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The causes of adverse changes of testosterone levels in men

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Abstract

Introduction: As men age, progressive testosterone deficiency syndrome becomes an increasingly common problem. However, the decreased testosterone levels are not only the result of advanced age.

Areas covered: PubMed search of published data on testosterone, nutritional deficiency, stress, sleep and obesity. Many factors impact the male HPG axis (the hypothalamic-pituitary-adrenal), including body weight, calorific and nutritional value of a diet, the amount and quality of sleep, as well as the level of stress. In the case of persons of healthy weight, a below-average calorific value of a diet may decrease the levels of testosterone in men. On the other hand, the same caloric deficiency in obese persons may result in a neutral or positive impact on testosterone levels.

Expert opinion: Many factors, including external, environmental and internal factors, influence testosterone levels. Undoubtedly, nutritional deficiency, and particularly of such nutrients as zinc, magnesium, vitamin D, together with low polyphenols intake, affects the HPG axis. The levels of mental and oxidative stress can also adversely impact the axis. Hence, a diagnosis of the cause of disturbance in testosterone levels depends on many factors and requires a broad range of research, as well as a change of patients' lifestyle.

Keywords: Nutrition, stress, obesity, endocrinology, testosterone

Article highlights

- Most factors influencing testosterone levels in men are modifiable, such as diet, amount of sleep or stress levels.
- Zinc is a cofactor of LH and FSH enzymes catalysing the synthesis of trophic hormones of the pituitary. Zinc deficiency correlates with lower testosterone levels.
- The reduction of sleeping time to five hours per day during a single examination contributed to reducing testosterone levels by 10-15%. However, the evidence confirming the influence of sleep deprivation or circadian rhythm disorders on testosterone are inconclusive.
- In the case of people with healthy weight, too low calorific value of diet may result in the reduction of testosterone levels in men. This influence was not observed in obese persons.
- Excessive body mass may lead to higher levels of cortisol and affect androgens levels. Hair analysis of people of different body mass showed higher cortisol levels and lower testosterone levels in obese people.
- Long-term effects of treatment of hypogonadism are well-documented and are reported to decrease a risk of prostate cancer, cardiovascular diseases, type II diabetes, prediabetic state, nephropathy or erection disorders.

1. Introduction

The popularity of healthy lifestyle and rapid technological and medical progress have helped reduce mortality rates and increase life expectancy among both men and women over the past two decades in Poland. According to Statistics Poland (Pol. GUS), in 2018 the average life expectancy of an average 30-year-old man was 78 years [1], whereas in 1980 it was 66. As men age, the risk of late-life health problems increases. Apart from the most common afflictions, such as cardiovascular diseases or cancer, testosterone deficiency syndrome becomes an increasingly common problem for men [2]. However, testosterone secretion disorders are not characteristic only for older men. Many factors influence the male HPG axis, including environmental factors, such as excessive stress or low physical activity, as well as drugs intake, diet and body mass. Therefore, in order to prevent the risk of TDS during middle and older age, it is significant to determine which factors may adversely impact testosterone levels in men.

This study offers a brief outline of scientific articles on the subject of possible factors influencing testosterone level disorders in men. Although this article focuses primarily on nutritional factors, it also discusses the impact of mental stress, sleep duration, and age. We have critically reviewed available scientific literature on the impact of diet on testosterone levels, body mass, body mass change, mental stress, age, and sleep duration. We have typed the above keywords into PubMed search engine in search for the relevant data on the subject. The bibliographical references consist of sources dated from 1980 to 2020.

2.Testosterone synthesis in the body

The function of male gonads, including secretion of testosterone, is regulated by pituitary hormones (hypothalamic-pituitary-gonadal axis). The luteinizing hormone (LH) activates steroidogenic enzymes by influencing Leydig cells, which enables a testosterone synthesis from cholesterol. The follicle-stimulating hormone (FSH) stimulates testicular growth, impacts Sertoli cells and regulates spermatogenesis. Testosterone exerts negative feedback on gonadotropin secretion (GnRH) by affecting hypothalamus, and LH, by impacting the anterior pituitary gland. The gonadal protein hormones, in turn, suppress (inhibin), or, alternatively, stimulate (activin) FSH secretion [3].

