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Article

Exploration on the change process of human glucocorticoid during incremental exercise load training

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Abstract: Glucocorticoid is a kind of hormone synthesized from glycogen, which has many physiological functions such as improving the body's anti fatigue, anti stress, and promoting growth. Oxidation medicine is a new medical science with dual characteristics of theory and technology, which is based on biological processes. Glucocorticoids can treat many diseases, but there are certain limitations in this process, especially in diseases that play a vital role. The purpose of this paper is to explore the change process of human glucocorticoid in the process of incremental exercise load training. This paper put forward the algorithm of incremental load training and action recognition in sports training, and analyzed the changes of human glucocorticoid (GC) in the process of incremental load training based on this research. The experimental design includes the selection of research subjects, the determination of sample size, and the setting of experimental and control groups. The load was set to start at 10 a.m., with cycling training from full effort to exhaustion. The initial load was 100 W, and it increased by 20 W every 10 min. The experimental results in this paper showed that for the changes of testosterone (T) during exercise, the salivary T secretion rate immediately after exercise was significantly different from that in the resting state at the recovery period of 30 min. For the change of GC during exercise, the secretory rate of saliva GC was 2.84 mmol/min in the resting state; the secretion rate of saliva GC was 2.46 mmol/min after 20 min of exercise and 2.15 mmol/min after 40 min of exercise; the secretion rate was 1.71 mmol/min immediately after exercise and 2.55 mmol/min after 30 min rest; there was a significant difference in the secretion rate of saliva GC for 5 times. In a word, there was no significant change in saliva T/GC value during exercise and rehabilitation under static state, which was related to strong adaptability of the body and no significant stress response.

Keywords: changes of glucocorticoid; exercise training; incremental load training; oxidative medicine; support vector machines

1. Introduction

With the continuous innovation and development of modern basketball, the competition among the world's top teams is becoming increasingly fierce, and higher requirements are also placed on the physical quality of athletes. There are many ways to improve the physical quality of athletes by conventional means. For a long time, people mainly rely on scientific methods to achieve this goal. Athletes must use their physical potential to the limit if they want to beat their opponents. Finding ways to improve the physical fitness of basketball players to increase the effectiveness of their physical reserves is an important topic in current basketball research. For basketball players, physical fitness is the most basic athletic ability of the body, and it is also an important part of basketball athletic ability. Physical fitness is an important basis for

basketball players to carry out technical training and improve sports performance.

In most cases, the body is very sensitive to energy and nutrition. When athletes carry out high-intensity training, the body would produce a kind of glucocorticoid. When the body converts energy into exercise ability through the regulation of glucocorticoid and other glucose metabolism, it would produce changes in glucocorticoid in the body. Glucocorticoids are bioactive substances necessary for protein metabolism and fat metabolism in the body, and are important components involved in the development, repair and regeneration of muscles and bones. For some athletes, the body glucocorticoid level is high during low level training and low after high level training. When energy intake is insufficient, blood sugar would rise. The increase of blood sugar would lead to the decrease of energy reserve of muscle tissue, which would cause symptoms such as muscle soreness and fatigue. When the level of glucocorticoid is reduced, the muscle tissue cannot recover its normal ability and strength. Therefore, it is very important to improve the glucocorticoid level of athletes. The glucocorticoids mainly include cortisol and adrenal cortisol, which belong to the cortisol in the neuroendocrine hormone system. When athletes exert too much force, their glucocorticoids would also increase correspondingly, so it is very important to understand the change process of glucocorticoids in the human body. The purpose of this paper is to explore the change process of human glucocorticoid in the process of incremental exercise load training, with a view to making some contributions to glucocorticoid.

According to the existing research progress, different researchers have also conducted corresponding cooperative research on glucocorticoids. Stout et al. consulted the relevant literature and combined the existing data on the absorption of intra-articular and epidural glucocorticoids and clinical adverse reactions. His purpose was to make people understand the risks associated with injection [1]. The glucocorticoid injected into the river water by the wastewater treatment plant would have a certain impact on the composition of the microbial community in the water body, thus having a certain impact on the groundwater quality. Li et al. evaluated typical natural and artificial glucocorticoids [2]. Nawata et al. aimed to explore the transitional changes of bone necrosis related to glucocorticoids in systemic lupus erythematosus, and focused on the use of immunosuppressants and glucocorticoids [3]. Lu et al. aimed to explore the functional changes of bone microvascular endothelial cells after glucocorticoid treatment, and observe the changes of its related genes using microarray technology [4]. Research by Doğan et al. showed that long-term use of glucocorticoids may lead to osteonecrosis in patients with systemic lupus erythematosus [5]. In one study, 30% of patients who used glucocorticoids for a long time developed symptoms of osteoporosis [6]. Therefore, they should be used with caution in actual practice and the patient's bone density should be monitored regularly. However, these scholars lacked some technical argumentation on the exploration of glucocorticoid. It was found that it would be better to explore the changes of glucocorticoids through sports training. For this, this paper consulted the relevant literature on sports training.

Some scholars also have some research in sports training. Tacey et al. aimed to explore the effects of glucocorticoids on exercise volume and performance, and the correlation between them and metabolism [7]. After a period of high-intensity training,

Nicoll et al. studied the phosphorylation of androgen and glucocorticoid receptors [8]. Du et al. aimed to study whether exercise training affects obesity related pulmonary inflammation by regulating local glucocorticoid synthesis or metabolism [9]. The study by Correia et al. showed that the phosphorylation of androgen and glucocorticoid receptors changed significantly after high-intensity training, which is consistent with the findings in this study [10]. However, these scholars did not discuss the change process of human glucocorticoid through incremental exercise load training, but only unilaterally discussed its significance.

Through research and analysis of changes in human glucocorticoids during incremental exercise load training, the results of this article show that the secretion rates of salivary T and GC decreased significantly after high-intensity exercise. However, the results varied under different training loads and environments. In low-intensity training, the changes in T and GC may not be as significant as high-intensity training, which has certain clinical medical value.

