Testosterone-Optimizing Strategies in Athletes

Artemii Lazarev, MD,[†‡‡] George G.A. Pujalte, MD,[*†¶] Christina Philibert, MS, CSCS, CCFT, ACSM CPT, ACSM EP,[†] Shon E. Meek, MD, PhD,[‡] Gregory A. Broderick, MD,[§] Dani G. Zapp, DO,[#] Michael R. Mayo, DO,[||] and Anthony C. Hackney, PhD, DSc[**]

Context: Testosterone is a steroid hormone produced primarily in the testes in men and ovaries in women, playing crucial roles in androgenic, anabolic, and psychological functions, including muscle growth, bone formation, erythropoiesis, risk-taking, and aggression, making it important for athletes. Sports performance is linked closely to testosterone level, prompting athletes to explore legal and illegal ways to boost testosterone. This review examines testosterone physiology and legal strategies for optimizing testosterone levels in athletes, as well as their practical applications.

Evidence Acquisition: Database search.

Study Design: Narrative review.

Level of Evidence: Level 5.

Results: Maintaining healthy testosterone levels requires energy balance and optimal nutrition with adequate macronutrients and micronutrients, especially for athletes prone to dieting and food restriction. Testosterone boosters are marketed widely but lack strong evidence for efficacy and may pose risks. While some substances show promise, further research is needed. Sleep is critical as testosterone secretion is linked to the rapid eye movement phase, highlighting the need for proper sleep hygiene and addressing sleep disorders. Moderate-to-high intensity free-weight resistance exercises are most effective for increasing testosterone, while the effects of sexual activity remain unclear. Endocrine-disrupting chemicals can lower testosterone levels and should be avoided. While cold-water immersion may decrease testosterone, sauna bathing appears to be neutral. Radiofrequency electromagnetic radiation from modern electronic devices may harm the hypothalamic-pituitary-gonadal axis, warranting limited use. Over-the-counter analgesics, such as nonsteroidal anti-inflammatory drugs and acetaminophen, may decrease testosterone levels, suggesting cautious use. Seasonal changes in testosterone levels require further study. Testosterone-optimizing strategies excluding banned substances may aid in treating functional low testosterone or reducing harm in anabolic-androgenic steroid users.

Conclusion: Educating athletes on safe and effective strategies to increase testosterone is crucial, with ongoing research needed to explore additional methods.

Strength-of-Recommendation Taxonomy: B.

Keywords: anabolic androgenic steroids; athletes; exercise; testosterone

From [†]Department of Family Medicine, Mayo Clinic College of Medicine and Science, Jacksonville, Florida, [‡]Division of Endocrinology, Mayo Clinic College of Medicine and Science, Jacksonville, Florida, [§]Department of Urology, Mayo Clinic College of Medicine and Science, Jacksonville, Florida, [||]Division of Hospital Internal Medicine, Mayo Clinic, Jacksonville, Florida, [¶]Department of Orthopedic Surgery, Mayo Clinic, Jacksonville, Florida, [#]Department of Family Medicine, Mayo Clinic School of Graduate Medical Education, Mayo Clinic College of Medicine and Science, Jacksonville, Florida, **Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, North Carolina, and [‡‡]Department of Internal Medicine, Mount Sinai, Chicago, Illinois

*Address correspondence to George G.A. Pujalte, MD, Department of Family Medicine, Mayo Clinic, 4500 San Pablo Rd, Jacksonville, FL 32224 (email: pujalte.george@mayo.edu).

The following author declared potential conflicts of interest: A.C.H. is a recipient of the Fulbright-Saastamoinen Distinguished Chair in Health Sciences grant, University of Eastern Finland, funded by the Saastamoinen Foundation and the Fulbright Finland Foundation.

DOI: 10.1177/19417381251411933

Testosterone is a steroid hormone produced in Leydig cells of the testes in men, ovaries in women, and in the adrenal and peripheral tissues in both sexes.[41,75] Testosterone production is regulated by the hypothalamic-pituitary-gonadal (HPG) axis via gonadotropin-releasing hormone (GnRH) and luteinizing hormone (LH) through a negative feedback loop. Testosterone circulates as free testosterone (FT) or binds to sex-hormone binding globulin (SHBG) and albumin. FT either activates androgen receptors (ARs), converts to dihydrotestosterone via 5-alpha reductase, or transforms to estradiol via aromatase. AR upregulation increases receptor availability, enhancing testosterone action. Testosterone also acts nongenomically by stimulating transcription and translation via intracellular signaling molecules.

Testosterone has a role in androgenic (eg, masculinization, libido), anabolic (eg, muscle growth, bone formation, erythropoiesis), and psychological (eg, risk-taking, aggression) systems.[53] Athletes seek to optimize testosterone levels due to its association with improved physical performance, recovery, including strength, power, and endurance.[76] Studies show testosterone supplementation increases fat-free mass and muscle strength and reduces fat mass. Testosterone also influences competition, with precompetition testosterone spikes enhancing motivation and physical readiness.[18,94,180,199] Winning increases testosterone levels, reinforcing positive behaviors, motivation, and reactivity—critical traits for athletes.[6,202]

Athletes are motivated to explore methods for increasing testosterone levels, both legally and illegally. Legal methods for safely enhancing testosterone include optimized nutrition, supplements, exercise, sleep, stress management, and environmental adjustments. The purpose of this study was to review and evaluate these methods based on the medical literature available. Proper implementation of these methods may help athletes improve performance while maintaining health and compliance with antidoping regulations.

METHODS

We performed a literature search using PubMed to identify English-language, peer-reviewed articles on various potential legal methods to enhance testosterone in athletes and/or healthy adults. To provide the reader with a broader understanding of the subject and cover a wide range of methods, we chose a narrative review structure. Titles, abstracts, and full texts (when appropriate) were reviewed, and the most relevant papers were included based on the authors' judgment of relevance and scientific impact. We then performed a qualitative synthesis of the data and grouped key findings by topic to present a coherent narrative overview of the subject.

RESULTS

Energy Deficiency and Balance

Energy balance is vital for healthy testosterone production as the hypothalamus regulates GnRH pulses based on energy intake and expenditure. A deficiency in energy intake relative to expenditure, low energy availability (LEA), often occurs in athletes due to intense exercise and is linked to an increased risk of developing Relative Energy Deficiency in Sport (REDs). While focused initially on female athletes, REDs was later recognized to also affect male athletes, highlighting that the physiologic consequences of LEA are not sex-specific.[105]

REDs disrupts endocrine function, reducing testosterone, estradiol, and progesterone levels via hypothalamic hypogonadism, where decreased GnRH pulses lower LH and follicle-stimulating hormone, impairing reproductive hormone production. Traditionally associated with aesthetic and endurance sports, REDs is now recognized across various disciplines, including combat sports and jockeying. No athlete is immune, emphasizing the need for vigilance.[23]

Management of REDs involves balancing energy by reducing training loads and increasing caloric intake. Recent research suggests that macronutrient composition may also influence REDs-related endocrine disruptions. Severe energy imbalance in REDs can lower testosterone levels and affect performance, recovery, and health, while even subtle imbalances may impair performance.[67]

Nutrition

Optimal nutrition with sufficient energy intake and essential nutrients (ie, carbohydrates, proteins, fats, and micronutrients) is critical for athletes and significantly influences androgen levels.[24,117] Proper nutrition helps prevent LEA and REDs—conditions linked to decreased testosterone levels.[97] Calorie restriction, which is associated with reduced testosterone, should be avoided.[179] Some foods, particularly polyphenol-rich products, may act as natural aromatase inhibitors by decreasing the conversion of testosterone to estradiol.[212] This research, initially from breast cancer studies, highlights flavonoid-rich products for potential aromatase inhibition.[26,63] Macronutrients, such as proteins and fats, micronutrients, such as vitamin D, zinc, magnesium, and boron, and certain supplements are also being studied for their testosterone-boosting potential.[198]

Fat tissue increases estradiol through aromatization, lowering testosterone levels; however, testosterone deficiency from obesity is rare in athletes. Popular diets among athletes, such as vegetarianism, veganism, ketogenic diets, and intermittent fasting, are under investigation for their effects on performance and testosterone levels.[95] Low-fat diets appear to reduce testosterone in men, while saturated and monounsaturated fats predict higher testosterone levels.[84] However, excessive protein intake (>3.4 g/kg/day) with low carbohydrates may lower basal testosterone, likely due to liver SHBG synthesis.[4,198] Low-carbohydrate diets can increase the risk of LEA, REDs, and low testosterone.[136] Contrary to popular belief, plant-based diets and soy-based proteins or phytoestrogens have no significant effect on testosterone levels in men.[151]

Testosterone Boosters

Testosterone boosters (TBs) are multi-ingredient supplements marketed to increase testosterone levels, enhance performance,[132] and prevent REDs or testosterone deficiency,[107] particularly in athletes with high training loads.[70] However, their efficacy is questionable, with most compounds lacking substantial evidence or showing conflicting results.[132] Some substances, like *Eurycoma longifolia* (or tongkat ali), ashwagandha, fenugreek, β-hydroxy β-methyl butyrate, and betaine, have demonstrated potential to increase testosterone.[25,188] Among these, eurycoma longifolia has the strongest evidence, shown to raise testosterone by inhibiting aromatase, boosting LH and follicle-stimulating hormone, and increasing FT by dissociation from SHBG. A meta-analysis of 5 randomized trials confirmed significant testosterone increases in men using eurycoma longifolia.[109]

Zinc—a common TB component—has been shown to boost testosterone levels, particularly in people with both with and without zinc deficiency.[17,80,88,98,138,148,164,170] Its effects are attributed to antioxidant activity in the testes and activation of steroidogenic enzymes.

Despite claims of safety, TB consumption poses risks, including thromboembolic events, liver injury, and pancreatitis.[21,139] Adulteration and contamination, affecting up to 50% of samples, are major issues, with many supplements containing prohibited substances that risk both health and anti-doping violations.[87] More research is needed to evaluate TB safety and effectiveness.

Recreational Substances

Recreational substances are used widely by athletes.[124] We review the substances used most, namely, alcohol, nicotine, and cannabinoids. The relationship between testosterone and alcohol remains unclear. Some studies have shown association between higher alcohol intake may increase testosterone and FT levels, with Jensen et al[90] reporting higher FT in men consuming over 20 units weekly (1 unit = 12 g). Moderate alcohol consumption might influence testosterone levels positively due to altered liver steroid metabolism during alcohol detoxification, favoring androstenedione conversion to testosterone and estradiol.[90] However, chronic alcohol abuse has been linked to decreased testosterone levels, potentially due to Leydig cell toxicity or HPG-axis disruption.[119,137] Alcohol's effects on SHBG are inconsistent, with some studies suggesting it lowers SHBG and total testosterone levels,[160] while others find no association[186] or even increases in SHBG levels with alcohol consumption.[86] Overall, the testosterone-alcohol relationship is complex and warrants further research.