Testosterone, the principal male sex hormone, belongs to a group of steroid hormones. The group also includes 17β-estradiol, dihydrotestosterone (DHT) and adrenal androgen dehydroepiandrosterone. In a male body, steroid hormones are synthesised primarily by Leydig cells of the testis. Androgens are synthesised from cholesterol as a result of many enzymatic changes in the process of steroidogenesis [4-5]. The process starts when the receptors in the membrane of Leydig cells take up a cholesterol molecule and transport it inside the cell through endocytosis. Next, the luteinizing hormone stimulates the transport of cholesterol through StAR (steroidogenic acute regulatory protein) from the cytosol to the inner mitochondrial membrane in which multistage enzymatic conversion of cholesterol to testosterone occurs. As a result of the activity of cholesterol pregnenolone, the side-chain cleavage enzyme (P450scc cytochrome) is formed. Subsequently, the synthesis involves two pathways. The first is the dehydroepiandrosterone pathway, promoted in male gonads, in which pregnenolone, employing five enzymes, converts to 17-hydroxypregnenolone, and then to dehydroepiandrosterone (DHEA) and Δ5-androstenediol, and finally to testosterone. The second, a less active pathway of synthesis of the hormone, is the so-called progesterone pathway in which progesterone as well as 17-hydroxyprogesterone and androstenedione, respectively, are synthesised prior to the production of testosterone[6-7]. Physiological testosterone levels (80-280pg per cm^3 of blood plasma) are regulated through the hypothalamus-pituitary-gonads axis[8]. The reduction of the testosterone levels stimulates the hypothalamus to release gonadoliberin (GnRH) which, while influencing the pituitary, precipitates the release of luteinizing (LH) and gametokinetic (FSH) hormones. The hormones, in turn, directly impact gonads (testicles) and stimulate testosterone synthesis [9]. The human body can synthesise up to 7 mg of testosterone in a day. Nevertheless, the healthy synthesis of the hormone results in the secretion of 4 to 6 mg of testosterone into the bloodstream per day. Free testosterone is transported into the cytoplasm of target tissue cells, where it can merge with the androgen receptor, or can be reduced to DHT by the cytoplasmic enzyme 5a-reductase. The T-receptor or DHT-receptor complex moves into the cell nucleus and activates specific genes. Protein products of the genes mediate numerous hormonal functions [9-10].

2.1 The importance of testosterone

Androgens have pleiotropic functional properties. In the early weeks (7-20) of foetal development, testosterone impacts a differentiation of internal organs of the male reproductive system, and DHT impacts the external organs of the male reproductive system. Later, during perinatal period (from the 8th month of foetal life to the 5th month after birth) androgens take part in testicular migration and differentiation of sexually dimorphic brain structures and functions of hypothalamus as well as determine male gender.In puberty androgens impact height, development of somatic traits of male sex, initiation and sustenance of spermatogenesis and development of libido. During the period of maturity, the hormones serve to sustain spermatogenesis and libido, have an anabolic effect on muscular system, bone structure, immune system, blood circulation, and the liver. The level of testosterone decreases with age, which leads to a reduction in size of male gonads, libido, bone density, muscle mass, erythropoiesis, and increase in fat production [3].