The innovations of this paper are as follows: (1) This paper explained the physiological role of glucocorticoid. This paper analyzed the increasing load training in sports training, and put forward an action recognition algorithm. (2) The changes of human glucocorticoid in the process of increasing exercise load training were studied experimentally.

However, this study has some limitations. First, the sample size was small, which may affect the generalizability of the results. Second, experimental conditions may have resulted in some variables not being adequately controlled. Finally, the use of glucocorticoids may induce some adverse reactions, such as immunosuppression and osteoporosis [11].

2. Research methods of human glucocorticoid changes during exercise load training

2.1. Physiological effects of glucocorticoids

Glucocorticoids have physiological effects as shown in **Figure 1**. Anti-inflammatory effect: In the absence of glucocorticoids, the muscle's ability to repair and regenerate is weakened or eliminated, leading to increased inflammation and pain [12,13]. Immune regulation: when the body is stimulated by stress, the body would secrete a large amount of glucocorticoids for immune regulation [14,15]. Anti fatigue effect: when the body is tired and does not have enough rest, a large amount of adrenocortical hormone would stimulate the body to produce a large number of hormones for regulation to restore the normal physiological function of the body [16,17]. For example, when cells are damaged, they secrete large amounts of inflammatory factors to attack immune cells; when the body is under stress, hormones are released. Anti stress reaction: when stress occurs in the body, the body would secrete a lot of hormones to cope with various environmental changes and maintain the stability of the body.

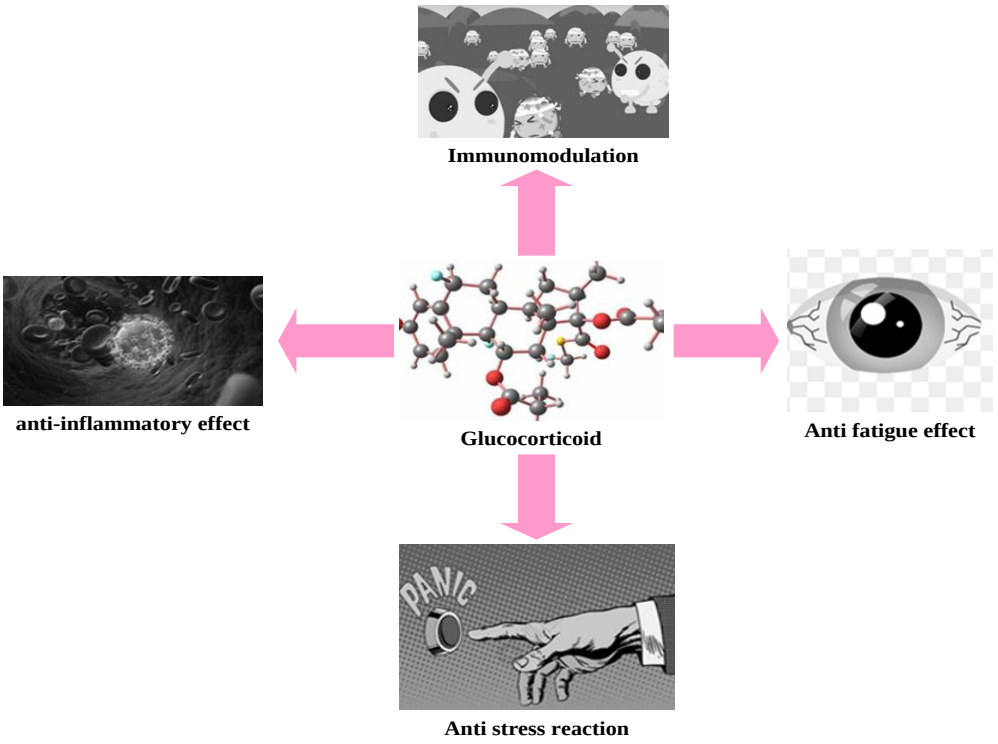

Figure 1. Physiological effects of glucocorticoids.

Glucocorticoids can reduce the hyperglycemia caused by excessive consumption of glycogen under the condition of excessive fatigue and stress, and increase the secretion of lactic acid in the human body and make it difficult to control the change of blood sugar, thus causing hypoglycemic reaction [18,19]. This hypoglycemic reaction can reduce the secretion of adrenal cortical hormones. It can also reduce the secretion of adrenergic, norepinephrine, cortisol and other hormones to reduce blood pressure and blood viscosity, thus stabilizing the systemic nervous balance and reducing the occurrence of adverse events. It also increases the concentration of platelet content in capillaries, and reduces the clotting effect by making the blood vessels more dilated and promoting the production of clotting factors. It plays an important role in platelet count and anticoagulation. At the same time, it can also promote leukocyte infiltration and stimulate lymphocytes to secrete immunoglobulin and interleukin-1 to produce antibodies, which can effectively prevent the occurrence of coagulation events and vascular diseases caused by thrombosis. In addition, it can also promote wound healing and reduce the occurrence of post-traumatic stress reaction. This shows that the body still has the potential capacity of physiological activities in the case of hypoglycemia. This is why glycogen plays an important role in preventing and controlling stress response. It can be seen that glucocorticoids play the most important role in human health [20,21].

When taking glucocorticoid, the drug should be stopped immediately in case of allergic reaction or drug poisoning, and symptomatic treatment should be taken. At the same time, attention should be paid to drugs that may react or damage the health of the central nervous system. When using glucocorticoids, blood pressure and blood sugar should be closely monitored to avoid hypoglycemia and hyperglycemia [22,23]. Glucocorticoid cannot be used together with oral or intravenous glucocorticoids. If

oral and intravenous glucocorticoids are taken at the same time, attention should be paid to monitoring the change of blood drug concentration [24]. The blood drug concentration should be closely monitored during medication. In particular, during intravenous injection, blood glucose should be closely monitored to guide drug use, and the drug use plan should be adjusted in time. Calcium antagonists should be avoided during medication. If the blood drug concentration is too high, it should be reduced or stopped under the guidance of the doctor. To prevent adverse reactions to glucocorticoids, it is recommended to regularly monitor the patient's bone density and blood sugar levels during use, and adopt appropriate nutritional supplements and exercise plans. In addition, gradually reducing the dosage of glucocorticoids is also an effective method.