Nicotine use is high in sports (>20% of athletes),[146] with team sports (eg, baseball and football) and winter sports (eg, ice hockey, skiing, and biathlon) showing the highest numbers.[120,190] The relationship between nicotine and testosterone is not clear. Some studies reported higher testosterone and FT in smokers compared with nonsmokers[40,184]; Wu et al[206] reported elevation in total but not FT and increased SHBG. At the same time, Halmenschlager et al[73] failed to show this effect, and there were reports that nicotine can cause increased apoptosis of Leydig cells and thus lower testosterone.[215] Interestingly, in women, cigarette smoking was associated with higher testosterone levels in 1 study.[16] Those who quit smoking were reported to have lower testosterone levels than their smoking counterparts.[191] Altogether, a systematic review and meta-analysis of related observational studies showed a positive association between smoking and testosterone levels, which might be related etiologically to competitive inhibition of androgen disposal, aromatase inhibition, central nervous system, and LH stimulation.[214]

Cannabis use is prevalent among athletes, with approximately 1 in 4 athletes using cannabis.[125] The association between cannabis and testosterone is unclear. Results vary, with reports of higher testosterone values in cannabis users,[52,173] no difference,[12,39,102] and decreased testosterone in users versus nonusers.[99] Further research is needed to fully establish the effects of cannabis on testosterone levels.

Sleep

Testosterone is secreted primarily during the rapid eye movement (REM) phase of sleep, explaining its peak levels in the morning. REM sleep occurs later in the night, so reduced sleep duration or quality can lower REM episodes, decreasing testosterone secretion.[3] Athletes often experience sleep issues, including poor quality sleep, less REM sleep,[197] insomnia, nonrestorative sleep, sleep apnea, and fatigue.[65] Swinbourne et al[187] reported that 38% of elite athletes identified as snorers, and 8% experienced apneic episodes. Apnea risk increases with higher body mass index, particularly among American football and rugby players, with studies showing a 30% prevalence of obstructive sleep apnea in contact sport athletes.[156] While earlier research linked obstructive sleep apnea treatment to improved testosterone levels,[64,163] a more recent study did not confirm that.[29] In addition, jetlag from frequent travel across time zones may disrupt hormonal balance.[61]

Melatonin supplementation might assist in reducing sleep latency and increasing duration,[112] although its effects on testosterone remain unclear.[30] Studies suggest mixed outcomes, with some reporting inhibitory, stimulatory, or neutral effects on testosterone production.[150] Napping, which can include REM phases, may also support testosterone synthesis, but its impact on testosterone remains understudied.[123,197] Other strategies, such as sleep extension and pre-sleep high-glycemic meals, may counteract insufficient sleep, which can reduce testosterone by 15%.[116] However, sleep extension studies, including a trial of 10-hour sleep for 6 nights, failed to show substantial testosterone benefits, and further research into nutraceutical approaches is needed.[177]

Exercise

Given the anabolic effects of testosterone, the interaction of testosterone and various exercise regimens has been studied extensively.[2,38,69,210] Moderate- to high-intensity exercise triggers testosterone release, while mild activity shows no impact.[38] Testosterone showed the highest increase when measured immediately after, and up to 30 minutes after, exercise.[38] While high volumes of endurance exercise without sufficient energy intake might result in LEA, REDs, and testosterone decrease, acute endurance exercise has been shown to increase testosterone in some studies.[56,89] For example, Galbo et al[56] showed a 31% increase in testosterone concentration occurring 40 minutes after exhaustive treadmill running, and Jensen et al[89] showed 37% increase in testosterone levels during hard endurance training.

The link between resistance exercise and testosterone is well-studied. Resistance exercise does increase testosterone, especially moderate- and high-intensity, with large muscle involvement, bigger exercise volume, and short resting intervals between sets.[153,196] Smaller muscle exercises do not lead to significant testosterone increase, even when the intensity is high. In a study of young untrained men, unilateral biceps curls did not lead to a significant increase in testosterone concentration; however, a bilateral knee extension and leg press using the same protocol did.[77] Free weight training has been measured against machine training to determine benefit to FT levels.[172] Free weights showed a significant change in FT levels from before to after workouts, likely related to increased muscle mass required for exercise performance.[166] Regarding the mechanism, exercise appears to increase FT in the blood, with some authors proposing an association with HPG-axis upregulation and LH release stimulation; however, there are insufficient data to be conclusive.[36] Over time, transient elevations in testosterone with resistance training may result in more muscle mass and better performance.[38,82] Resistance exercise also upregulates the AR content in skeletal muscle, thus increasing sensitivity to testosterone.[38,152]

Masturbation, Coitus, and Abstinence

Although commonly believed in sports, there is no evidence of sexual activity reducing performance, with studies showing ejaculation may boost testosterone levels.[48,55,149] The association between the number of sexual encounters and testosterone levels has been described previously, with loss of sexual activity related to decreased testosterone and restoration of it related to increased testosterone.[122]

Masturbation is prevalent in the general population[54]; however, the effects of masturbation and abstinence on testosterone levels remain understudied. Exton et al[51] showed that abstinence from masturbation for 3 weeks significantly increased testosterone levels; however, ejaculation did not lead to changes in testosterone levels. Jiang et al[92] showed a 145% increase in testosterone levels after 1 week of abstinence from masturbation. This study gained high popularity and even led to the formation of an anti-masturbation movement called "Nofap," which reported multiple benefits of abstinence.[122,217] Later an English version of the Jiang et al[92] article was retracted due to duplicate publication; however, the Chinese version is still available.[91] Isenmann et al[85] found that masturbation reduced circadian drop of FT, but recommended larger studies for validation.

Endocrine Disruptors

Endocrine-disrupting chemicals (EDCs), such as bisphenol A, phthalates, and dioxins, are common synthetic hormonal substances. EDCs have been associated with multiple adverse events, including obesity, male and female infertility, cardiovascular disease, and cancer.[8,34,42,114,194,211] EDCs disrupt primarily normal endocrine system functioning. For example, Skakkebaek[175] linked EDCs to a combination of adverse health outcomes related to men's health, including decreased testosterone levels in men. EDCs can affect testosterone levels during testicular production and HPG-axis regulation.[44] For example, higher pesticide levels were associated with lower testosterone levels in consumers.[127] Intake of organic food, which has fewer pesticide residues,[176] was associated with better sperm profile (but not testosterone levels) in 1 study.[27] Phthalates and bisphenol A exposure (commonly found in packaging, solvents, fragranced household products, and personal care products) were also associated with low testosterone levels in men.[126,203,216] Interest in reducing personal EDC exposure is growing. For example, limited use of plastics, personal care products and cosmetics, consumption of homegrown food, and limited automobile use were associated with lower levels of EDCs.[121] Limiting plastic use in favor of metal and glass cartons, prevention of dust formation at home, and consumption of fresh organic produce have also been recommended.[33] Interventional studies have shown that consumption of fresh foods and dietary supplements, replacement of plastic packaging for household products, personal products, and food, and education are all efficient methods of decreasing EDCs levels.[78,79,144,158,169,208] Further studies should evaluate the effects of these interventions on testosterone levels, but their simplicity and safety make them recommended.

Sauna

Sauna bathing is used actively by many athletes and has been shown to have multiple endocrine effects.[13,83] The impact of sauna use on testosterone remains unclear. A study by Leppaluoto et al[110] showed no changes in testosterone in 10 healthy men visiting a Finnish sauna (80°C) for 1 hour twice a day for 7 days. Kukkonen-Harjula et al[101] observed testosterone increases during dry heat exposure at 80°C until exhaustion. Another study performed by Opaszowski et al[140] showed elevation in testosterone-cortisol ratio (but not in testosterone) in participants exposed to a 1-hour sauna, with rehydrated participants experiencing higher increases. Similar results were obtained by Podstawski et al,[147] showing no significant increase in testosterone but a decrease in cortisol (thus increasing the testosterone-cortisol ratio) in 30 men who attended 4 12-minute sauna sessions of 90°C followed by a 6-minute cool down. A longitudinal study by Garolla et al[57] showed no changes in testosterone in patients undergoing 2 15-minute sauna sessions per week for 3 months. Mero et al[129] showed no testosterone increases after traditional and infrared sauna. While it appears that sauna use does not change testosterone levels, the effects of sauna bathing on testosterone-cortisol ratio need to be further studied.

Cold-Water Immersion

Cold-water immersion (CWI) has been studied relative to testosterone. One study showed that testosterone increased by 21% after exercise but decreased by 10% after cold water stimulation.[161] Furthermore, Earp et al[46] found that CWI after exercise may reduce circulating testosterone levels as post-CWI testosterone levels decreased below that of pre-exercise levels. Burke et al[22] and Roberts et al[155] have also observed attenuated strength and hypertrophy after resistive training associated with CWI. This may result from reduced testosterone availability, increased muscle fluid viscosity, and decreased neural stimulation.

Radiofrequency Electromagnetic Radiation

Radiofrequency electromagnetic radiation (RF-EMR) is abundant in modern environments, with mobile phones and Wi-Fi devices being the most common sources of RF-EMR.[118] Most animal studies have shown a significant decrease in testosterone levels from mobile phones and Wi-Fi devices.[7,60,96,103,128,141,142,167,168,171,207] It appears to be a dose-dependent effect. A low (8 h/day) and middle (16 h/day) exposure to a 900-MHz mobile phone for 30 days in mice did not affect the testosterone synthesis function of the testes, but high (24 h/day) exposure showed a reduction in testosterone level.[213] A decrease in testosterone was also observed after exposure to a 2.45-GHz Wi-Fi device for 2 hours per day in rats.[103]

Human studies have had inconsistent results; some have reported decreased testosterone with prolonged exposure (900 MHz Global System for Mobile Communications radiofrequency from regular cellular phone use or from base stations),[45,50] and some have reported increased testosterone in cell phone users.[66]

RF-EMR might have deleterious effects on the HPG-axis at various levels. Possible mechanisms include thermal (ie, increased temperature) and nonthermal (eg, increased reactive oxygen species production) effects on the testes,[11,162] causing Leydig cell dysfunction, or direct effect on the hypothalamus or hypophysis, causing gonadotropin decrease.[60,174,213] RF-EMR effects depend on usage duration, with longer exposure linked to lower testosterone (60 minutes a day vs 0-30 minutes a day in rats).[128] Tissue absorption varies by device proximity, closer locations (eg, side pockets) increasing impact.[14] Thus, it might be wise for athletes to decrease their RF-EMR exposure by limiting excessive mobile phone and Wi-Fi device use.