However, since the androgen receptors (AR) of the hormone are present in almost every body cell, one may assume that its role in the human body is crucial. While promoting anabolic processes of a body, testosterone influences the synthesis of skeletal muscle proteins [11]. Also, while leading to the changes in the levels of enzymes responsible for the regeneration of myocytes, it accelerates the renewal of homeostasis in muscle tissues after a physical activity [12]. Moreover, testosterone positively impacts the amount of satellite glial cells in muscle tissues, as well as the number of cell nuclei in myocytes. The application of anabolic steroids, the source of exogenous testosterone, resulted in the increase of the number of cell nuclei in the myocytes of the athletes, and the increase in the volume of type I, IIA and lix muscle fibres [13-15,82]. Testosterone also impacts the increase of bone mass, regeneration of neurons, blood vessels, and erythropoiesis [16-19]. Moreover, due to the transcription stimulation of insulin receptors substrates IRS-1 and IRS-2 as well as GLUT-4 transporters, testosterone regulates the circulation and metabolism of glucose in a human body [12]. Testosterone has a significant influence on men’s behaviour since their tendency to taking risks, increased assertiveness and aggression correlate with testosterone levels [20]. This hypothesis seems to be proved by the fact that during the oestrous cycle, which promotes increased testosterone levels, women are more likely to behave aggressively. Also, when presented with a dishonest offer, they are more likely to turn it down, which bespeaks their increased assertiveness [21].

3.The influence of energy intake and body mass

The level of energy intake in a diet is a leading factor conditioning the intensity of catabolic or anabolic processes. In the case of decreased energy levels, the human body promotes an increased activity of catabolic energy pathways, including lipolysis, beta-oxidation and glycogenolysis. Apart from regulating metabolism rates, energy deficit also influences testosterone levels. Depending on some factors, including body mass, the impact might suppress or, paradoxically, induce the testosterone synthesis. In the research involving men aged 21-31, ranging from those with healthy body mass to the slightly overweight (BMI 21-28), who participated in the 14-day mountain march resulting in energy expenditure of 6670 kcal/day while the diet caloric value was 3600 kcal/day, the testosterone levels significantly decreased when compared to the results obtained before the march [22]. The influence of long-term energy deficit on androgens levels was also observed in another research involving a group of men of healthy body mass. The research on testosterone levels in a group of 24 men who declared having been on a low energy diet for about 7,4 ± 4,5 years, on average, showed that testosterone levels were statistically lower than in a group of people who did not apply energy deficit [23]. The analysis of the mentioned research may lead to the assumption that sustained energy deficit positively impacts testosterone levels. However, some publications seem to question this hypothesis. Dietary interventions based on three-month-long energy deficit in a group of overweight men had neither a negative nor positive impact on testosterone levels. It is significant that in the same research, the rise of testosterone levels was observed in men exposed to increased physical activity, specifically aerobic workout (without energetic restrictions) [24]. In another research involving 48 overweight men (the average BMI was 27,5) the energy deficit of 400 kcal applied for 12 weeks resulted in the reduction of body mass by 4,2 ± 0,8 kg and, importantly, the increase in sexual capacities and testosterone levels [25]. Also, similar results were obtained by Shulte et al. [26] in the study involving 13 obese men whose BMI median was 42,7. The three-month-long energy deficit of 800 kcal resulted in the rise of overall testosterone levels by 6,97 nmol /l, on average, to 13,21 nmol /l. According to the researchers, there are two distinct ways of interpreting the achieved results. The first is increased testosterone synthesis in gonads as a result of the normalisation of body mass. The second is a significant reduction in aromatisation of testosterone in blood to 17β-estradiol, which results from the decreased activity of an enzyme catalysing the process of aromatase. Aromatase is secreted in the adipose tissue, which decreased as a result of the energy deficit in the examined group [26]. Consequently, in the case of men of healthy body mass too low energy intake in a diet may result in a reduction in testosterone levels in men. The same deficit in overweight men may, in turn, result in a neutral or positive impact on the levels of the hormone.