2.2. Increasing load training in physical training

The development of competitive sports has gone through several stages: from the maximum load to the maximum load and then to the lowest load. Each technical improvement would have a greater impact on the physical function, but the extent of its impact and the impact on health need to be further studied. The emergence of the method of increasing load marks the development direction of modern sports training. **Figure 2** shows the incremental load training. In competitive sports, load training refers to a training method of high-intensity and high-load sports under the condition of high-intensity exercise. Load training increases the exercise time to a certain stage through training to make the body reach the fatigue limit, and then recovers the normal life through the load with a certain intensity and speed gradually reduced. Finally, the training method has achieved the goal of sports training. The purpose of muscle enhancement can be achieved by increasing the training intensity, which is to consume human fat and muscle tissue to a certain extent. In order to achieve the goal of muscle enhancement, the human body must adjust its physiological function and physical fitness to meet the needs of sports and maintain the normal operation of body functions, thereby improving human immunity. During exercise, a large amount of energy needs to be consumed to supply body heat and make muscle fibers shrink and thicken. At this time, it is necessary to increase the blood flow rate to accelerate blood circulation and promote the regeneration and repair of cells and tissues. At the same time, it is also necessary to expel the metabolites from the body to maintain the normal operation of the basic functions inside the cells, and provide energy to support the growth and development of the human body. However, when the muscle recovers, it would affect its function (i.e., fatigue) or make the system enter a "sleep" state. At this time, it is necessary to stop training. It is also the fitness method of most fitness enthusiasts to achieve the goal of muscle enhancement by increasing high load to carry out a certain amount of exercise (such as strength training, explosive force training, etc.). One of the most important loads is to make the muscles quickly thicken or consume a lot of energy to maintain health and extend the exercise time. Incremental load training is a way to gradually increase the load with the growth of body muscles without reducing strength and intensity and the training effect.

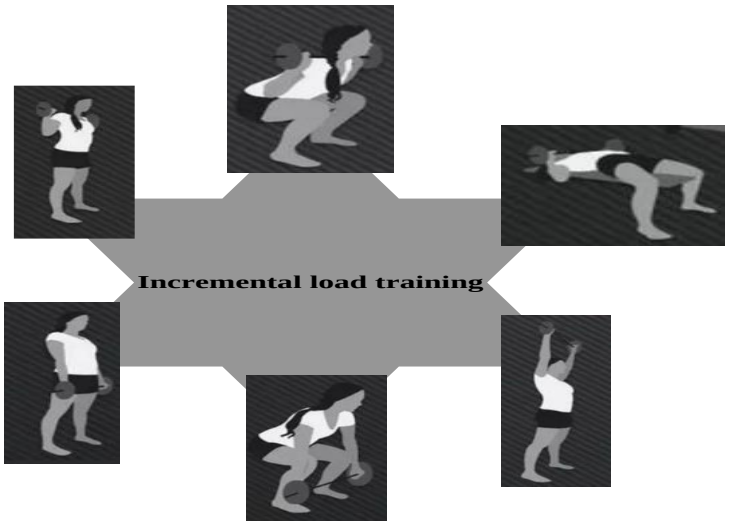

Figure 2. Incremental load training.

2.3. Action recognition algorithm

Support vector machine is a discrimination method based on the maximum distance between classes, and it is a binary classification model. This maximum optimal problem can be equivalent to a quadratic programming problem. The descriptors in each action video are encoded separately, and then each descriptor is pooled as a whole to obtain a feature vector describing the video. After that, the feature vectors of human behavior are used for classification and training, and their performance is compared. Finally, it is concluded that support vector machine is a good choice for human motion classifier. SVM has applications in pattern recognition in various fields, including portrait recognition, text classification, handwritten character recognition, bioinformatics, etc.

Linear support vector machine (LSVM) refers to the linear decomposable sampling in the input space. The set *D* shown in Equation (1) is a set of data sets used to train the support vector machine. Among them, $c_o \in \varphi = T^m$, and $u_o \in \delta = \{+1, -1\}$, $o = 1, 2, \cdots, m$. c_o is the descriptor of the *o*-th sample, and the corresponding u_o is the category number of sample c_o. It is assumed that when u_o is 1, it is regarded as a positive sample; when u_o is −1, it is considered as a negative sample.

$$D = \{(c_1, u_1), (c_2, u_2), \cdots, (c_m, u_m)\} \tag{1}$$

Among them, when the training data set is linearly decomposable, it is relatively simple. It has linear decomposability, so the data can be separated with the maximum distance.

The optimal linear objective of linear support vector machine is the decision surface between two categories, which has the same distance from the boundary of two categories and is the largest. Therefore, it is necessary to calculate a plane, so that the two descriptors can be accurately divided into different types, so as to maximize the distance between them. It is necessary to conform to the inequality of Equation (2):

$$\begin{cases} e \times c + n \geq +1, u_o = +1 \\ e \times c + n \leq -1, u_o = -1 \end{cases} \tag{2}$$

In order to ensure the maximum distance, the objective function shown in the

demand solution Equation (3):

$$\max_{e}\left[\frac{2}{\|e\|}\right] \Leftrightarrow \min_{e}\left[\frac{1}{2}\|e\|\right] \tag{3}$$

According to Equation (3), a limited extreme value problem can be established equivalently. Equation (4) is a strict convex optimization problem, and its solution is unique.

$$\begin{cases} \min\limits_{e,n} \|e\|^2/2 \\ u_o(e \times c_o + n) \geq 1, o = 1, 2, \cdots, m \end{cases} \tag{4}$$