Analgesics

Analgesic use, including nonsteroidal anti-inflammatory drugs (NSAIDs), opioids, and acetaminophen, is widely prevalent among athletes. For example, NSAID use has a 90% prevalence in some disciplines.[28,62,81,157,200] In 1 study, 32% of American football players used NSAIDs daily, compared with 20% reported for professional soccer players using NSAIDs during the World Cup competitive period.[143,192] NSAIDs, used to reduce pain and inflammation, have poorly studied endocrine effects. One study on humans suggested ibuprofen may suppress testicular endocrine cell activity, potentially causing hypogonadism.[100] Another in vitro study reported that aspirin and indomethacin caused endocrine disruption at the level of the testes.[1] Another study showed that men with NSAID prescriptions had lower testosterone levels compared with their counterparts without NSAIDs.[58] In contrast, Halpern et al[74] did not establish a relationship between regular NSAID use and testosterone levels. Interestingly, another study of women with hyperandrogenism showed a testosterone decrease attributed to a direct inhibitory effect of ibuprofen on ovarian steroidogenesis.[9]

Although acetaminophen use is not as common as NSAID use, it is still consumed frequently by athletes.[49,111,154,201,209] Acetaminophen has been shown to be associated negatively with gonadal development in animal fetuses.[15,35,113,193] In 1 in vitro study, acetaminophen was shown to cause endocrine disruption in the testes.[1]

Opioid use is prevalent in sports, even at the high school level,[47] with some studies showing misuse among athletes at 7%,[159] making the effects of opioid important to review. Both acutely and chronically, opioids are known to suppress GnRH, inhibiting upstream regulation of testosterone production and to decrease the negative feedback of sex steroids on pituitary LH secretion.[115] Hypogonadism was estimated to occur in >60% of male opioid users, with long-acting opioids at higher dosages leading to a higher degree of hypogonadism.[43] Clearly, opioid use in athletes should be very limited given the significant effects on testosterone levels seen in previous studies (in addition to other adverse effects, including addiction).

Seasonal Variation in Testosterone Levels and Daylight

Given that a significant number of athletes migrate to the warmer climate during the wintertime to continue training and competition,[19,59,130] information on seasonal variation of testosterone is of great interest. While the diurnal pattern of testosterone secretion is well established, there is conflicting evidence about testosterone and seasonality.[178] The Tromso study by Svartberg et al[185] found men in Northern Norway had peak testosterone in December with the lowest levels in August. The investigators attributed these fluctuations to temperature and daylight changes in the Arctic climate.[185] In a follow-up study, Svartberg and Barrett-Connor[183] did not establish testosterone variation in men residing in Southern California, proposing that the difference in study results was due to a milder climate with fewer changes in weather, daylight, and sleep patterns between the seasons. Lee and Lee[108] studied testosterone levels in male Korean police officers, suggesting links to daylight and weather. They reported that the participants' testosterone was highest in January and lowest in May, with a negative relationship between amount of daylight and outdoor temperature and testosterone levels.[108] Recently, Zornitzki et al[218] found significant seasonal variations in testosterone levels of Israeli men, with the highest values in August to October compared with March (northern hemisphere). In contrast, some studies have shown no changes in testosterone levels between seasons. Moskovic et al[135] studied circannual patterns of sex hormones and whether seasonality should be considered in clinical practice guidelines. Data from their men's health practice showed no significant seasonal differences in testosterone levels.[135] Similarly, an analysis of men in Miami and Pittsburgh found no seasonal variation, although Miami men had higher overall testosterone levels.[131] Current data on seasonal testosterone level changes are limited, requiring further research.

Contraceptive Methods in Female Athletes

While most of the reviewed research has focused on male athletes due to higher amount of data available for male athletes compared with female athletes, there is a unique modifiable behavior in women that can also affect testosterone levels. Contraception can be hormonal and nonhormonal, with most female athletes using hormonal contraception both in oral (predominantly) and nonoral forms.[104,106,195] A systematic review and meta-analysis of combined oral contraceptive (COC) pills showed decreased total (31%) and FT (61%), with a degree of FT decrease higher due to concurrent increase of SHBG.[31] COC with second-degree progestins were shown to have less effect on SHBG, while third- and fourth-degree progestins had higher effects. Apart from SHBG-mediated FT decrease, COC can suppress androgen production in ovaries and adrenals, with the resulting decreased peripheral conversion of testosterone precursors.[31] Interestingly, both free and total testosterone levels were maintained when dehydroepiandrosterone (DHEA) was added orally,[32] but DHEA has been banned by the World Anti-Doping Agency (WADA).[204] Other forms of hormonal contraception, such as depot medroxyprogesterone acetate (DMPA) injection, resulted in higher FT levels compared with COC.[165] Levonorgestrel implant caused even less testosterone decrease, compared with DMPA.[189] Compared with hormonal methods, the copper intrauterine device does not affect testosterone levels and remains the preferred contraceptive method for female athletes concerned about hormonal effects.

DISCUSSION

Although many testosterone-optimizing strategies are used by athletes, many lack supporting evidence. Athletes, coaches, and healthcare providers should evaluate strategies based on their clinical safety, resource demands (eg, time, cost), supporting evidence, and compliance with WADA regulations. Our research highlights considerations for implementing testosterone-optimizing approaches.

We emphasized testosterone-related factors but acknowledged the influence of other anabolic components. As mentioned earlier, in its mechanism of action, testosterone binds to ARs to induce physiologic changes; receptor expression and functionality is critical to testosterone effectiveness on anabolic parameters.[152] AR upregulation could indirectly enhance testosterone's effects by increasing the body's sensitivity to it. Previously, the genetic composition of the AR gene (ie, number of CAG triplets in the gene) was shown to affect personal sensitivity to testosterone, with a smaller number of triplets connected to higher sensitivity to testosterone. AR upregulation was observed in anabolic-androgenic steroid (AAS) intake, electrical stimulation of the muscle, and high-intensity resistance exercise. Muscle contraction and elevated testosterone may synergistically increase AR content, enhancing tissue anabolism; however, the relationship between these 2 variables is complex. Interestingly, some researchers have postulated that it is AR content, and not hormone levels (including testosterone), that play the primary role in evoking the noted response to resistance exercise.[134] Further research should investigate methods to enhance AR sensitivity. Strategies such as energy balance, avoiding alcohol, and managing cortisol effects may prevent AR downregulation, supporting anabolic action.

After exercise, testosterone and cortisol exhibit a negative interrelationship.[5,10] The negative effect is more prominent in the case of total testosterone levels and is absent or less robust in the case of FT levels.[71] It has been postulated that elevated cortisol levels might serve as a testosterone suppressor.[37] That is, cortisol might affect the HPG-axis in differing ways, including decreased release of regulatory hormones (ie, GnRH and LH), direct inhibition of steroidogenesis in the testicles, and downregulation of AR.[5] On the contrary, FT demonstrates a positive association with cortisol, possibly due to competition between cortisol and testosterone and carrier proteins, as well as greater adrenal contribution toward FT levels.[20] At the same time, the dynamics of testosterone and cortisol changes after exercise are complex and influenced by exercise mode, intensity, and duration[72]; however, it does appear cortisol levels recover faster than testosterone levels. The ratio between FT and cortisol—the anabolic-catabolic ratio—has been studied as an indicator of training loads and overtraining state.[10] The importance remains unclear, but reducing cortisol levels may indirectly enhance testosterone action.

Testosterone-optimizing strategies may prevent or treat testosterone deficiency—a common issue among athletes with estimates showing high prevalence (from 25% up to 80%) of testosterone deficiency among athletes.[133,181,182] Possible etiologies of testosterone deficiency in athletes include exercise-hypogonadal male condition,[68] LEA, REDs, AAS-induced hypogonadism, trauma-induced hypopituitarism, and readjustment in HPG-axis regulation.[70] WADA does not allow therapeutic use exemption for testosterone medication for nonorganic causes of low testosterone.[205] Legal testosterone-optimizing strategies can aid athletes in maintaining testosterone levels.

Another possible application of testosterone-optimizing strategies is the treatment of current or former AAS users. AAS use is a significant public health problem, especially among athletes. Prevalence of the AAS use in the athletic population, both professional and amateur, might be as high as 46% in the former and 14% in the latter.[93,145] Testosterone-optimizing strategies may complement harm reduction protocols for AAS users under study, while education on natural, legal methods could reduce AAS use.

Athletes should exercise caution when implementing testosterone-optimizing strategies, as many advertised methods lack evidence and are speculative, costly, or time-consuming. Searching for ways to boost testosterone often yields unproven techniques, diverting resources from effective strategies. Worse, some improper interventions, even if well-intentioned, can harm athletes' health or end their careers. For instance, supplements containing AAS could result in WADA antidoping violations. An evidence-based approach is essential when evaluating such claims. Education is crucial, involving sports physicians, coaches, and nutritionists to develop and monitor training and recovery plans. Notably, most studies focus on men, with limited research on women. Our narrative approach aims to provide a broad overview of testosterone-optimizing strategies. The efficiency of the strategies described should be evaluated in further studies with both hormonal and performance measures calculated, with accurate comparisons between various techniques as well as combination studies.

CONCLUSION

Sports performance is associated closely with testosterone levels, with several testosterone-optimizing strategies available, such as maintaining energy balance via a calorie-neutral or calorie-proficient, balanced healthy diet; moderation of alcohol; implementing high- or moderate-intensity resistance exercises with short rest intervals; maintain proper sleep hygiene and addressing sleep disorders; limiting exposure to EDCs, RF-EMR, CWI, analgesics, and alcohol. Evaluating the efficacy of these strategies requires further research considering hormonal and performance outcomes. Athletes should adopt these approaches carefully to optimize testosterone levels safely.

CLINICAL RECOMMENDATIONS

- Athletes should be educated on the importance of testosterone for exercise training and performance as well as the prevalence of low testosterone. Strength of recommendation: B.
- Athletes should be educated on strategies to increase testosterone that are not prohibited by WADA. Strength of recommendation: B.
- Athletes should maintain a healthy balanced diet to avoid energy deficiency with a cautious approach to various supplements to increase testosterone. Strength of recommendation: B.
- EDCs and CWI exposure should be avoided. Strength of recommendation: B.
- In respect to testosterone production, NSAID, acetaminophen, and opioid use should be minimized. Strength of recommendation: B.

ACKNOWLEDGMENT

The Scientific Publications staff at Mayo Clinic provided copyediting, proofreading, administrative, and clerical support.

