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The usefulness of the cortisol: testosterone ratio in assessing the catabolic and anabolic balance of athletes

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ABSTRACT

Introduction and purpose:

The balance between catabolic and anabolic processes is crucial for achieving optimal athletic performance and maintaining the health of athletes. The cortisol-to-testosterone ratio (C/T) is a commonly used indicator to assess this balance, as it allows for monitoring the equilibrium between these two hormones. This literature review aims to evaluate the utility of T/C ratio in monitoring this balance, providing insights into its relevance for athletic training and performance. The paper is based on a relevant review of literature about the practical aspects of measuring the C/T ratio and its correlation with athletic performance, recovery, overtraining, and training adaptation were analyzed.

Description of the state of knowledge:

The cortisol-to-testosterone ratio is a useful indicator for evaluating between catabolic and anabolic states in athletes. It can be practically applied to fine-tune training regimens and help prevent overtraining.

However, its effectiveness is dependent on various factors, including individual variability and the influence of external factors such as sleep.

Summary:

The C/T ratio remains a valuable tool for assessing the metabolic-anabolic balance in athletes. Practical aspects of measurement and interpretation are essential for its effective application. Continued research is needed to refine the use of this biomarker across different sports and training contexts.

Keywords: Athletes, Exercise, Cortisol, Testosterone, Recovery

Introduction and purpose

Endocrinology, a branch of physiological medical science, is increasingly being adopted by exercise scientists in their research [1].

Glucocorticoids, originating from the adrenal cortex, play a key role in the metabolism of glucose, proteins, and fats [2] where circulating cortisol, the dominant glucocorticoid produced by the human adrenal glands, is regulated by the hypothalamic-pituitary-adrenal feedback system.[3]. During a stress condition, the human body synthesizes catecholamine neurotransmitters and specific hormones (called "stress hormones"), the most important of which is cortisol [4]. The primary actions of cortisol include regulating metabolism and immune functions. Prolonged stress leads to changes in circulating cortisol levels, which can result in alterations in both physical and mental states [5]. Cortisol and testosterone are biomarkers of significant interest owing to their association with the stress response and overall health [6, 7].

Physical exercise impacts the hormone levels of the hypothalamic-pituitary-gonadal axis in males and females, particularly in sports of high intensity and physical demands [8].
In sports physiology, the testosterone-to-cortisol ratio has been used to analyze the balance between anabolic and catabolic processes. Since testosterone exhibits anabolic effects and cortisol promotes catabolic effects, the testosterone-to-cortisol ratio has been considered a marker for overtraining syndromes [9].
Physical exercise plays a crucial role in the production and regulation of testosterone (T) and cortisol (C). The T to C ratio responds to metabolic stress related to fatigue and recovery from exercises, serving as an indicator of anabolic-catabolic balance, psychophysical stress, and fatigue, and providing information for adjusting training loads [10].
Tracking the workload of athletes during both training and competition has become a highly discussed topic in sports science [11]. The purpose of this literature review is to examine the role of the C/T ratio in assessing the catabolic-anabolic balance of athletes, discuss the practical aspects of its measurement, and present its usefulness in the context of monitoring the physiological status of athletes.

Assessment of Training Adaptation

Adaptation to training is a key element in improving athletic performance. The C/T ratio reflects the body's hormonal response to different types of training loads.
The findings indicate that cortisol levels in athletes can affect both the immediate response to competition and the medium-term recovery phase. Additionally, the results suggest that coaches should avoid excessive training loads for at least two days after competitions, as physical and mental recovery may still be ongoing [12].
A study comparing the effects of high-intensity interval training (HIIT) and continuous aerobic training on testosterone and cortisol levels showed that both types of exercise significantly increased testosterone levels immediately after the session. However, the T/C ratio dropped below baseline levels after 12 hours only in the case of HIIT [13]. Although exercise increases plasma testosterone concentration, this effect depends on various factors, including age, weight, and the type of exercise performed. The T/C ratio can be used to assess athletes' recovery status and how different factors, such as training intensity and rest duration, can influence this indicator. The optimal T/C ratio varies depending on the individual characteristics of the athlete [14]. Monitoring the T/C ratio is crucial in preventing overtraining and optimizing workouts, indicating that prolonged physical exertion without adequate recovery leads to a decrease in the T/C ratio, which is a sign of a dominance of catabolic processes [15].
HIIT may be more effective in short-term increases in testosterone levels, which can support intense training sessions and rapid adaptations[16]; therefore, different training programs should be tailored to individual athletes' needs to optimize hormonal balance [17].

