Marliss and Vranic, 2002). At the 10-minute recovery mark following exercise, a significant increase in both insulin and glucose concentrations was observed, with average increases of 83.9% and 31.9% ($p \leq 0.05$), respectively (Marliss and Vranic, 2002). Peak glucose concentration was noted at 20 minutes (40.6%, $p \leq 0.05$), followed by a gradual decrease and return to baseline values at 60 minutes (0.4%) (Table 2).

As for insulin in the blood of the athletes, noteworthy is the detected increase in its concentration in response to physical load at the 20th and 40th minutes, which was retained until the 60th minute of recovery at 131.3%, 111.3% and 50.9% ($p \leq 0.05$), respectively. At the same time, the insulin peak was noted at the 20th and 40th minutes after intense physical load. Having made a general analysis of the dynamics of insulin and glucose concentrations, we determined that an increase in glucose immediately after exercise leads to a rise in insulin. However, in the future, the severity and dynamics of changes in them will be different, which varies from the data from other studies (Kliszczewicz et al., 2017). The glucose concentration in athletes decreased to baseline at 60 minutes of recovery, consistent with the data (Marliss and Vranic, 2002).

In our opinion, the fact that there is no correlation between the concentration of insulin and glucose—that is, the insulin level after exercise does not depend on changes in glucose concentration—was interesting. Perhaps another mechanism is involved, and this result is due to the sensitivity of the receptors, which requires further research. A large discrepancy and variation in insulin changes were also found.

There are different approaches to assessing the concentration of insulin in the blood, so for a better analysis of its changes we divided the athletes into two groups and used 95% of the confidence interval. The first group included athletes with an insulin concentration on an empty stomach which was below the upper limit of the average confidence interval ($\leq 4.5 \mu\text{U} \cdot \text{ml}^{-1}$), whereas the athletes in the second group had an insulin concentration above the upper limit of the average confidence interval ($\geq 4.6 \mu\text{U} \cdot \text{ml}^{-1}$).

In the first group, glucose and insulin concentrations acted synchronously; that is, they were closely related since an increase in glucose led to a rise in insulin, and vice versa, to a decrease. Their concentrations reached their maximum value at the 20th minute (Table 3).

In the second group, glucose concentration peaked at the 10th minute and then gradually decreased. Meanwhile, insulin concentration reached a peak and plateaued from the 20th to the 40th minute, only declining thereafter. These findings are consistent with some previous research (Kraemer et al., 1998), but they contradict another study (Kliszczewicz et al., 2017).

Most of all, the two groups differ in the magnitude of the changes in insulin concentration after performing the load. In the first group, insulin levels increased significantly by 168.3%, 224.3% and 177.3% at the 10th, 20th and 40th minutes of recovery after intense exercise, respectively. In contrast, in the athletes of the second group, the increase was less pronounced—21.9%, 62.0% and 61.3% at the 10th, 20th and 40th minutes of recovery, respectively. It should be noted that such an increase in insulin was not accompanied by a significant increase in glucose concentration during recovery. Insulin concentration at 60 minutes of recovery in the first and second groups did not return to the original value but exceeded it, which is inconsistent with other studies (Kluszczewicz et al., 2017; Marliss and Vranic, 2002).

Correlation relationships of athletes between the initial data of insulin concentration and its value during the recovery period were revealed as the following: in the first group $r = -0.59$ at the 10th minute, $r = -0.59$, $p \leq 0.05$ at the 20th minute, $r = -0.62$, $p \leq 0.05$ at the 40th minute; in the second group $r = 0.61$ at the 60th minute. Thus, the lower the initial concentration of insulin, the higher its increased value after intensive exercise, and the higher the basal level of insulin, the higher its concentration in the early recovery period.

Conclusions

By studying changes in insulin concentration in athletes during the early recovery after physical loads, we found a significant increase in glucose and insulin concentration in response to exercise load. In addition, there was a relationship between insulin concentration increase after intensive physical activity compared to its initial value. A lower basal insulin concentration was accompanied by a higher increase after load. Thus, it can be concluded that the magnitude of changes in insulin depends on its basal level. This is an interesting fact and requires further research to determine the boundaries of the optimal values of the basal insulin level.

Understanding the dynamics of the insulin response to intense physical load will allow for accelerated metabolic recovery processes through a planned intake of nutrients during the rapid recovery period after training. This can be applied to enhance the efficiency of developing nutrition strategies for professional athletes. We also consider it essential to further research the impact of food with different chemical compositions on recovery processes after physical loads of varying intensity and duration.

Conflicts of interest. The authors declare no conflict of interest.

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