Equation (4) can construct the Lagrangian function and convert it into the optimal solution, and the results are as:

$$A(e, \beta, n) = \frac{1}{2}\|e\|^2 - \sum_{o=1}^{m} \beta_o [u_o(e \times c_o + n) - 1] \tag{5}$$

$$\begin{cases} \dfrac{\partial A(e, \beta, n)}{\partial e} = e - \sum\limits_{o=1}^{m} [\beta_o u_o c_o] = 0 \\ \beta_o [u_o(e \cdot c_o + n) - 1] = 0, \beta_o \geq 0, o = 1, 2, \cdots, m \\ \sum\limits_{o=1}^{m} \beta_o u_o = 0 \end{cases} \tag{6}$$

By simplifying the above steps, the final dual problem can be obtained, which can be written as:

$$\begin{cases} \min\limits_{\beta} \dfrac{1}{2} \sum\limits_{o=1}^{m} \sum\limits_{k=0}^{m} u_o u_k \beta_o \beta_k (c_o \times c_k) - \sum\limits_{o=1}^{m} \beta_o \\ \sum\limits_{o=1}^{m} \beta_o u_o = 0, \beta_o \geq 0, o = 1, 2, \cdots, m \end{cases} \tag{7}$$

From Equation (7), the optimal solution β^* of β can be obtained. On this basis, the final results e^* and n^* of e and n are calculated, and the decision surface of classification is obtained, which are as Equations (8) and (9):

$$\begin{cases} e^* = \sum\limits_{o=1}^{m} \beta_o^* u_o c_o \\ n^* = u_k - \sum\limits_{o=1}^{m} \beta_o^* u_o (c_o \times c_k) \end{cases} \tag{8}$$

$$g(c) = \text{sign}(e^* \times c + n) = \text{sign}\left(\sum_{o=1}^{m} \beta_o^* u_o (c_o \times c_k) + n^*\right) \tag{9}$$

3. Evaluation of the experimental results of human glucocorticoid changes during incremental exercise load training

3.1. Test objects and methods

A survey was conducted on 20 male college students in a sports college. The age was about 21 years old, and the height was 176.93; the weight was 71.87 kg, and the percentage of body fat was 12.03%; the training period was 3 years, and they were in good health. Before the trial, all subjects were explained their research purpose and

scheme, and signed the informed consent form. Three days before the experiment, the precautions were described. Precautions include the following: no eating within 2 h before sampling, that is, eating before 7:30 a.m. on the test day; no drinking within 24 h; avoid any oral treatment within 48 h; don't do strenuous exercise the day before the experiment. Before the test, the subjects' mouths were examined. It was strictly prohibited to have any bleeding wound in the mouth and chewing gum.

The load was set to start from 10 a.m. to carry out bicycle training from full strength to exhausted strength. The initial load was 100 W, with an increase of 20 W every 10 min, and the rotation speed was 60 times/min until the subject was exhausted.

Hormone changes would be affected by the physiological rhythm, so in order to ensure that the collection time is consistent, all subjects must be on time at 9:00 in the morning. First, the basic information of the subject was recorded, and the height, weight and body composition were measured. Secondly, the heart rate band was tied for the subjects, and the oral cavity of the subjects was checked to prevent bleeding. Thirdly, the subjects were asked to rinse their mouth with water for 2–4 times, then the mouthwash and the remaining saliva were drained and they sat in silence for 20 min. After the heart rate of the subjects was basically stable, saliva and blood were collected at rest for the first time. At 10 a.m., participants began to exercise with powered bicycles until their physical strength was exhausted. During this exercise, saliva and blood were collected during the recovery period after training. The heart rate changes of the subjects were recorded during the whole experiment from the quiet state to the recovery period of 30 min. In addition, due to the limitations of experimental conditions, the test was conducted for 17 consecutive days, with one subject tested every day.

Judgment of exhaustion: when the heartbeat of the subject exceeds 180 times/min and the heart beat no longer increases within 2 min, the subjective feeling of the subject has been exhausted, and the subject cannot maintain a normal speed with repeated encouragement.

Statistical analysis indexes include salivary T concentration, salivary T secretion rate, serum T concentration, salivary GC concentration, salivary GC secretion rate, serum GC concentration, salivary T/GC, and serum T/GC.

The index secretion rate (mol/min) is the amount of secretion produced per minute, which is the product of the index concentration and the salivary secretion rate. The salivary secretion rate is the amount of saliva collected in a certain time (2 min) divided by the time obtained.

The method for measuring glucocorticoids uses an Empsun brand immunoassay analyzer, which is calibrated regularly to ensure accuracy. The measurement frequency is to collect saliva and blood samples before exercise, 20 min and 40 min during exercise, immediately after exercise, and 30 min during recovery.

Data processing and statistical analysis methods included using SPSS 17.0 for data analysis, using one-way analysis of variance (ANOVA) and multiple comparison tests, with the significance level set at $P < 0.05$. Precautions were explained to the subjects before the experiment to ensure sample consistency and avoid interference from external factors. In the normality test of each index before, during and after exercise, each index conformed to the normal distribution ($P > 0.05$).

3.2. Evaluation of T change during movement

Figure 3 shows the changes of salivary T and serum T concentrations during exercise. **Figure 3a** shows the change of salivary T concentration, and **Figure 3b** shows the change of serum T concentration. The test results of saliva T concentration showed that the saliva T concentration was 1.14 mmol/L at rest and 1.1 mmol/L at 20 min of exercise; the concentration was 1.15 mmol/L at 40 min of exercise and 1.13 mmol/L immediately after exercise; the concentration was 1.12 mmol/L after 30 min of recovery, and there was no significant difference in saliva T concentration after 5 times of recovery. The results of serum T test showed that the concentration of serum T was 23.31 mmol/L at rest and 23.01 mmol/L at 20 min of exercise; the concentration was 23.48 mmol/L at 40 min of exercise and 22.95 mmol/L immediately after exercise; the concentration was 22.97 mmol/L after 30 min of recovery, and there was no significant difference in serum T concentration after 5 times of recovery.