ORCID ID

George G.A. Pujalte https://orcid.org/0000-0002-7537-7457

REFERENCES

1. Albert O, Desdoits-Lethimonier C, Lesne L, et al. Paracetamol, aspirin and indomethacin display endocrine disrupting properties in the adult human testis in vitro. *Hum Reprod*. 2013;28(7):1890-1898. doi:10.1093/humrep/det112
2. Ambrozy T, Rydzik L, Obminski Z, et al. The effect of high-intensity interval training periods on morning serum testosterone and cortisol levels and physical fitness in men aged 35-40 years. *J Clin Med*. 2021;10(10):2143. doi:10.3390/jcm10102143
3. Andersen ML, Tufik S. The effects of testosterone on sleep and sleep-disordered breathing in men: its bidirectional interaction with erectile function. *Sleep Med Rev*. 2008;12(5):365-379. doi:10.1016/j.smrv.2007.12.003
4. Anderson KE, Rosner W, Khan MS, et al. Diet-hormone interactions: protein/carbohydrate ratio alters reciprocally the plasma levels of testosterone and cortisol and their respective binding globulins in man. *Life Sci*. 1987;40(18):1761-1768. doi:10.1016/0024-3205(87)90086-5
5. Anderson T, Lane AR, Hackney AC. Cortisol and testosterone dynamics following exhaustive endurance exercise. *Eur J Appl Physiol*. 2016;116(8):1503-1509. doi:10.1007/s00421-016-3406-y
6. Archer J. Testosterone and human aggression: an evaluation of the challenge hypothesis. *Neurosci Biobehav Rev*. 2006;30(3):319-345. doi:10.1016/j.neubiorev.2004.12.007
7. Azimzadeh M, Jelodar G. Alteration of testicular regulatory and functional molecules following long-time exposure to 900 MHz RFW emitted from BTS. *Andrologia*. 2019;51(9):e13372. doi:10.1111/and.13372
8. Azizi D, Arif A, Blair D, et al. A comprehensive review on current technologies for removal of endocrine disrupting chemicals from wastewaters. *Environ Res*. 2022;207:112196. doi:10.1016/j.envres.2021.112196
9. Banaszewska B, Ozegowska K, Polska M, Pawelczyk L, Chang RJ, Duleba AJ. Ibuprofen reduces testosterone level in women with polycystic ovary syndrome. *J Endocr Soc*. 2022;6(10):bvac128. doi:10.1210/jendso/bvac128
10. Banfi G, Dolci A. Free testosterone/cortisol ratio in soccer: usefulness of a categorization of values. *J Sports Med Phys Fitness*. 2006;46(4):611-616.
11. Behari J. Biological responses of mobile phone frequency exposure. *Indian J Exp Biol*. 2010;48(10):959-981.
12. Belladelli F, Del Giudice F, Kasman A, et al. The association between cannabis use and testicular function in men: a systematic review and meta-analysis. *Andrology*. 2021;9(2):503-510. doi:10.1111/andr.12953
13. Bezuglov E, Lazarev A, Khaitin V, et al. The prevalence of use of various post-exercise recovery methods after training among elite endurance athletes. *Int J Environ Res Public Health*. 2021;18(21):11698. doi:10.3390/ijerph182111698
14. Bhat MA. Effects on testis of human being with specific absorption rate (SAR) of mobile phone. *Scholars J Eng Technol*. 2017;5(10):599-601.
15. Blecharz-Klin K, Sznejder-Pachołek A, Wawer A, et al. Early exposure to paracetamol reduces level of testicular testosterone and changes gonadal expression of genes relevant for steroidogenesis in rats offspring. *Drug Chem Toxicol*. 2022;45(4):1862-1869. doi:10.1080/01480545.2021.1892941
16. Brand JS, Chan MF, Dowsett M, et al. Cigarette smoking and endogenous sex hormones in postmenopausal women. *J Clin Endocrinol Metab*. 2011;96(10):3184-3192. doi:10.1210/jc.2011-1165
17. Brilla LR, Conte V. Effects of a novel zinc-magnesium formulation on hormones and strength. *J Exerc Physiol Online*. 2000;3(4):26-36.
18. Brodsky IG, Balagopal P, Nair KS. Effects of testosterone replacement on muscle mass and muscle protein synthesis in hypogonadal men—a clinical research center study. *J Clin Endocrinol Metab*. 1996;81(10):3469-3475. doi:10.1210/jcem.81.10.8855787

19. Brown HA, Topham TH, Clark B, et al. Quantifying exercise heat acclimatisation in athletes and military personnel: a systematic review and meta-analysis. *Sports Med*. 2024;54(3):727-741. doi:10.1007/s40279-023-01972-4
20. Brownlee KK, Moore AW, Hackney AC. Relationship between circulating cortisol and testosterone: influence of physical exercise. *J Sports Sci Med*. 2005;4(1):76-83.
21. Bui PV, Moualla M, Upson DJ. A possible association of diindolylmethane with pulmonary embolism and deep venous thrombosis. *Case Rep Med*. 2016;2016:7527098. doi:10.1155/2016/7527098
22. Burke DG, MacNeil SA, Holt LE, MacKinnon NC, Rasmussen RL. The effect of hot or cold water immersion on isometric strength training. *J Strength Cond Res*. 2000;14(1):21-25.
23. Burke LM, Close GL, Lundy B, Mooses M, Morton JP, Tenforde AS. Relative energy deficiency in sport in male athletes: a commentary on its presentation among selected groups of male athletes. *Int J Sport Nutr Exerc Metab*. 2018;28(4):364-374. doi:10.1123/ijsnem.2018-0182
24. Bytomski JR. Fueling for performance. *Sports Health*. 2018;10(1):47-53. doi:10.1177/1941738117743913
25. Chaing HS, Merino-chavez G, Yang LL, Wang FN, Hafez ES. Medicinal plants: conception / contraception. *Adv Contracept Deliv Syst*. 1994;10(3-4): 355-363.
26. Chen S, Oh SR, Phung S, et al. Anti-aromatase activity of phytochemicals in white button mushrooms (*Agaricus bisporus*). *Cancer Res*. 2006;66(24):12026-12034. doi:10.1158/0008-5472.CAN-06-2206
27. Chiu YH, Gaskins AJ, Williams PL, et al. Intake of fruits and vegetables with low-to-moderate pesticide residues is positively associated with semen-quality parameters among young healthy men. *J Nutr*. 2016;146(5):1084-1092. doi:10.3945/jn.115.226563
28. Christopher S, Tadlock BA, Veroneau BJ, et al. Epidemiological profile of pain and non-steroid anti-inflammatory drug use in collegiate athletes in the United States. *BMC Musculoskelet Disord*. 2020;21(1):561. doi:10.1186/s12891-020-03581-y
29. Cignarelli A, Castellana M, Castellana G, et al. Effects of CPAP on testosterone levels in patients with obstructive sleep apnea: a meta-analysis study. *Front Endocrinol (Lausanne)*. 2019;10:551. doi:10.3389/fendo.2019.00551
30. Cipolla-Neto J, Amaral FG, Soares JM Jr, et al. The crosstalk between melatonin and sex steroid hormones. *Neuroendocrinology*. 2022;112(2):115-129. doi:10.1159/000516148
31. Clapes J. Diet in digestive system diseases (I) [article in Spanish]. *Rev Enferm*. 1985;8(78):33-34.
32. Coelingh Bennink HJT, Zimmerman Y, Laan E, et al. Maintaining physiological testosterone levels by adding dehydroepiandrosterone to combined oral contraceptives: I. endocrine effects. *Contraception*. 2017;96(5):322-329. doi:10.1016/j.contraception.2016.06.022
33. Corbett GA, Lee S, Woodruff TJ, et al. Nutritional interventions to ameliorate the effect of endocrine disruptors on human reproductive health: a semi-structured review from FIGO. *Int J Gynaecol Obstet*. 2022;157(3):489-501. doi:10.1002/ijgo.14126
34. Corti M, Lorenzetti S, Ubaldi A, Zilli R, Marcoccia D. Endocrine disruptors and prostate cancer. *Int J Mol Sci*. 2022;23(3):1216. doi:10.3390/ijms23031216
35. Culha MG, Serefoglu EC. Prolonged exposure to acetaminophen during pregnancy reduces testosterone production by the human fetal testis. *Ann Transl Med*. 2017;5(10):218. doi:10.21037/atm.2017.01.57
36. Cumming DC, Brunsting LA III, Strich G, Ries AL, Rebar RW. Reproductive hormone increases in response to acute exercise in men. *Med Sci Sports Exerc*. 1986;18(4):369-373.
37. Cumming DC, Quigley ME, Yen SS. Acute suppression of circulating testosterone levels by cortisol in men. *J Clin Endocrinol Metab*. 1983;57(3):671-673. doi:10.1210/jcem-57-3-671
38. D'Andrea S, Spaggiari G, Barbonetti A, Santi D. Endogenous transient doping: physical exercise acutely increases testosterone levels-results from a meta-analysis. *J Endocrinol Invest*. 2020;43(10):1349-1371. doi:10.1007/s40618-020-01251-3
39. da Silva J, Dochez-Arnault J, Desdoits-Lethimonier C, Dejucq-Rainsford N, Gely-Pernot A. The acute exposure of human adult testis tissue to cannabinoids THC and CBD does not impact testosterone production nor germ cell lineage. *World J Mens Health*. 2023;41(4):928-939. doi:10.5534/wjmh.220210
40. Dai WS, Gutai JP, Kuller LH, Cauley JA. Cigarette smoking and serum sex hormones in men. *Am J Epidemiol*. 1988;128(4):796-805. doi:10.1093/oxfordjournals.aje.a115033
41. Davison SL, Bell R, Donath S, Montalto JG, Davis SR. Androgen levels in adult females: changes with age, menopause, and oophorectomy. *J Clin Endocrinol Metab*. 2005;90(7):3847-3853. doi:10.1210/jc.2005-0212
42. De Coster S, van Larebeke N. Endocrine-disrupting chemicals: associated disorders and mechanisms of action. *J Environ Public Health*. 2012;2012:713696. doi:10.1155/2012/713696
43. de Vries F, Bruin M, Lobatto DJ, et al. Opioids and their endocrine effects: a systematic review and meta-analysis. *J Clin Endocrinol Metab*. 2020;105(3):1020-1029. doi:10.1210/clinem/dgz022
44. Di Nisio A, Foresta C. Water and soil pollution as determinant of water and food quality/contamination and its impact on male fertility. *Reprod Biol Endocrinol*. 2019;17(1):4. doi:10.1186/s12958-018-0449-4
45. Djeridane Y, Touitou Y, de Seze R. Influence of electromagnetic fields emitted by GSM-900 cellular telephones on the circadian patterns of gonadal, adrenal and pituitary hormones in men. *Radiat Res*. 2008;169(3):337-343. doi:10.1667/RR0922.1
46. Earp JE, Hatfield DL, Sherman A, Lee EC, Kraemer WJ. Cold-water immersion blunts and delays increases in circulating testosterone and cytokines post-resistance exercise. *Eur J Appl Physiol*. 2019;119(8):1901-1907. doi:10.1007/s00421-019-04178-7
47. Ekhtiari S, Yusuf I, AlMakadma Y, MacDonald A, Leroux T, Khan M. Opioid use in athletes: a systematic review. *Sports Health*. 2020;12(6):534-539. doi:10.1177/1941738120933542
48. Escasa MJ, Casey JF, Gray PB. Salivary testosterone levels in men at a US sex club. *Arch Sex Behav*. 2011;40(5):921-926. doi:10.1007/s10508-010-9711-3
49. Esh CJ, Mauger AR, Palfreeman RA, Al-Janubi H, Taylor L. Acetaminophen (paracetamol): use beyond pain management and dose variability. *Front Physiol*. 2017;8:1092. doi:10.3389/fphys.2017.01092
50. Eskander EF, Estefan SF, Abd-Rabou AA. How does long term exposure to base stations and mobile phones affect human hormone profiles? *Clin Biochem*. 2012;45(1-2):157-161. doi:10.1016/j.clinbiochem.2011.11.006
51. Exton MS, Krüger TH, Bursch N, et al. Endocrine response to masturbation-induced orgasm in healthy men following a 3-week sexual abstinence. *World J Urol*. 2001;19(5):377-382. doi:10.1007/s003450100222
52. Fantus RJ, Lokeshwar SD, Kohn TP, Ramasamy R. The effect of tetrahydrocannabinol on testosterone among men in the United States: results from the National Health and Nutrition Examination Survey. *World J Urol*. 2020;38(12):3275-3282. doi:10.1007/s00345-020-03110-5
53. Finkelstein JS, Lee H, Leder BZ, et al. Gonadal steroid-dependent effects on bone turnover and bone mineral density in men. *J Clin Invest*. 2016;126(3): 1114-1125. doi:10.1172/JCI84137
54. Fischer N, Graham CA, Traeen B, Hald GM. Prevalence of masturbation and associated factors among older adults in four European countries. *Arch Sex Behav*. 2022;51(3):1385-1396. doi:10.1007/s10508-021-02071-z
55. Fox CA, Ismail AA, Love DN, Kirkham KE, Loraine JA. Studies on the relationship between plasma testosterone levels and human sexual activity. *J Endocrinol*. 1972;52(1):51-58. doi:10.1677/joe.0.0520051
56. Galbo H, Hummer L, Peterson IB, Christensen NJ, Bie N. Thyroid and testicular hormone responses to graded and prolonged exercise in man. *Eur J Appl Physiol Occup Physiol*. 1977;36(2):101-106. doi:10.1007/BF00423117
57. Garolla A, Torino M, Sartini B, et al. Seminal and molecular evidence that sauna exposure affects human spermatogenesis. *Hum Reprod*. 2013;28(4):877-885. doi:10.1093/humrep/det020
58. Gates MA, Araujo AB, Hall SA, Wittert GA, McKinlay JB. Non steroidal anti-inflammatory drug use and levels of oestrogens and androgens in men. *Clin Endocrinol (Oxf)*. 2012;76(2):272-280. doi:10.1111/j.1365-2265.2011.04188.x
59. Gatterer H, Dünnwald T, Turner R, et al. Practicing sport in cold environments: practical recommendations to improve sport performance and reduce negative health outcomes. *Int J Environ Res Public Health*. 2021;18(18):9700. doi:10.3390/ijerph18189700
60. Gevrek F, Aydin D, Ozsoy S, Aygun H, Bicer C. Inhibition by Egb761 of the effect of cellphone radiation on the male reproductive system. *Bratisl Lek Listy*. 2017;118(11):676-683. doi:10.4149/BLL_2017_128
61. Golstein J, Van Cauter E, Désir D, et al. Effects of "jet lag" on hormonal patterns. IV. Time shifts increase growth hormone release. *J Clin Endocrinol Metab*. 1983;56(3):433-440. doi:10.1210/jcem-56-3-433
62. Gorski T, Cadore EL, Pinto SS, et al. Use of NSAIDs in triathletes: prevalence, level of awareness and reasons for use. *Br J Sports Med*. 2011;45(2):85-90. doi:10.1136/bjsm.2009.062166
63. Grube BJ, Eng ET, Kao YC, Kwon A, Chen S. White button mushroom phytochemicals inhibit aromatase activity and breast cancer cell proliferation. *J Nutr*. 2001;131(12):3288-3293. doi:10.1093/jn/131.12.3288
64. Grunstein RR, Handelsman DJ, Lawrence SJ, Blackwell C, Caterson ID, Sullivan CE. Neuroendocrine dysfunction in sleep apnea: reversal by continuous positive airways pressure therapy. *J Clin Endocrinol Metab*. 1989;68(2):352-358. doi:10.1210/jcem-68-2-352