4. Nutritional deficiency

A well-balanced diet is a significant factor which impacts the maintenance of homeostasis and proper functioning of the endocrine system. In the case of the deficiency of particular nutrients in the diet, the synthesis of enzymes or substrates, which is essential in testosterone synthesis, may be disturbed. The example of an element which forms part of enzymes related to the HPG axis is zinc. The role of zinc is essential in higher levels of the axis, since it is a cofactor of the enzymes which catalyse the synthesis of LH and FSH tropic hormones [27]. Zinc deficiency in a body correlates with lower testosterone levels [28--31,14]. Compensation for zinc deficiencies, in turn, results in the restoration of the testosterone levels to its physiological values [32-34, 28]. Another element whose deficit may decrease testosterone levels is magnesium. Even though there is no scientific evidence to prove the direct role of magnesium in testosterone synthesis, its low concentration positively correlates with the concentration of the hormone [34-35]. The hypothetical mechanism responsible for this regularity is the impact of the magnesium deficiency on the increase of cortisol concentration [36-38], the hormone which was shown to inhibit the secretion of androgens [39-41]. Also, vitamin D is believed to play a role in testosterone synthesis. Due to the presence of VDR (vitamin D receptors) in Leydig cells, one may surmise that vitamin D impacts the HPG axis [42-44]. The thesis is also substantiated by the studies which show that compensation for vitamin D deficiency increases testosterone levels [45-47]. This led us to conclude that the supplementation of this vitamin is highly recommended for the purpose of offsetting testosterone levels disorders. Whereas there is a low probability that the cholecalciferol deficiency is the only factor inhibiting the synthesis of testosterone, the inclusion of vitamin D supplementation might be an effective subsidiary intervention in the treatment of hypogonadism (the decrease of testosterone levels with age) [47]. Apart from vitamins and mineral components, there are other substances in food that impact testosterone levels. Low intake of products which are the source of polyphenols, such as flavones, flavonoids, resveratrol or oleuropein, may foster an increased aromatisation of testosterone to estrogens [48-50]. In the longer term, this may cause undesirable effects, such as increased estrogens levels in a male body.

5. Stress and testosterone

The relation between testosterone and stress, or rather cortisol levels, is well-documented in the scientific literature [39-41, 51-61]. Some of these studies postulate the antagonistic influence of cortisol on androgens, one of which puts forward the hypothesis concerning the functions of the glucocorticoid receptor (GR). In physiological conditions, the secreted cortisol joins GR, which causes a particular effect connected with the functions of cortisol. In the case of increased cortisol levels, glucocorticoid receptor joins the genes of similar hormones, including androgens, which decreases their impact on the body. In other words, testosterone demonstrates an affinity to GR, which inhibits its effects and decreases free testosterone levels in the plasma [39-40]. Another mechanism associated with the functioning of cortisol is based on its lipophilic nature. Due to their affinity to fatty acids, glucocorticoids may accumulate in the mitochondrial and lysosomal membrane. In the case of low cortisol levels, the effect stabilises the membrane. However, when cortisol levels are too high, membrane transport is disturbed, which increases the oxidation potential and promotes catabolic reactions. Consequently, the physiological fluctuation of cortisol does not disturb the homeostasis of the body, including the secretion of androgens. However, if the cortisol levels surpass the physiological values in a long time, for example, as a consequence of chronic stress, this may condition negative aspects connected with testosterone secretion. It is worth noting that psychological factors may induce the secretion of cortisol in the body, which results in a reduction in testosterone levels. A low-carbohydrate diet, which is a diet providing the body with less than 45% energy from carbohydrates, leads to the increased cortisol levels [41, 51-52]. Moreover, excessive physical activity impacts cortisol levels. In the study involving an examination of 57 men subjected to 8-week Finnish physical training, the researchers noted the increase of cortisol in less trained soldiers, which correlated with the decrease of testosterone levels [53]. Similar results were obtained by the researchers examining a group of 52 skydivers taking part in an 11-week-long vocational training. During this period, the soldiers underwent intensive 5-day-long physical training. The hormonal changes caused by intensive and extended training included the decrease of testosterone levels by 46%, IGF-1 by 28%, and SHGB by 25% [62]. An interesting relation between the primary cortisol levels and fluctuation of testosterone were shown by the scientists from the University of Alabama at Birmingham [55]. It was proved that during the study on hormonal changes in a stressful social situation, participants demonstrating lower primary cortisol levels showed a higher increase in testosterone levels. It means that people who are less likely to be exposed to stressful situations in social interactions with others also show a higher activity of the HPG axis [56-58]. Moreover, it is worth noting that the basic cortisol levels depend not only on social anxieties, but they are connected with many other factors, including body mass. Excessive body mass may lead to higher levels of cortisol and affect androgens levels. Hair analysis of people of different body mass showed higher cortisol levels and lower testosterone levels in obese people [59]. In this case, one should also pay attention not only to cortisol levels but also to endocrine functions of adipose tissue, which secrets, among others, aromatase converting testosterone to estrogen or resistin, which induces oxidative stress in body cells, which, in turn, affects Leydig cells [60-61, 63, 47].