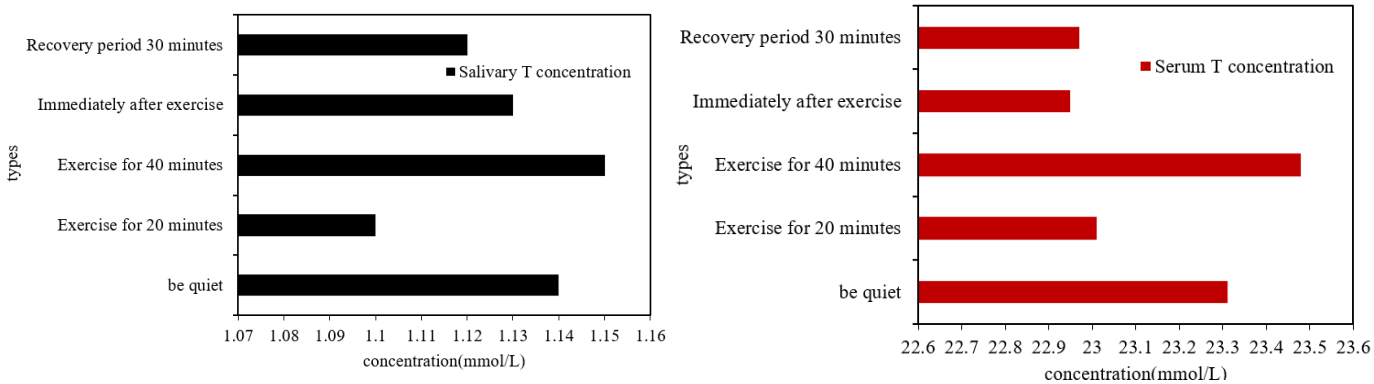

Figure 3. Changes of salivary T and serum T concentrations. **(a)** Variation of salivary T concentration; **(b)** variation of serum T concentration.

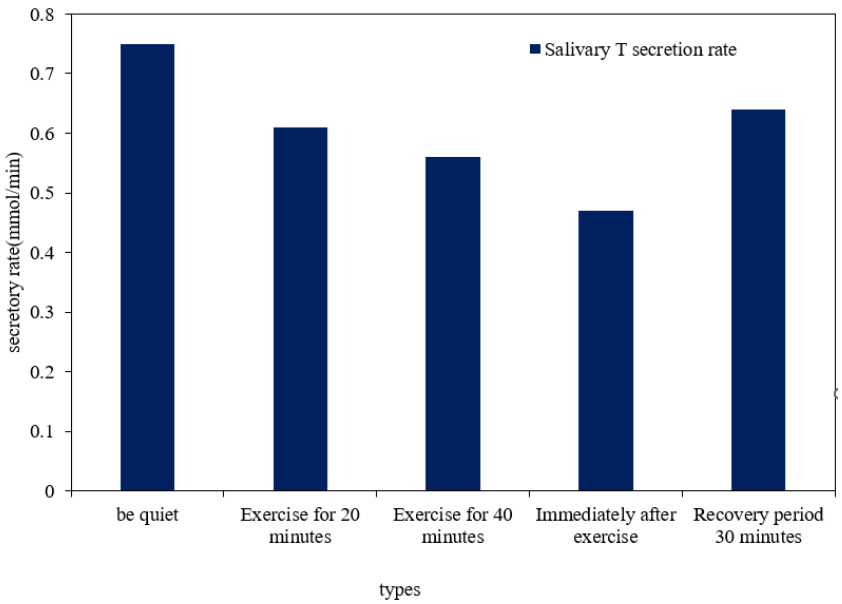

Figure 4. Changes in salivary T secretion rate.

The test results of salivary T secretion rate are shown in **Figure 4**. The salivary T secretion rate was 0.75 mmol/min at rest and 0.61 mmol/min at 20 min of exercise;

the secretion rate was 0.56 mmol/min after 40 min of exercise, and 0.47 mmol/min immediately after exercise; the secretion amount was 0.64 mmol/min after 30 min of recovery, and the difference of T secretion rate between the five times was statistically significant. The results of multiple comparisons showed that the salivary T secretion rate at the moment of exercise was significantly different from that at rest and in the recovery period of 30 min, and there is no obvious difference between the other points.

3.3. Evaluation of GC changes during movement

Figure 5 shows the changes of saliva GC and serum GC concentrations during exercise. **Figure 5a** shows the change of saliva GC concentration, and **Figure 5b** shows the change of serum GC concentration. The results of saliva GC concentration test showed that the saliva GC concentration was 4.33 mmol/L at rest and 4.42 mmol/L at 20 min of exercise; the concentration was 4.34 mmol/L at 40 min of exercise and 4.22 mmol/L immediately after exercise; the concentration was 4.42 mmol/L after 30 min of recovery, and there was no significant difference in the concentration of saliva GC for five times. The test results of serum GC concentration showed that the saliva GC concentration was 26.93 mmol/L at rest and 26.81 mmol/L at 20 min of exercise; the concentration was 28.06 mmol/L at 40 min of exercise and 28.31 mmol/L immediately after exercise; the concentration was 27.8 mmol/L after 30 min of recovery, and there was no significant difference in serum GC concentration after 5 times of recovery.