65. Gupta L, Morgan K, Gilchrist S. Does elite sport degrade sleep quality? A systematic review. *Sports Med*. 2017;47(7):1317-1333. doi:10.1007/s40279-016-0650-6
66. Gutschi T, Mohamad Al-Ali B, Shamloul R, Pummer K, Trummer H. Impact of cell phone use on men's semen parameters. *Andrologia*. 2011;43(5):312-316. doi:10.1111/j.1439-0272.2011.01075.x
67. Hackney AC. A bad situation made worse: low carbohydrate intake amplifies low energy availability hormonal disturbances. https://blogs.bmj.com/bjsm/2023/08/14/a-bad-situation-made-worse-low-carbohydrate-intake-amplifies-low-energy-availability-hormonal-disturbances/. Accessed January 5, 2025.
68. Hackney AC. Effects of endurance exercise on the reproductive system of men: the "exercise-hypogonadal male condition." *J Endocrinol Invest*. 2008;31(10):932-938. doi:10.1007/BF03346444
69. Hackney AC. Endurance training and testosterone levels. *Sports Med*. 1989;8(2):117-127. doi:10.2165/00007256-198908020-00004
70. Hackney AC. Hypogonadism in exercising males: dysfunction or adaptive-regulatory adjustment? *Front Endocrinol (Lausanne)*. 2020;11:11. doi:10.3389/fendo.2020.00011
71. Hackney AC, Prado RCR, Dolan E. Androgenic steroid hormones and endurance exercise in athletic women. *Endocrines*. 2024;5(3):252-260. doi:10.3390/endocrines5030018
72. Hackney AC, Walz EA. Hormonal adaptation and the stress of exercise training: the role of glucocorticoids. *Trends Sport Sci*. 2013;20(4):165-171.
73. Halmenschlager G, Rossetto S, Lara GM, Rhoden EL. Evaluation of the effects of cigarette smoking on testosterone levels in adult men. *J Sex Med*. 2009;6(6):1763-1772. doi:10.1111/j.1743-6109.2009.01227.x
74. Halpern JA, Fantus RJ, Chang C, et al. Effects of nonsteroidal anti-inflammatory drug (NSAID) use upon male gonadal function: a national, population-based study. *Andrologia*. 2020;52(4):e13542. doi:10.1111/and.13542
75. Handelsman DJ. Androgen physiology, pharmacology, use and misuse. In: Feingold KR, Anawalt B, Blackman MR, et al, eds. *Endotext*. South Dartmouth, MA: MDText.com, Inc; 2000.
76. Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. *Endocr Rev*. 2018;39(5):803-829. doi:10.1210/er.2018-00020
77. Hansen S, Kvorning T, Kjaer M, Sjøgaard G. The effect of short-term strength training on human skeletal muscle: the importance of physiologically elevated hormone levels. *Scand J Med Sci Sports*. 2001;11(6):347-354. doi:10.1034/j.1600-0838.2001.110606.x
78. Harley KG, Calderon L, Nolan JES, et al. Changes in Latina women's exposure to cleaning chemicals associated with switching from conventional to "green" household cleaning products: the LUCIR intervention study. *Environ Health Perspect*. 2021;129(9):97001. doi:10.1289/EHP8831
79. Harley KG, Kogut K, Madrigal DS, et al. Reducing phthalate, paraben, and phenol exposure from personal care products in adolescent girls: findings from the HERMOSA intervention study. *Environ Health Perspect*. 2016;124(10):1600-1607. doi:10.1289/ehp.1510514
80. Hartoma TR, Nahoul K, Netter A. Zinc, plasma androgens and male sterility. *Lancet*. 1977;2(8048):1125-1126. doi:10.1016/s0140-6736(77)90563-3
81. Holmes N, Cronholm PF, Duffy AJ III, Webner D. Nonsteroidal anti-inflammatory drug use in collegiate football players. *Clin J Sport Med*. 2013;23(4):283-286. doi:10.1097/JSM.0b013e318286d0fa
82. Hooper DR, Kraemer WJ, Focht BC, et al. Endocrinological roles for testosterone in resistance exercise responses and adaptations. *Sports Med*. Sep 2017;47(9):1709-1720. doi:10.1007/s40279-017-0698-y
83. Huhtaniemi IT, Laukkanen JA. Endocrine effects of sauna bath. *Curr Opin Endocr Metab Res*. 2020;11:15-20. doi:10.1016/j.coemr.2019.12.004
84. Ingram DM, Bennett FC, Willcox D, de Klerk N. Effect of low-fat diet on female sex hormone levels. *J Natl Cancer Inst*. 1987;79(6):1225-1229.
85. Isenmann E, Schumann M, Notbohm HL, Flenker U, Zimmer P. Hormonal response after masturbation in young healthy men—a randomized controlled cross-over pilot study. *Basic Clin Androl*. 2021;31(1):32. doi:10.1186/s12610-021-00148-2
86. Iturriaga H, Lioi X, Valladares L. Sex hormone-binding globulin in non-cirrhotic alcoholic patients during early withdrawal and after longer abstinence. *Alcohol Alcohol*. 1999;34(6):903-909. doi:10.1093/alcalc/34.6.903
87. Jagim AR, Harty PS, Erickson JL, Tinsley GM, Garner D, Galpin AJ. Prevalence of adulteration in dietary supplements and recommendations for safe supplement practices in sport. *Front Sports Act Living*. 2023;5:1239121. doi:10.3389/fspor.2023.1239121
88. Jalali GR, Roozbeh J, Mohammadzadeh A, et al. Impact of oral zinc therapy on the level of sex hormones in male patients on hemodialysis. *Ren Fail*. 2010;32(4):417-419. doi:10.3109/08860221003706958
89. Jensen J, Oftebro H, Breigan B, et al. Comparison of changes in testosterone concentrations after strength and endurance exercise in well trained men. *Eur J Appl Physiol Occup Physiol*. 1991;63(6):467-471. doi:10.1007/BF00868080
90. Jensen TK, Swan S, Jorgensen N, et al. Alcohol and male reproductive health: a cross-sectional study of 8344 healthy men from Europe and the USA. *Hum Reprod*. 2014;29(8):1801-1809. doi:10.1093/humrep/deu118
91. Jiang M. Periodic changes in serum testosterone levels after ejaculation in men [Article in Chinese]. *Sheng Li Xue Bao*. 2002;54(6):535-538.
92. Jiang M, Xin J, Zou Q, Shen JW. A research on the relationship between ejaculation and serum testosterone level in men. *J Zhejiang Univ Sci*. 2003;4(2):236-240. doi:10.1631/jzus.2003.0236
93. Kanayama G, Pope HG Jr. History and epidemiology of anabolic androgens in athletes and non-athletes. *Mol Cell Endocrinol*. 2018;464:4-13. doi:10.1016/j.mce.2017.02.039
94. Katznelson L, Finkelstein JS, Schoenfeld DA, Rosenthal DI, Anderson EJ, Klibanski A. Increase in bone density and lean body mass during testosterone administration in men with acquired hypogonadism. *J Clin Endocrinol Metab*. 1996;81(12):4358-4365. doi:10.1210/jcem.81.12.8954042
95. Kaufman M, Nguyen C, Shetty M, Oppezzo M, Barrack M, Fredericson M. Popular dietary trends' impact on athletic performance: a critical analysis review. *Nutrients*. 2023;15(16): doi:10.3390/nu15163511
96. Kesari KK, Behari J. Evidence for mobile phone radiation exposure effects on reproductive pattern of male rats: role of ROS. *Electromagn Biol Med*. 2012;31(3):213-222. doi:10.3109/15368378.2012.700292
97. Kim J, Kim EK. Nutritional strategies to optimize performance and recovery in rowing athletes. *Nutrients*. 2020;12(6):1685. doi:10.3390/nu12061685
98. Koehler K, Parr MK, Geyer H, Mester J, Schänzer W. Serum testosterone and urinary excretion of steroid hormone metabolites after administration of a high-dose zinc supplement. *Eur J Clin Nutr*. 2009;63(1):65-70. doi:10.1038/sj.ejcn.1602899
99. Kolodny RC, Masters WH, Kolodner RM, Toro G. Depression of plasma testosterone levels after chronic intensive marihuana use. *N Engl J Med*. 1974;290(16):872-874. doi:10.1056/NEJM197404182901602
100. Kristensen DM, Desdoits-Lethimonier C, Mackey AL, et al. Ibuprofen alters human testicular physiology to produce a state of compensated hypogonadism. *Proc Natl Acad Sci USA*. 2018;115(4):E715-E724. doi:10.1073/pnas.1715035115
101. Kukkonen-Harjula K, Oja P, Laustiola K, et al. Haemodynamic and hormonal responses to heat exposure in a Finnish sauna bath. *Eur J Appl Physiol Occup Physiol*. 1989;58(5):543-550. doi:10.1007/BF02330710
102. Kulin ET, Demidova SI, Kasimenko VB. Dependence of the phagocytic function of Paramecium on the frequency and strength of an electromagnetic field [Article in Russian]. *Biofizika*. 1968;13(1):81-85.
103. Kumar S, Kesari KK, Behari J. The therapeutic effect of a pulsed electromagnetic field on the reproductive patterns of male Wistar rats exposed to a 2.45-GHz microwave field. *Clinics (Sao Paulo)*. 2011;66(7):1237-1245. doi:10.1590/s1807-59322011000700020
104. Kunzel W. Development of child dentistry at the universities of the German Democratic Republic [Article in German]. *Zahn Mund Kieferheilkd Zentralbl*. 1974;62(7):637-644.
105. Lane AR, Hackney AC. Reproductive dysfunction from the stress of exercise training is not gender specific: the "exercise-hypogonadal male condition." *J Endocrinol Diabetes*. 2014;1(2):4. doi:10.15226/2374-6890/1/2/00108
106. Larsen B, Morris K, Quinn K, Osborne M, Minahan C. Practice does not make perfect: a brief view of athletes' knowledge on the menstrual cycle and oral contraceptives. *J Sci Med Sport*. 2020;23(8):690-694. doi:10.1016/j.jsams.2020.02.003
107. Lazarev A, Baezuglov E. Testosterone boosters intake in athletes: current evidence and further directions. *Endocrines*. 2021;2(2):109-120. doi:10.3390/endocrines2020011
108. Lee JH, Lee SW. Monthly variations in serum testosterone levels: results from testosterone screening of 8,367 middle-aged men. *J Urol*. 2021;205(5):1438-1443. doi:10.1097/JU.0000000000001546
109. Leisegang K, Finelli R, Sikka SC, Panner Selvam MK. *Eurycoma longifolia* (Jack) improves serum total testosterone in men: a systematic review and meta-analysis of clinical trials. *Medicina (Kaunas)*. 2022;58(8):1047. doi:10.3390/medicina58081047
110. Leppäluoto J, Huttunen P, Hirvonen J, Väänänen A, Tuominen M, Vuori J. Endocrine effects of repeated sauna bathing. *Acta Physiol Scand*. 1986;128(3):467-470. doi:10.1111/j.1748-1716.1986.tb08000.x
111. Leyk D, Ruther T, Hartmann N, Vits E, Staudt M, Hoffmann MA. Analgesic use in sports. *Dtsch Arztebl Int*. 2023;120(10):155-161. doi:10.3238/arztebl.m2023.0003