6. Age and testosterone levels

With age, secretion and, consequently, testosterone levels in a body decrease. Male population after the age of 35-40 demonstrate on average lower androgens levels. It results from structural changes in male gonads. Over time, the number of the Leydig cells in male gonads decreases and their efficiency of secretion deteriorates. Also, the blood flow in gonads and microcirculation decrease [63]. Apart from the decreased level of testosterone synthesis, the amount of the free form of the hormone (fT) changes with age. It is understood that free testosterone in blood constitutes about 1,5-2% of the overall amount; the rest is linked with proteins that bind steroid hormones. The most common protein of this type is globulin which is responsible for binding steroid hormones (SHGB). It is assumed that it binds about 60% of testosterone in the bloodstream [64]. Only fT has an impact on the biological functions of the male body. Hence, the higher level of SHGB, the lower efficiency of free testosterone circulation, and the higher risk of body disorders. It is estimated that, in general, testosterone levels decrease by about 1% a year, and the level of fT by about 1,3-2% [65-66]. Apart from the age factor, adverse lifestyle habits (increased alcohol intake, hypertension, Western pattern diet) may lead to a reduction in testosterone levels [67]. Therefore, observational studies show that a significant decrease in the testosterone levels in the bloodstream is found in 8% of men at the age 40-60, and in 20% of men at the age of 60-80 [31]. Unfortunately, hypogonadism is linked with increased mortality; hence, regular check-ups of healthy men and implementation of healthy lifestyle and pharmacotherapy in men with testosterone level disorders is necessary for sustaining a long and comfortable life [68]. This is particularly important considering that decreased testosterone levels may increase the risk of cardiovascular disease and type 2 diabetes, while the use of hormone replacement therapy decreases the risk [69-72]. The researchers who treated a group of 360 men (age: 60,7 ± 7,2 years) with hypogonadism using testosterone therapy have obtained interesting results. The median of time of observation in both groups was 7 years. The reduction of death rate among the patients under treatment ranged from 66 to 92%. Moreover, during the observation of the control group, 30 nonfatal strokes and 26 myocardial infarctions were recorded, whereas in the group in which the patients were treated with the use of testosterone, no cases of such conditions were recorded [73]. The treatment of hypogonadism has also been proved effective for patients with urinary disorders. An experiment involving a group of patients treated with testosterone showed a reduction in I-PSS (International Prostate Symptom Score) and post-void bladder volume ($p <0,0001$) in patients receiving testosterone therapy when compared to placebo treatment [74]. Moreover, in another experiment the researchers confirmed a correlation between testosterone level disorder and the risk of prostate cancer in men with hypogonadism [75]. The risk significantly rises when the level of testosterone in blood is too low. On the other hand, when the level of testosterone is suboptimal, the risk of cancer has not been shown to rise significantly among the men under treatment [76]. Also, one may observe the correlation between the treatment of hypogonadism and improvement of health parameters of metabolic syndrome. In the group of 77 men with hypogonadism and medical record of cardiovascular diseases, the average body mass of the patients decreased from 114 ± 13 kg to 91 ± 9 kg following hormone replacement therapy. Moreover, the cardiovascular parameters, including blood pressure, heart rate, lipid profile or glycaemia, significantly improved [77]. Long-term effects of treatment of hypogonadism are well-documented and show a decrease a risk of prostate cancer, cardiovascular diseases, type II diabetes, prediabetic state, nephropathy or erection disorders [78-79]. During the 12-year-long observation of the patients undergoing testosterone therapy, the researchers found a significantly lower risk of cardiovascular diseases, prostate cancer and mortality rate in the testosterone treated men (412 patients) than in men who did not undergo testosterone therapy (393 patients) [80]. Another experiment showed that testosterone treatment of men with hypogonadism may improve kidney function. During the experiment the patients under treatment demonstrated the decrease of creatinine levels in serum (1,14 ± 0,18 do 1,07 ± 0,8 mg / dl), uric acid (6,8 ± 1,5 do 5,5 ± 1,6 mg / dl), urea (47,5 ± 12,0 do 31,7 ± 12,9 mg / dl), and increase in GFR (86,6 ± 12,8 do 98,5 ± 8,6 ml / min / 1,73m2). The authors of the experiment suggest that a long-term treatment of hypogonadism which positively impacts kidney functions leads to a reduction of death rate caused by CVD [81]