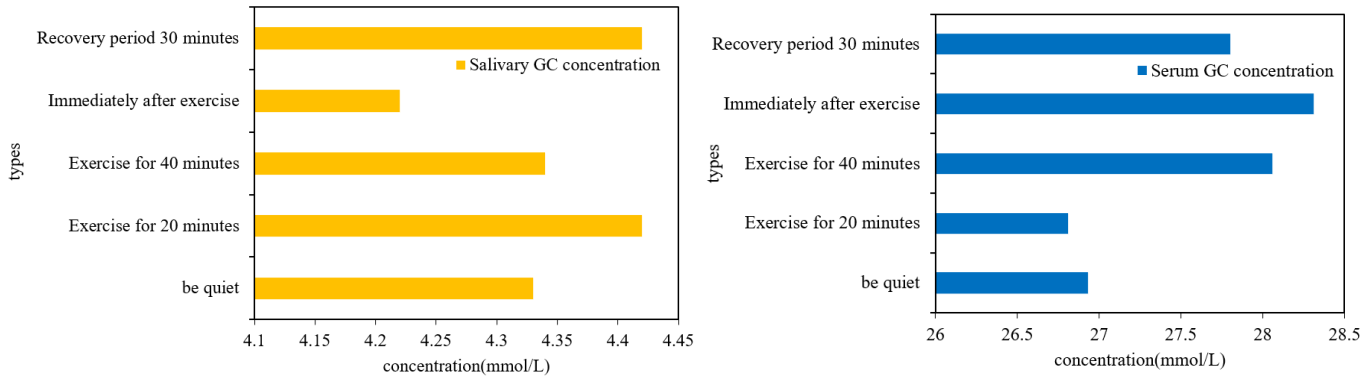

Figure 5. Salivary GC and serum GC concentration changes. **(a)** Changes in GC concentration in saliva; **(b)** changes in GC concentration in serum

The test results of saliva GC secretion rate are shown in **Figure 6**. The secretory rate of saliva GC was 2.84 mmol/min at rest and 2.46 mmol/min at 20 min of exercise; the secretion rate was 2.15 mmol/min after 40 min of exercise, and 1.71 mmol/min immediately after exercise; the secretion rate was 2.55 mmol/min after 30 min of recovery, and there was a significant difference in the secretion rate of saliva GC for five times. The results of multiple comparisons showed that the salivary GC secretion rate at the moment of exercise was significantly different from the salivary GC secretion rate in the quiet state and the recovery period of 30 min, and there was no significant difference between the other points.

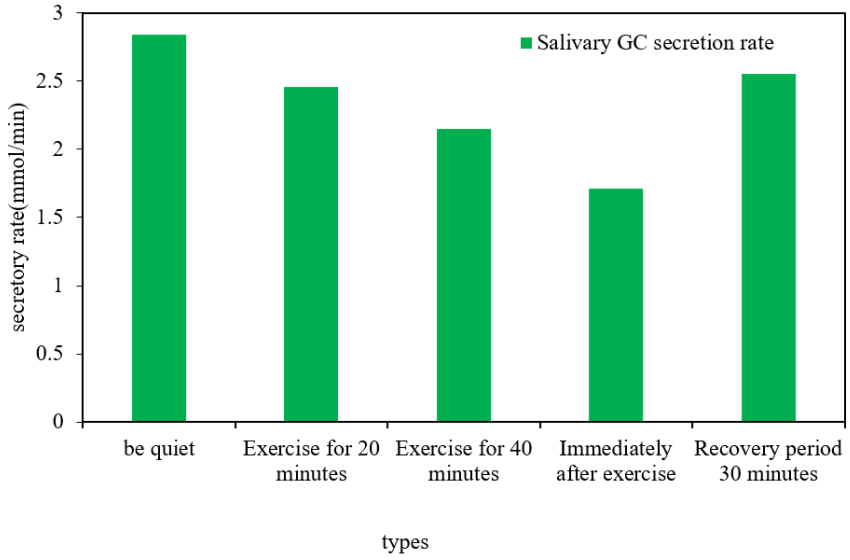

Figure 6. Changes in salivary GC secretion rate.

3.4. Correlation evaluation of GC and T

The correlation analysis results of serum T concentration and serum GC concentration are shown in **Table 1**. There was a significant negative correlation between serum T and GC at rest ($R < 0$, $P < 0.01$). In the process of exercise, there was a significant negative correlation between the two, ($R < 0$, $P < 0.05$). After 30 min of recovery period, there was no correlation between the two concentrations ($P > 0.05$). From the whole exercise process, there was also a significant negative correlation between the two ($R < 0$, $P < 0.01$).

Table 1. Correlation between serum T concentration and serum GC concentration.

	R	***P***
Be quiet	−0.649	0.007
Exercise for 20 min	−0.753	0.002
Exercise for 40 min	−0.598	0.015
Immediately after exercise	−0.579	0.023
Recovery period 30 min	−0.181	0.531
The whole movement process	−0.549	0.001

Table 2. Correlation between salivary T concentration and salivary GC concentration.

	R	***P***
Be quiet	−0.21	0.411
Exercise for 20 min	−0.679	0.006
Exercise for 40 min	−0.699	0.003
Immediately after exercise	−0.721	0.002
Recovery period 30 min	−0.029	0.909
The whole movement process	−0.501	0.001

The correlation analysis results of salivary T concentration and salivary GC

concentration are shown in **Table 2**. There was no correlation between salivary T concentration and salivary GC concentration at rest ($P > 0.05$). There was a significant negative correlation between the two groups during exercise ($R < 0$, $P < 0.01$). After 30 min of recovery, there was no correlation between their concentrations ($P > 0.05$). In the whole exercise process, there was also a significant negative correlation between the two ($R < 0$, $P < 0.01$).

The correlation analysis results of salivary T secretion rate and salivary GC secretion rate are shown in **Table 3**. There was a significant correlation between salivary T secretion and salivary GC secretion rate at rest ($R > 0$, $P < 0.01$). After 30 min of exercise and recovery, there was a significant positive correlation between them ($R > 0$, $P < 0.01$). In the whole exercise process, there was a very significant positive correlation between them ($R > 0$, $P < 0.01$).

Table 3. Correlation between salivary T secretion rate and salivary GC secretion rate.