Monitoring overtraining

The competition between athletes and the growth of sports knowledge have significantly influenced training methods, concurrently increasing their diversity. As a result, there is a growing number of athletes who have intensified both the frequency and intensity of their training sessions, while simultaneously reducing recovery time [18].

Overtraining syndrome (OTS) is characterized by a prolonged and unexplained decline in athletic performance, typically accompanied by significant psychological symptoms. This condition arises from an imbalance in training, resulting in metabolic, endocrine, and biochemical changes associated with chronic energy deficiency and impaired recovery mechanisms [19].

Chronic competitive workload and the acute number of severe impacts are key parameters to monitor in order to prevent undesirable outcomes. High levels of chronic competitive workload can disrupt homeostasis, leading to a decreased T/C ratio, making it crucial to monitor this indicator during periods of congested fixtures [20]. Considering that testosterone (T) and cortisol (C) play significant roles in protein and carbohydrate metabolism, a decrease of more than 30% in their ratio is recognized as a marker of overtraining [21, 22].

The decrease in endocrinological markers observed in the post-season assessment suggests that athletes should transition more smoothly into off-season training to mitigate negative changes like fatigue and overtraining, thereby starting the off-season in a more advantageous position [23].

Athletes who physically overload themselves to improve performance may experience overtraining if they lack a proper balance between stress and recovery, and overtraining is difficult to diagnose as there is no definitive diagnostic marker [24].

Research studies encompass a wide array of sporting disciplines, ranging from endurance to strength sports. In each of these disciplines, monitoring the C/T ratio facilitates a better understanding of training adaptations and optimization of training programs.

Taking into account other disciplines like swimming, where both male and female swimmers showed a significant increase in the T/C ratio over time, indicating a favorable (anabolic) response to nearly two months of intensive preseason training. The increase in T/C was primarily due to a steady decrease in serum cortisol levels, while serum testosterone levels remained unchanged [25]. The results suggest that proper management of training load and recovery is crucial for preventing overtraining. Athletes are advised to adhere to a structured plan during the transition period to the off-season to ensure complete physiological recovery and prepare for future challenges [26].

Individual variability in the T/C ratio, including additional personal aspects such as age, gender, and mood disorders related to stress.

Understanding the internal effects of a competitive season on each player can enhance individualized programming. Monitoring plasma testosterone and cortisol levels is essential to manage stress from professional basketball demands, which vary by player position [27].

A thorough assessment of psycho-physiological responses to training can provide valuable insights during the gradual adaptation planning to intense professional demands, and also serve as an additional tool to enhance athletes' performance outcomes [28].

Athletes are constantly exposed to various physical and psychological stressors, both during training and competitions [29].

Changes in cortisol hormone levels can be influenced by various factors, including anticipation of the upcoming day [30].

The levels of cortisol (C) are not correlated with total mood disturbance during different competition periods, unlike testosterone (T) levels, which showed a relationship with total mood disturbance during the congested period, suggesting the influence of mood changes on T responsiveness. The positive correlation between the T/C ratio and total mood disturbance suggests that tracking changes in T may be more useful than changes in C in assessing fatigue levels and mood state changes [31].

One should also consider the differences in hormonal responses to training between women and men. Biological sex is a primary determinant of performance outcomes in many sports events and physical tasks. Models that offer insights into the role of sex steroid hormones in athletic performance, including their augmentation and suppression, are crucial for understanding these dynamics.

The study aimed to analyze the chronic hormonal responses in CrossFit practitioners after a six-month training period and compare these outcomes between genders. By the end of the study, testosterone (T) levels were notably elevated, with men demonstrating higher T levels than women. Conversely, cortisol (C) levels remained lower throughout the training period compared to baseline, with men consistently showing lower C levels than women. As a result, women maintained a consistently lower C/T ratio throughout the study duration [32].

Testosterone is considered one of the most important factors explaining the performance differences between male and female athletes, which can amount to a 10 to 20% variation in performance outcomes [33].

Physical exercise impacts the hormone levels of the hypothalamic-pituitary-gonadal axis in males and females, particularly in sports of high intensity and physical demands [34].

Men show greater adaptations in muscle mass than women after long-term endurance training (> 9 months), likely facilitated by high concentrations of endogenous testosterone [35].