7. Sleeping time and testosterone levels

People spend about one-third of their lives asleep, and even though it seems to be a passive process of resting, for the body it is a process of an active regeneration of tissues, organs and systems, including an endocrine system which is responsible for the secretion of hormones [82]. The level of testosterone follows the circadian rhythm, which ends late at night. The levels of testosterone in plasma change with the circadian rhythm peaking during the sleep, and reaching a nadir in the late afternoon with additional pulses every 90 minutes, which reflects the rhythm of secretion of pulsatile luteinizing hormone (LH) [83-85, 17]. It has been shown that the sleep-dependent increase in testosterone levels occurs irrespective of whether the sleep occurs during the night or during the parallel time of the day. The increase in testosterone during the sleeping time and its reduction during waking hours are linear, but there are apparent individual differences in men [86-87]. Hence, sleep may significantly affect the production and secretion of testosterone. Various studies prove the impact of sleep deprivation on the decrease of testosterone levels [29]. Nevertheless, it should be pointed out that the data regarding the influence of such deprivation on the HPG axis remain discrepant. One of the studies showed that the restriction of sleep to 4,5 hours resulted in the lower daytime testosterone levels when the participants were allowed to sleep in the first half of the night (the examined group slept between 10.30 pm and 3 am). On the other hand, when the examined group slept through the second half of the night (between 2.45 am and 7 am), no negative impact on testosterone levels was observed [88]. The results probably do not contradict each other since the testosterone levels decreased with the prolongation of the waking time. Many scientific studies show contradictory data pertaining to sleep deprivation in healthy young men as recorded during scientific experiments. The restriction of sleep to five hours per day for five days was shown to reduce the levels of testosterone by 10-15% [89]. In another study, in the course of which the sleeping time was reduced during the first half of the night to the 4 am to 8 am time slot for five days, there were no significant changes in the levels of testosterone [90]. Various sleep disorders, including those resulting from the disruption of the quality of sleep, sleep deprivation, and circadian rhythm disturbance, may lead to a reduction in testosterone levels. Nevertheless, there is no substantial evidence to confirm the influence of sleep deprivation and circadian rhythm disorders on the functioning of testosterone [86]. Interestingly, the positive influence of sleep on the levels of testosterone depends on age, physical activity and body mass [91]. However, it is worth noting that with age, men are more likely to suffer from the disorders of sleep, including the intensification of sleep apnea. Hence, sleeping time may be one of the factors leading to the disorders of testosterone levels [92]. For that reason, the length and quality of sleep in preventive treatment and treatment of low levels of testosterone is significant. Lastly, it is important to note that sleep deprivation may be a symptom of hypogonadism. In patients with sleep deprivation and hypogonadism, who underwent a hormone replacement therapy, the quality of sleep improved after the period of 12 months [93].