	R	***P***
Be quiet	0.971	0.001
Exercise for 20 min	0.951	0.001
Exercise for 40 min	0.942	0.001
Immediately after exercise	0.901	0.001
Recovery period 30 min	0.923	0.001
The whole movement process	0.939	0.001

3.5. Evaluation of the changing trend of T/GC and its correlation

Figure 7 shows the T/GC value during the subject's exercise. Among them, **Figure 7a** is the serum T/GC value, and **Figure 7b** is the saliva T/GC value. The analysis results of the serum T/GC value showed that the serum T/GC was 0.98 when quiet, and the serum T/GC was 0.93 when exercising for 20 min; the serum T/GC was 0.93 when exercising for 40 min, and the serum T/GC was 0.9 immediately after exercise; the serum T/GC was 0.89 when recovering for 30 min, and there was no significant difference in serum T/GC values for 5 times. The analysis results of the saliva T/GC value showed that the saliva T/GC was 0.26 when it was quiet, and the saliva T/GC was 0.25 when it was exercised for 20 min; the saliva T/GC was 0.27 when it was exercised for 40 min, and the saliva T/GC was 0.27 immediately after exercise; the saliva T/GC was 0.25 when it was restored for 30 min, and there was no significant difference in the saliva T/C value for 5 times.

The correlation analysis results of serum T/GC value and saliva T/GC value are shown in **Table 4**. In the quiet state, during exercise, and from the perspective of the entire exercise process, the two are not related ($P > 0.05$).

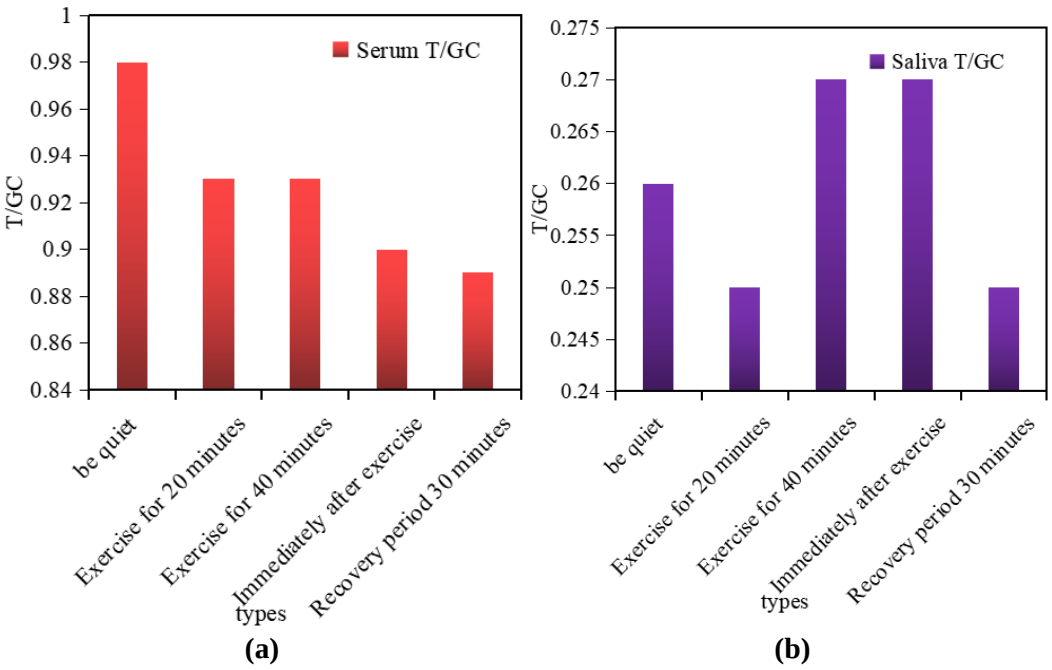

Figure 7. The T/GC value of the subject during exercise. **(a)** Serum T/GC values; **(b)** salivary T/GC values

Table 4. Correlation between serum T/GC value and saliva T/GC value.

	R	***P***
Be quiet	−0.071	0.811
Exercise for 20 min	0.059	0.819
Exercise for 40 min	0.189	0.501
Immediately after exercise	−0.091	0.759
Recovery period 30 min	−0.401	0.139
The whole movement process	−0.041	0.741

The results of this experiment showed that there was no significant difference in the concentration of salivary T, serum T, salivary GC and serum GC between quiet, exercise and post exercise. One of the main reasons for this phenomenon was that the test adopted an incremental load depletion test. The initial load was 100 W, and after 10 min, it increased by 20 W. With the gradual increase of the load, and from small to large, the fitness of the body to the exercise load was gradually improved. There was no significant stress response, so the changes of T and GC were not significant. The salivary T secretion rate and salivary GC secretion rate decreased significantly during exercise and immediately after exercise, with a statistically significant difference. After a 30 min rest, it gradually returned to the state before exercise. For example, after high-intensity exercise, the salivary T secretion rate decreases, reaching 0.61 mmol/min after 20 min of exercise and 0.56 mmol/min after 40 min of exercise (**Figure 4**). These data indicate that salivary T secretion rate significantly decreases with increasing exercise time. The results showed that the salivary T secretion rate and salivary GC secretion rate decreased after high load exercise, which is related to the human body's response to fatigue, and has certain clinical application value.

4. Conclusions

The comprehensive analysis of T and GC can better reflect the relationship between anabolism and catabolism of the human body, so as to evaluate the fatigue and competitive state of athletes. T/GC is an important indicator to measure the state of exercise and the degree of fatigue. During sports training, coaches can dynamically monitor athletes' T and GC levels at rest to understand their physical functions and ability to adapt to load. When the T/GC value of athletes decreases greatly after training, it indicates that catabolism exceeds anabolism, and athletes would have more serious fatigue. Therefore, coaches should take a variety of physical, biological and nutritional recovery measures to promote athletes' recovery by adjusting exercise load; if the ratio remains unchanged or increases, it indicates that the physical function of the athletes is good. The coach can appropriately increase the exercise load to promote the recovery of athletes, so as to improve sports performance. In this experiment, the salivary T/GC value did not change significantly from rest to exercise to recovery, which is related to the better adaptability of the body to load and no obvious stress response. However, due to the limitations of time and technology, there are problems in the study of human glucocorticoids in this paper, which have not been analyzed yet. This would be further discussed in the future.