While endocrine dysregulation is linked to aging, it's difficult to attribute these changes entirely to age alone. Factors like physical activity and exercise also play a significant role in shaping the hormonal environment [36].

In young athletes, stress rather than inadequate training can significantly influence performance outcomes. Just before outdoor races, cortisol levels were observed to decrease, while testosterone levels increased, especially prior to ergometer or boat races, continuing to rise towards the end of the race. Significant differences were noted in the testosterone-to-cortisol ratio between indoor and outdoor competitions, with higher ratios observed during indoor events across all considered time points [37].

The study suggests that despite unfavorable hormonal changes among Africans, the absence of overtraining symptoms may be due to their higher testosterone levels, which support the body's adaptation to intense training. These differences in training response between ethnic groups underscore the need to tailor training programs and healthcare for athletes based on their individual physiological characteristics [38].

Recently, research has been presented showing that this ratio can reveal even more important information about our health than either of these biomarkers alone [39].

A study was conducted to assess the impact of high training loads on endothelial function in female sprinters and middle-distance runners.

The athletes showed significantly reduced flow-mediated dilation (FMD) ($p < 0.01$) and higher baseline levels of hyaluronan (HA) and syndecan-1 (SDC-1) in serum ($p < 0.05$ and $p < 0.001$, respectively). Significantly lower T/C and fT/C ratios were observed in the athletes compared to the control group ($p < 0.01$). Additionally, the fT/C ratio was significantly positively correlated with FMD and negatively with HA in all women studied [40].

Personalization of Training

The findings indicate that cortisol levels in athletes can affect both the immediate response to competition and the medium-term recovery phase. Additionally, the results suggest that coaches should avoid excessive training loads for at least two days after competitions, as physical and mental recovery may still be ongoing.[41]

The results of studies evaluating the physical, physiological demands, and steroid hormone responses during basketball small-sided games (SSGs) with different tactical tasks and training regimens showed a significant increase in cortisol levels after the SSGs. Testosterone levels increased following the defense-long SSG, decreased after the offense-short SSG, and remained unchanged after both the defense-short and offense-long SSGs [42].

Understanding the internal effects of a competitive season on each player can enhance individualized programming. Monitoring plasma testosterone and cortisol levels is essential to manage stress from professional basketball demands, which vary by player position.

Changes in cortisol hormone levels can be influenced by various factors, including anticipation of the upcoming day.[43]

Conclusion

The future of exercise endocrinology is promising, with researchers poised to build on the past 60 years of work, uncovering new insights into human adaptation to exercise that will enhance health and performance.[44] Insufficient data exists regarding the stress and motivation responses of adolescent athletes during competitions. During this developmental stage, athletic performance can be significantly influenced by stress rather than by the effectiveness of training programs [45].

Physical activity induces significant changes in the C/fT ratio, potentially affecting GH and IGF-I secretion from the liver, making it a valuable diagnostic tool for assessing skeletal muscle regenerative capacity or identifying early stages of functional muscle overload [46].

Furthermore, the studies have shown that intense training loads can impair endothelial function in young female athletes, which is associated with disruptions in the balance of anabolic and catabolic hormones. Given that training-induced endothelial dysfunction may have a negative impact on vascular health, endothelial status should be regularly monitored during training to minimize health risks in athletes [47]. Since many established biomarker reference ranges cater to the general population rather than athletes specifically, repeated measurements are essential for coaches to establish personalized benchmarks. The individual values can vary from day to day or week to week, allowing athletes and professionals to monitor chronic changes that may indicate risks such as injuries, overtraining, or performance decline [48].

Despite varying training levels, acute exercise appears capable of disrupting the circadian rhythm of the T:C ratio, leading to a reduced ratio observed several hours post-physical activity, potentially following a biphasic pattern. [49].
Steroid hormones enhance performance and influence physiological adaptation in response to a similar exercise dosage in both men and women [50].
Reviewing these studies allows for a better understanding of how the cortisol to testosterone ratio can be a useful tool in assessing the catabolic-anabolic balance in athletes. It also highlights the practical implications of these findings for sports training and monitoring athletes' health.

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Author's contribution
Conceptualization: EL, RJ; Investigation: EL; Writing -rough preparation: ML, AR, BM; Writing -review and editing: EL, BM; Visualization: ML, RJ; Supervision: AR.

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