8. Summary

Proper testosterone levels play a significant role in the regulation of male reproductive abilities, sexual functions, as well as the proper functioning of the skeletal system, metabolism, fatty acids, bone mass, and muscular strength [94]. Many factors, including external, environmental and internal factors, influence testosterone levels. The impact of energy intake derived from a testosterone-boosting diet depends on a human body mass. In the case of people of healthy body mass, insufficient energy intake may result in a reduction in testosterone levels in men. The same energy deficit in obese people, may, in turn, result in a neutral or positive impact on the levels of the hormone. Undoubtedly, nutritional deficiency, and particularly of such nutrients as zinc, magnesium, vitamin D, together with low polyphenols intake, affects the HPG axis. The levels of mental and oxidative stress can also adversely impact the axis. The higher the cortisol levels in a human body, or the higher its daily fluctuation, the lower the testosterone levels. What is more, the effect seems to be strengthened by excessive body weight, which is related to the increased oxidative stress affecting the functions of the Leydig cells. Other factors which might disrupt testosterone synthesis may be the length and quality of sleep. Even though the issue is relatively unknown, it appears that both sleep deprivation (shorter than five hours) and low quality of sleep (sleeping with the light on, sleeping during the day, under the influence of alcohol) impact the testosterone levels negatively.

9. Expert opinion

Testosterone is a primary male hormone that performs many functions in a body, including the impact on primary and secondary gender-related characteristics such as muscle mass, facial features, as well as promoting athletic body and regulation of spermatogenesis. The available studies show a probable impact of diet composition and lifestyle on the testosterone level in men. However, the number of studies is limited. The correlation between vitamin D level in a body and the hormonal balance, as well as the impact of the energy from carbohydrates and fats on the calorific value of a diet, seems to be one of the most exciting areas of research on the correlation of a diet and testosterone level. It appears that modification of a diet, regarding the amount of carbohydrates and fats, may positively impact the hormonal parameters in men. More studies show that the role of cholecalciferol is not confined only to the skeletal system. It was proved that the active form of vitamin D (1,25 (OH) D) is a hormone of paracrine and autocrine signalling, which impacts cells through the vitamin D receptors (VDR). The presence of the receptors in almost all body cells (apart from erythrocytes and mature cells of skeletal muscle) suggests that vitamin D runs in different directions. Due to its properties, vitamin D is a subject of many studies, and undoubtedly, it is worth waiting for the newest research on the correlation between vitamin D and the level of male hormones. Also, physical activity seems crucial as far as the proper functioning of male hormonal balance is concerned. The current research shows that any physical activity may positively influence the level of testosterone if it is adapted to the participant's physical capabilities. The current research shows that the most effective is strength training which leads to hypertrophy and increased synthesis of testosterone shortly after the training session has been completed. Another factor which may interfere with testosterone synthesis may be the length and quality of sleep. Although the matter has not been comprehensively examined, it seems that both sleep deprivation (lower than 5 hours), or reduced quality of sleep (sleeping when the light is on, sleeping during the day in a state of intoxication) negatively impact the testosterone level. Hence, further research on the issue as well as on the impact of macronutrients intake on hormonal homeostasis in men is required. Undoubtedly, energy deficit, in the case of athletes with low body fat mass, may negatively impact the production of testosterone. However, as far as overweight persons are concerned, the low calorific value of a diet may lead to the reduction of excessive body fat, which, in turn, increases the level of testosterone. Moreover, too low or too high fats intake may negatively impact the level of testosterone. Nevertheless, the quality of fat is also crucial. It appears that monosaturated fatty acids should predominate over other nutrients in the athletes' diet, especially if they eat a low-fat diet. Also, carbohydrates in a diet impact the optimization of the level of testosterone, since they reduce the deficit of glycogen and the level of cortisol after training. Finally, it has to be noted that more detailed research on the correlation between the calorific value of a diet, as well as macronutrients intake and the level of steroid hormones, is required. These aspects need further explication. Furthermore, the correlation between the level of cortisol and testosterone in the participants is a promising area of research. The factors impacting the level of a stress hormone also help reduce the level of testosterone. However, the exact processes and the size of the influence has not been fully explained so far.

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