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References

1. Stout A, Friedly J, Standaert CJ. Systemic Absorption and Side Effects of Locally Injected Glucocorticoids. PM&R. 2019; 11(4): 409-419. doi: 10.1002/pmrj.12042
2. Li X, Ma M, Rene ER, et al. Changes in microbial communities during the removal of natural and synthetic glucocorticoids in three types of river-based aquifer media. Environmental Science and Pollution Research. 2018; 26(33): 33953-33962. doi: 10.1007/s11356-018-2748-x
3. Nawata K, Nakamura J, Ikeda K, et al. Transitional changes in the incidence of osteonecrosis in systemic lupus erythematosus patients: focus on immunosuppressant agents and glucocorticoids. Rheumatology. 2018; 57(5): 844-849. doi: 10.1093/rheumatology/key009
4. Lu Y, Yu Q, Guo W, et al. Effect of glucocorticoids on the function of microvascular endothelial cells in the human femoral head bone. Advances in Clinical and Experimental Medicine. 2020; 29(3): 345-353. doi: 10.17219/acem/112602
5. Doğan I, Kalyoncu U, Kilic L, et al. Avascular necrosis less frequently found in systemic lupus erythematosus patients with the use of alternate day corticosteroid. Turkish Journal of Medical Sciences. 2020; 50(1): 219-224. doi: 10.3906/sag-1908-182
6. Hu K, Adachi JD. Glucocorticoid induced osteoporosis. Expert Review of Endocrinology & Metabolism. 2019; 14(4): 259-266. doi: 10.1080/17446651.2019.1617131
7. Tacey A, Parker L, Garnham A, et al. The effect of acute and short term glucocorticoid administration on exercise capacity and metabolism. Journal of Science and Medicine in Sport. 2017; 20(6): 543-548. doi: 10.1016/j.jsams.2016.10.016

8. Nicoll JX, Fry AC, Mosier EM, et al. MAPK, androgen, and glucocorticoid receptor phosphorylation following high-frequency resistance exercise non-functional overreaching. European Journal of Applied Physiology. 2019; 119(10): 2237-2253. doi: 10.1007/s00421-019-04200-y
9. Du SF, Yu Q, Chuan K, et al. In obese mice, exercise training increases 11β-HSD1 expression, contributing to glucocorticoid activation and suppression of pulmonary inflammation. Journal of Applied Physiology. 2017; 123(4): 717-727. doi: 10.1152/japplphysiol.00652.2016
10. Correia RR, Batista VRG, Veras ASC, et al. High-intensity interval training attenuates the effects caused by arterial hypertension in the ventral prostate. The Prostate. 2021; 82(3): 373-387. doi: 10.1002/pros.24285
11. Chotiyarnwong P, McCloskey EV. Pathogenesis of glucocorticoid-induced osteoporosis and options for treatment. Nature Reviews Endocrinology. 2020; 16(8): 437-447. doi: 10.1038/s41574-020-0341-0
12. Zannas AS, Chrousos GP. Epigenetic programming by stress and glucocorticoids along the human lifespan. Molecular Psychiatry. 2017; 22(5): 640-646. doi: 10.1038/mp.2017.35
13. Filaretova L, Podvigina T, Yarushkina N. Physiological and Pharmacological Effects of Glucocorticoids on the Gastrointestinal Tract. Current Pharmaceutical Design. 2020; 26(25): 2962-2970. doi: 10.2174/1381612826666200521142746
14. Krontira AC, Cruceanu C, Binder EB. Glucocorticoids as Mediators of Adverse Outcomes of Prenatal Stress. Trends in Neurosciences. 2020; 43(6): 394-405. doi: 10.1016/j.tins.2020.03.008
15. Yates N, Crew RC, Wyrwoll CS. Vitamin D deficiency and impaired placental function: potential regulation by glucocorticoids? Reproduction. 2017; 153(5): R163-R171. doi: 10.1530/rep-16-0647
16. Sehrsweeney M, Wilson DR, Bain M, et al. The effects of stress and glucocorticoids on vocalizations: a test in North American red squirrels. Behavioral Ecology. 2019; 30(4): 1030-1040. doi: 10.1093/beheco/arz044
17. Willi RA, Faltermann S, Hettich T, et al. Active Glucocorticoids Have a Range of Important Adverse Developmental and Physiological Effects on Developing Zebrafish Embryos. Environmental Science & Technology. 2017; 52(2): 877-885. doi: 10.1021/acs.est.7b06057
18. Gray JD, Kogan JF, Marrocco J, et al. Genomic and epigenomic mechanisms of glucocorticoids in the brain. Nature Reviews Endocrinology. 2017; 13(11): 661-673. doi: 10.1038/nrendo.2017.97
19. Stedman JM, Hallinger KK, Winkler DW, et al. Heritable variation in circulating glucocorticoids and endocrine flexibility in a free-living songbird. Journal of Evolutionary Biology. 2017; 30(9): 1724-1735. doi: 10.1111/jeb.13135
20. Cain DW, Cidlowski JA. Immune regulation by glucocorticoids. Nature Reviews Immunology. 2017; 17(4): 233-247. doi: 10.1038/nri.2017.1
21. Hardy RS, Raza K, Cooper MS. Therapeutic glucocorticoids: mechanisms of actions in rheumatic diseases. Nature Reviews Rheumatology. 2020; 16(3): 133-144. doi: 10.1038/s41584-020-0371-y
22. Whirledge S, Cidlowski JA. Glucocorticoids and Reproduction: Traffic Control on the Road to Reproduction. Trends in Endocrinology & Metabolism. 2017; 28(6): 399-415. doi: 10.1016/j.tem.2017.02.005
23. Szeszko PR, Lehrner A, Yehuda R. Glucocorticoids and Hippocampal Structure and Function in PTSD. Harvard Review of Psychiatry. 2018; 26(3): 142-157. doi: 10.1097/hrp.0000000000000188
24. Taves MD, Ashwell JD. Glucocorticoids in T cell development, differentiation and function. Nature Reviews Immunology. 2020; 21(4): 233-243. doi: 10.1038/s41577-020-00464-0