112. Li J, Somers VK, Xu H, Lopez-Jimenez F, Covassin N. Trends in use of melatonin supplements among US adults, 1999-2018. *JAMA*. 2022;327(5):483-485. doi:10.1001/jama.2021.23652
113. Liu Y, Liu Y, Chen S, Kong Z, Guo Y, Wang H. Prenatal exposure to acetaminophen at different doses, courses and time causes testicular dysplasia in offspring mice and its mechanism. *Chemosphere*. 2023;345:140496. doi:10.1016/j.chemosphere.2023.140496
114. Lobstein T, Brownell KD. Endocrine-disrupting chemicals and obesity risk: a review of recommendations for obesity prevention policies. *Obes Rev*. 2021;22(11):e13332. doi:10.1111/obr.13332
115. Maekawa T, Horishi M, Fujii H, et al. Primary hepatocellular carcinoma growing in the complete remission of malignant lymphoma treated with curative segmentectomy [Article in Japanese]. *Nihon Naika Gakkai Zasshi*. 1988;77(6):808-813. doi:10.2169/naika.77.808
116. Mah CD, Mah KE, Kezirian EJ, Dement WC. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*. 2011;34(7):943-950. doi:10.5665/SLEEP.1132
117. Malsagova KA, Kopylov AT, Sinitsyna AA, et al. Sports nutrition: diets, selection factors, recommendations. *Nutrients*. 2021;13(11):3771. doi:10.3390/nu13113771
118. Maluin SM, Osman K, Jaffar FHF, Ibrahim SF. Effect of radiation emitted by wireless devices on male reproductive hormones: a systematic review. *Front Physiol*. 2021;12:732420. doi:10.3389/fphys.2021.732420
119. Maneesh M, Dutta S, Chakrabarti A, Vasudevan DM. Alcohol abuse-duration dependent decrease in plasma testosterone and antioxidants in males. *Indian J Physiol Pharmacol*. 2006;50(3):291-296.
120. Marclay F, Grata E, Perrenoud L, Saugy M. A one-year monitoring of nicotine use in sport: frontier between potential performance enhancement and addiction issues. *Forensic Sci Int*. 2011;213(1-3):73-84. doi:10.1016/j.forsciint.2011.05.026
121. Martina CA, Weiss B, Swan SH. Lifestyle behaviors associated with exposures to endocrine disruptors. *Neurotoxicology*. 2012;33(6):1427-1433. doi:10.1016/j.neuro.2012.05.016
122. Mascherek A, Reidick MC, Gallinat J, Kuhn S. Is ejaculation frequency in men related to general and mental health? Looking back and looking forward. *Front Psychol*. 2021;12:693121. doi:10.3389/fpsyg.2021.693121
123. McDevitt EA, Alaynick WA, Mednick SC. The effect of nap frequency on daytime sleep architecture. *Physiol Behav*. 2012;107(1):40-44. doi:10.1016/j.physbeh.2012.05.021
124. McDuff D, Stull T, Castaldelli-Maia JM, Hitchcock ME, Hainline B, Reardon CL. Recreational and ergogenic substance use and substance use disorders in elite athletes: a narrative review. *Br J Sports Med*. 2019;53(12):754-760. doi:10.1136/bjsports-2019-100669
125. McNicholas JM, Raffeld M, Loken MR, Reiter H, Knight KL. Monoclonal antibodies to rabbit lymphoid cells: preparation and characterization of a T-cell-specific antibody. *Mol Immunol*. 1981;18(9):815-822. doi:10.1016/0161-5890(81)90003-1
126. Meeker JD, Ferguson KK. Urinary phthalate metabolites are associated with decreased serum testosterone in men, women, and children from NHANES 2011-2012. *J Clin Endocrinol Metab*. 2014;99(11):4346-4352. doi:10.1210/jc.2014-2555
127. Mendy A, Pinney SM. Exposure to neonicotinoids and serum testosterone in men, women, and children. *Environ Toxicol*. 2022;37(6):1521-1528. doi:10.1002/tox.23503
128. Meo SA, Al-Drees AM, Husain S, Khan MM, Imran MB. Effects of mobile phone radiation on serum testosterone in Wistar albino rats. *Saudi Med J*. 2010;31(8):869-873.
129. Mero A, Tornberg J, Mantykoski M, Puurtinen R. Effects of far-infrared sauna bathing on recovery from strength and endurance training sessions in men. *Springerplus*. 2015;4:321. doi:10.1186/s40064-015-1093-5
130. Meylan CMP, Bowman K, Stellingwerff T, Pethick WA, Trewin J, Koehle MS. The efficacy of heat acclimatization pre-world cup in female soccer players. *Front Sports Act Living*. 2021;3:614370. doi:10.3389/fspor.2021.614370
131. Miller D, Gurayah A, Weber A, et al. Seasonal variation in serum testosterone levels: evidence from 2 large institutional databases. *Urol Res Pract*. 2023;49(5):307-311. doi:10.5152/tud.2023.23077
132. Morgado A, Tsampoukas G, Sokolakis I, Schoentgen N, Urkmez A, Sarikaya S. Do "testosterone boosters" really increase serum total testosterone? A systematic review. *Int J Impot Res*. 2024;36(4):348-364. doi:10.1038/s41443-023-00763-9
133. Moris JM, Olendorff SA, Zajac CM, et al. Collegiate male athletes exhibit conditions of the Male Athlete Triad. *Appl Physiol Nutr Metab*. 2022;47(3):328-336. doi:10.1139/apnm-2021-0512
134. Morton RW, Sato K, Gallaugher MPB, et al. Muscle androgen receptor content but not systemic hormones is associated with resistance training-induced skeletal muscle hypertrophy in healthy, young men. *Front Physiol*. 2018;9:1373. doi:10.3389/fphys.2018.01373
135. Moskovic DJ, Eisenberg ML, Lipshultz LI. Seasonal fluctuations in testosterone-estrogen ratio in men from the Southwest United States. *J Androl*. 2012;33(6):1298-1304. doi:10.2164/jandrol.112.016386
136. Mountjoy M, Ackerman KE, Bailey DM, et al. 2023 International Olympic Committee's (IOC) consensus statement on relative energy deficiency in sport (REDs). *Br J Sports Med*. 2023;57(17):1073-1097. doi:10.1136/bjsports-2023-106994
137. Muthusami KR, Chinnaswamy P. Effect of chronic alcoholism on male fertility hormones and semen quality. *Fertil Steril*. 2005;84(4):919-924. doi:10.1016/j.fertnstert.2005.04.025
138. Netter A, Hartoma R, Nahoul K. Effect of zinc administration on plasma testosterone, dihydrotestosterone, and sperm count. *Arch Androl*. 1981;7(1):69-73. doi:10.3109/01485018109009378
139. Nguyen SM, Ko Ko N, Sattar AS, Gucuk Ipek E, Ali S. Pulmonary embolism secondary to testosterone-enhancing herbal supplement use. *Cureus*. 6 2017;9(8):e1545. doi:10.7759/cureus.1545
140. Opaszowski BH, Busko K, Blanchnio D. Effect of rehydration on hormonal responses to heat exposure in a Finnish sauna bath. *Biol Sport*. 2001;18(3): 193-208.
141. Oyewopo AO, Olaniyi SK, Oyewopo CI, Jimoh AT. Radiofrequency electromagnetic radiation from cell phone causes defective testicular function in male Wistar rats. *Andrologia*. 2017;49(10):12772. doi:10.1111/and.12772
142. Ozguner F, Aydin G, Mollaoglu H, Gökalp O, Koyu A, Cesur G. Prevention of mobile phone induced skin tissue changes by melatonin in rat: an experimental study. *Toxicol Ind Health*. 2004;20(6-10):133-139. doi:10.1191/0748233704th207oa
143. Pedersen JR, Andreucci A, Thorlund JB, et al. Prevalence, frequency, adverse events, and reasons for analgesic use in youth athletes: a systematic review and meta-analysis of 44,381 athletes. *J Sci Med Sport*. 2022;25(10):810-819. doi:10.1016/j.jsams.2022.08.018
144. Peng CY, Tsai EM, Kao TH, et al. Canned food intake and urinary bisphenol a concentrations: a randomized crossover intervention study. *Environ Sci Pollut Res Int*. 2019;26(27):27999-28009. doi:10.1007/s11356-019-05534-y
145. Piacentino D, Sani G, Kotzalidis GD, et al. Anabolic androgenic steroids used as performance and image enhancing drugs in professional and amateur athletes: toxicological and psychopathological findings. *Hum Psychopharmacol*. 2022;37(1):e2815. doi:10.1002/hup.2815
146. Plancak D, Vizner B, Jorgic-Srdjak K, Slaj M. Endocrinological status of patients with periodontal disease. *Coll Antropol*. 1998;22(Suppl):51-55.
147. Podstawski R, Borysławski K, Pomianowski A, Krystkiewicz W, Zurek P. Endocrine effects of repeated hot thermal stress and cold water immersion in young adult men. *Am J Mens Health*. 2021;15(2):15579883211008339. doi:10.1177/15579883211008339
148. Prasad AS, Mantzoros CS, Beck FW, Hess JW, Brewer GJ. Zinc status and serum testosterone levels of healthy adults. *Nutrition*. 1996;12(5):344-348. doi:10.1016/s0899-9007(96)80058-x
149. Purvis K, Landgren BM, Cekan Z, Diczfalusy E. Endocrine effects of masturbation in men. *J Endocrinol*. 1976;70(3):439-444. doi:10.1677/joe.0.0700439
150. Qin F, Zhang J, Zan L, et al. Inhibitory effect of melatonin on testosterone synthesis is mediated via GATA-4/SF-1 transcription factors. *Reprod Biomed Online*. 2015;31(5):638-646. doi:10.1016/j.rbmo.2015.07.009
151. Raben A, Kiens B, Richter EA, et al. Serum sex hormones and endurance performance after a lacto-ovo vegetarian and a mixed diet. *Med Sci Sports Exerc*. 1992;24(11):1290-1297.
152. Ratamess NA, Kraemer WJ, Volek JS, et al. Androgen receptor content following heavy resistance exercise in men. *J Steroid Biochem Mol Biol*. 2005;93(1):35-42. doi:10.1016/j.jsbmb.2004.10.019
153. Riachy R, McKinney K, Tuvdendorj DR. Various factors may modulate the effect of exercise on testosterone levels in men. *J Funct Morphol Kinesiol*. 2020;5(4):81. doi:10.3390/jfmk5040081
154. Robach P, Trebes G, Buisson C, et al. Prevalence of drug use in ultraendurance athletes. *Med Sci Sports Exerc*. 2024;56(5):828-838. doi:10.1249/MSS.0000000000003374
155. Roberts LA, Raastad T, Markworth JF, et al. Post-exercise cold water immersion attenuates acute anabolic signalling and long-term adaptations in muscle to strength training. *J Physiol*. 2015;593(18):4285-4301. doi:10.1113/JP270570
156. Rogers AJ, Xia K, Soe K, et al. Obstructive sleep apnea among players in the National Football League: a scoping review. *J Sleep Disord Ther*. 2017;6(5):278. doi:10.4172/2167-0277.1000278
157. Rosenbloom CJ, Morley FL, Ahmed I, Cox AR. Oral non-steroidal anti-inflammatory drug use in recreational runners participating in Parkrun UK: prevalence of use and awareness of risk. *Int J Pharm Pract*. 2020;28(6):561-568. doi:10.1111/ijpp.12646

158. Rudel RA, Gray JM, Engel CL, et al. Food packaging and bisphenol A and bis(2-ethyhexyl) phthalate exposure: findings from a dietary intervention. *Environ Health Perspect*. 2011;119(7):914-920. doi:10.1289/ehp.1003170
159. Rugg CM, Cheah JW, Vomer RP II, Lau B. Opiate use patterns among collegiate athletes. *Cureus*. 2022;14(11):e31152. doi:10.7759/cureus.31152
160. Ruusa J, Bergman B, Sundell ML. Sex hormones during alcohol withdrawal: a longitudinal study of 29 male alcoholics during detoxification. *Alcohol Alcohol*. 1997;32(5):591-597. doi:10.1093/oxfordjournals.alcalc.a008300
161. Sakamoto K, Wakabayashi I, Yoshimoto S, Masui H, Katsuno S. Effects of physical exercise and cold stimulation on serum testosterone level in men. *Nihon Eiseigaku Zasshi*. 1991;46(2):635-638. doi:10.1265/jjh.46.635
162. Saliev T, Begimbetova D, Masoud AR, Matkarimov B. Biological effects of non-ionizing electromagnetic fields: two sides of a coin. *Prog Biophys Mol Biol*. 2019;141:25-36. doi:10.1016/j.pbiomolbio.2018.07.009
163. Santamaria JD, Prior JC, Fleetham JA. Reversible reproductive dysfunction in men with obstructive sleep apnoea. *Clin Endocrinol (Oxf)*. 1988;28(5):461-470. doi:10.1111/j.1365-2265.1988.tb03680.x
164. Santos HO, Teixeira FJ. Use of medicinal doses of zinc as a safe and efficient coadjutant in the treatment of male hypogonadism. *Aging Male*. 2020;23(5):669-678. doi:10.1080/13685538.2019.1573220
165. Schaffir JA, Isley MM, Woodward M. Oral contraceptives vs injectable progestin in their effect on sexual behavior. *Am J Obstet Gynecol*. 2010;203(6):545.e1-5. doi:10.1016/j.ajog.2010.07.024
166. Schwanbeck SR, Cornish SM, Barss T, Chilibeck PD. Effects of training with free weights versus machines on muscle mass, strength, free testosterone, and free cortisol levels. *J Strength Cond Res*. 2020;34(7):1851-1859. doi:10.1519/JSC.0000000000003349
167. Sehitoglu I, Tumkaya L, Kalkan Y, et al. Biochemical and histopathological effects on the rat testis after exposure to electromagnetic field during fetal period. *Arch Esp Urol*. 2015;68(6):562-568.
168. Sepehrimanesh M, Saeb M, Nazifi S, Kazemipour N, Jelodar G, Saeb S. Impact of 900 MHz electromagnetic field exposure on main male reproductive hormone levels: a *Rattus norvegicus* model. *Int J Biometeorol*. 2014;58(7):1657-1663. doi:10.1007/s00484-013-0771-7
169. Sessa F, Polito R, Monda V, et al. Effects of a plastic-free lifestyle on urinary bisphenol a levels in school-aged children of southern Italy: a pilot study. *Front Public Health*. 2021;9:626070. doi:10.3389/fpubh.2021.626070
170. Shafiei Neek L, Gaeini AA, Choobineh S. Effect of zinc and selenium supplementation on serum testosterone and plasma lactate in cyclist after an exhaustive exercise bout. *Biol Trace Elem Res*. 2011;144(1-3):454-462. doi:10.1007/s12011-011-9138-2
171. Shahin S, Singh SP, Chaturvedi CM. 1800 MHz mobile phone irradiation induced oxidative and nitrosative stress leads to p53 dependent Bax mediated testicular apoptosis in mice, *Mus musculus*. *J Cell Physiol*. 2018;233(9):7253-7267. doi:10.1002/jcp.26558
172. Shaner AA, Vingren JL, Hatfield DL, Budnar RG Jr, Duplanty AA, Hill DW. The acute hormonal response to free weight and machine weight resistance exercise. *J Strength Cond Res*. 2014;28(4):1032-1040. doi:10.1519/JSC.0000000000000317
173. Shiff B, Blankstein U, Hussaen J, et al. The impact of cannabis use on male sexual function: a 10-year, single-center experience. *Can Urol Assoc J*. 2021;15(12):E652-E657. doi:10.5489/cuaj.7185
174. Singh KV, Gautam R, Meena R, Nirala JP, Jha SK, Rajamani P. Effect of mobile phone radiation on oxidative stress, inflammatory response, and contextual fear memory in Wistar rat. *Environ Sci Pollut Res Int*. 2020;27(16):19340-19351. doi:10.1007/s11356-020-07916-z
175. Skakkebaek NE. Endocrine disrupters and testicular dysgenesis syndrome. *Horm Res*. 2002;57(Suppl 2):43. doi:10.1159/000058100
176. Smith-Spangler C, Brandeau ML, Hunter GE, et al. Are organic foods safer or healthier than conventional alternatives?: a systematic review. *Ann Intern Med*. 2012;157(5):348-366. doi:10.7326/0003-4819-157-5-201209040-00007
177. Smith I, Salazar I, RoyChoudhury A, St-Onge MP. Sleep restriction and testosterone concentrations in young healthy males: randomized controlled studies of acute and chronic short sleep. *Sleep Health*. 2019;5(6):580-586. doi:10.1016/j.sleh.2019.07.003
178. Smith RP, Coward RM, Kovac JR, Lipshultz LI. The evidence for seasonal variations of testosterone in men. *Maturitas*. 2013;74(3):208-212. doi:10.1016/j.maturitas.2012.12.003
179. Smith SJ, Teo SYM, Lopresti AL, Heritage B, Fairchild TJ. Examining the effects of calorie restriction on testosterone concentrations in men: a systematic review and meta-analysis. *Nutr Rev*. 2022;80(5):1222-1236. doi:10.1093/nutrit/nuab072
180. Snyder PJ, Peachey H, Berlin JA, et al. Effects of testosterone replacement in hypogonadal men. *J Clin Endocrinol Metab*. 2000;85(8):2670-2677. doi:10.1210/jcem.85.8.6731
181. Sönksen PH, Holt RIG, Böhning W, et al. Why do endocrine profiles in elite athletes differ between sports? *Clin Diabetes Endocrinol*. 2018;4:3. doi:10.1186/s40842-017-0050-3
182. Stenqvist TB, Melin AK, Garthe I, et al. Prevalence of surrogate markers of relative energy deficiency in male Norwegian Olympic-level athletes. *Int J Sport Nutr Exerc Metab*. 2021;31(6):497-506. doi:10.1123/ijsnem.2020-0368
183. Svartberg J, Barrett-Connor E. Could seasonal variation in testosterone levels in men be related to sleep? *Aging Male*. 2004;7(3):205-210. doi:10.1080/13685530412331284696
184. Svartberg J, Jorde R. Endogenous testosterone levels and smoking in men. The fifth Tromso study. *Int J Androl*. 2007;30(3):137-143. doi:10.1111/j.1365-2605.2006.00720.x
185. Svartberg J, Jorde R, Sundsfjord J, Bønaa KH, Barrett-Connor E. Seasonal variation of testosterone and waist to hip ratio in men: the Tromso study. *J Clin Endocrinol Metab*. 2003;88(7):3099-3104. doi:10.1210/jc.2002-021878
186. Svartberg J, Midtby M, Bønaa KH, Sundsfjord J, Joakimsen RM, Jorde R. The associations of age, lifestyle factors and chronic disease with testosterone in men: the Tromso Study. *Eur J Endocrinol*. 2003;149(2):145-152. doi:10.1530/eje.0.1490145
187. Swinbourne R, Gill N, Vaile J, Smart D. Prevalence of poor sleep quality, sleepiness and obstructive sleep apnoea risk factors in athletes. *Eur J Sport Sci*. 2016;16(7):850-858. doi:10.1080/17461391.2015.1120781
188. Talbott SM, Talbott JA, George A, Pugh M. Effect of Tongkat Ali on stress hormones and psychological mood state in moderately stressed subjects. *J Int Soc Sports Nutr*. 2013;10(1):28. doi:10.1186/1550-2783-10-28
189. Tifford CD, Spero L, Luke T, Plancher KD. The relationship of the infrapatellar branches of the saphenous nerve to arthroscopy portals and incisions for anterior cruciate ligament surgery. An anatomic study. *Am J Sports Med*. 2000;28(4):562-567. doi:10.1177/03635465000280042001
190. Tronnier H. Experimental studies on the drying of the skin after industrial cleaning [Article in German]. *Berufsdermatosen*. 1968;16(4):181-189.
191. Trummer H, Habermann H, Haas J, Pummer K. The impact of cigarette smoking on human semen parameters and hormones. *Hum Reprod*. 2002;17(6):1554-1559. doi:10.1093/humrep/17.6.1554
192. Tscholl P, Junge A, Dvorak J. The use of medication and nutritional supplements during FIFA World Cups 2002 and 2006. *Br J Sports Med*. 2008;42(9):725-730. doi:10.1136/bjsm.2007.045187
193. van den Driesche S, Macdonald J, Anderson RA, et al. Prolonged exposure to acetaminophen reduces testosterone production by the human fetal testis in a xenograft model. *Sci Transl Med*. 20 2015;7(288):288ra80. doi:10.1126/scitranslmed.aaa4097
194. Varticovski L, Stavreva DA, McGowan A, Raziuddin R, Hager GL. Endocrine disruptors of sex hormone activities. *Mol Cell Endocrinol*. 2022;539:111415. doi:10.1016/j.mce.2021.111415
195. Verrilli LE, Landry M, Blanchard H. Contraceptive choices and menstrual patterns in high level female athletes. *Fertil Steril*. 2017;108(3):e122. doi:10.1016/j.fertnstert.2017.07.374
196. Vingren JL, Kraemer WJ, Ratamess NA, Anderson JM, Volek JS, Maresh CM. Testosterone physiology in resistance exercise and training: the up-stream regulatory elements. *Sports Med*. 2010;40(12):1037-1053. doi:10.2165/11536910-000000000-00000
197. Vlahoyiannis A, Aphamis G, Bogdanis GC, Sakkas GK, Andreou E, Giannaki CD. Deconstructing athletes' sleep: a systematic review of the influence of age, sex, athletic expertise, sport type, and season on sleep characteristics. *J Sport Health Sci*. 2021;10(4):387-402. doi:10.1016/j.jshs.2020.03.006
198. Volek JS, Kraemer WJ, Bush JA, Incledon T, Boetes M. Testosterone and cortisol in relationship to dietary nutrients and resistance exercise. *J Appl Physiol (1985)*. 1997;82(1):49-54. doi:10.1152/jappl.1997.82.1.49
199. Wang C, Swerdloff RS, Iranmanesh A, et al. Transdermal testosterone gel improves sexual function, mood, muscle strength, and body composition parameters in hypogonadal men. *J Clin Endocrinol Metab*. 2000;85(8):2839-2853. doi:10.1210/jcem.85.8.6747
200. Warner DC, Schnepf G, Barrett MS, Dian D, Swigonski NL. Prevalence, attitudes, and behaviors related to the use of nonsteroidal anti-inflammatory drugs (NSAIDs) in student athletes. *J Adolesc Health*. 2002;30(3):150-153. doi:10.1016/s1054-139x(01)00325-1
201. Wolf DA, Miller TW, Pescatello LS, Barnes C. National Collegiate Athletic Association Division I athletes' use of nonprescription medication. *Sports Health*. 2011;3(1):25-28. doi:10.1177/1941738110387515
202. Wood RI, Stanton SJ. Testosterone and sport: current perspectives. *Horm Behav*. 2012;61(1):147-155. doi:10.1016/j.yhbeh.2011.09.010
203. Woodward MJ, Obsekov V, Jacobson MH, Kahn LG, Trasande L. Phthalates and sex steroid hormones among men from NHANES, 2013-2016. *J Clin Endocrinol Metab*. 2020;105(4):e1225-e12234. doi:10.1210/clinem/dgaa039

204. World Anti-Doping Agency. The prohibited list. https://www.wada-ama.org/en/prohibited-list. Accessed June 26, 2025.
205. World Anti-Doping Agency. TUE physician guidelines - male hypogonadism. https://www.wada-ama.org/en/resources/therapeutic-use-exemption/tue-physician-guidelines-male-hypogonadism. Accessed January 6, 2025.
206. Wu FC, Tajar A, Pye SR, et al. Hypothalamic-pituitary-testicular axis disruptions in older men are differentially linked to age and modifiable risk factors: the European Male Aging Study. *J Clin Endocrinol Metab*. 2008;93(7):2737-2745. doi:10.1210/jc.2007-1972
207. Yahyazadeh A, Altunkaynak BZ, Kaplan S. Biochemical, immunohistochemical and morphometrical investigation of the effect of thymoquinone on the rat testis following exposure to a 900-MHz electromagnetic field. *Acta Histochem*. 2020;122(1):151467. doi:10.1016/j.acthis.2019.151467
208. Yang M, Lee HS, Hwang MW, Jin M. Effects of Korean red ginseng (*Panax Ginseng Meyer*) on bisphenol A exposure and gynecologic complaints: single blind, randomized clinical trial of efficacy and safety. *BMC Complement Altern Med*. 25 2014;14:265. doi:10.1186/1472-6882-14-265
209. Yargiç MP, Torgutalp SS, Erdagi K. Nonsteroidal anti-inflammatory drugs and paracetamol use in elite-level Olympic-style weightlifters: a survey study. *J Sports Med Phys Fitness*. 2021;61(7):991-996. doi:10.23736/S0022-4707.21.11604-4
210. Yeo JK, Cho SI, Park SG, et al. Which exercise is better for increasing serum testosterone levels in patients with erectile dysfunction? *World J Mens Health*. 2018;36(2):147-152. doi:10.5534/wjmh.17030
211. Yilmaz B, Terekeci H, Sandal S, Kelestimur F. Endocrine disrupting chemicals: exposure, effects on human health, mechanism of action, models for testing and strategies for prevention. *Rev Endocr Metab Disord*. 2020;21(1):127-147. doi:10.1007/s11154-019-09521-z
212. Zamir A, Ben-Zeev T, Hoffman JR. Manipulation of dietary intake on changes in circulating testosterone concentrations. *Nutrients*. 2021;13(10):3375. doi:10.3390/nu13103375
213. Zang Z-J, Ji S-Y, Huang S-Z, Jiang M-H, Fang Y-Q. Impact of cellphone radiation on sexual behavior and serum concentration of testosterone and LH in male mice. *Occup Dis Environ Med*. 2016;4(3):56-62. doi:10.4236/odem.2016.43007
214. Zhao J, Leung JYY, Lin SL, Mary Schooling C. Cigarette smoking and testosterone in men and women: a systematic review and meta-analysis of observational studies. *Prev Med*. 2016;85:1-10. doi:10.1016/j.ypmed.2015.12.021
215. Zhao X, Xu W, Wu J, et al. Nicotine induced autophagy of Leydig cells rather than apoptosis is the major reason of the decrease of serum testosterone. *Int J Biochem Cell Biol*. 2018;100:30-41. doi:10.1016/j.biocel.2018.05.001
216. Zhou Q, Miao M, Ran M, et al. Serum bisphenol-A concentration and sex hormone levels in men. *Fertil Steril*. 2013;100(2):478-482. doi:10.1016/j.fertnstert.2013.04.017
217. Zimmer F, Imhoff R. Abstinence from masturbation and hypersexuality. *Arch Sex Behav*. 2020;49(4):1333-1343. doi:10.1007/s10508-019-01623-8
218. Zornitzki T, Tshori S, Shefer G, Mingelgrin S, Levy C, Knobler H. Seasonal variation of testosterone levels in a large cohort of men. *Int J Endocrinol*. 2022;2022:6093092. doi:10.1155/2022/6093092.