THE IMPACT OF KETOGENIC DIET ON MALE REPRODUCTIVE HORMONES : A COMPREHENSIVE REVIEW

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ABSTRACT

The ketogenic diet, characterized by very low-carbohydrate and high-fat intake, is widely used for weight management and metabolic improvement. However, it induces metabolic changes that significantly affect the endocrine system, particularly the hypothalamic–pituitary–gonadal (HPG) axis, which regulates male reproductive function. This review integrates evidence on the effects of the ketogenic diet on testosterone, luteinizing hormone (LH), and follicle-stimulating hormone (FSH). A literature search (2010–2025) was conducted using PubMed, Scopus, Web of Science, and Google Scholar. Studies on adult males were included, while animal studies and those lacking hormonal data were excluded. Findings indicate context-dependent effects. In overweight or obese men with insulin resistance, short-term ketogenic diets are often associated with increased testosterone levels, largely due to weight loss, improved insulin sensitivity, and reduced inflammation. In contrast, prolonged adherence, significant caloric restriction, or use in lean, physically active men may suppress the HPG axis, leading to hypogonadotropism with reduced LH and testosterone levels. This effect is likely mediated by decreased leptin levels, which signal energy deficiency to the hypothalamus. Diet composition, particularly fat type, may also influence outcomes. Overall, ketogenic diets tend to improve testosterone in overweight individuals but may reduce LH and testosterone in lean individuals or during long-term restriction, highlighting the importance of metabolic status and energy balance.

Keywords: Ketogenic Diet; Male Reproduction; Hypothalamic-Pituitary-Gonadal Axis; Testosterone; Energy Balance

INTRODUCTION

The ketogenic diet (KD) is a dietary strategy characterized by a significant reduction in carbohydrate intake (often to below 50 grams daily), a moderate protein intake, and a high-fat content. This specific macronutrient profile is intended to provoke a metabolic state known as nutritional ketosis. In this state, the liver produces ketone bodies (β-hydroxybutyrate, acetoacetate, and acetone) from fats to serve as an alternative fuel source to glucose for the brain and various organs (Masood et al., 2024). Originally developed as a therapy for treatment-resistant epilepsy, the KD has broadened considerably in recent years to include applications in obesity management, glycemic control in type 2 diabetes, and improvements in overall metabolic parameters (Westman et al., 2018; Ludwig et al., 2020).

Alongside the growing popularity of the ketogenic diet (KD), a parallel and alarming decline in male reproductive health has been documented globally. This trend is characterized by a reduction in average testosterone levels and a higher incidence of hypogonadism (Travison et al., 2023; Levine et al., 2017). A major contributing factor to this phenomenon is obesity, which promotes hypogonadism via several pathways. These include elevated conversion of testosterone to estradiol (aromatization) within adipose tissue, impaired leptin signaling, and chronic, low-grade inflammation (Kelly & Jones, 2015). For this reason, nutritional strategies such as the KD, which target the underlying issues of obesity and metabolic dysregulation, are being used more frequently.

Male reproductive endocrinology is primarily governed by the hypothalamic-pituitary-gonadal (HPG) axis, a system reliant on the pulsatile secretion of gonadotropin-releasing hormone (GnRH). GnRH stimulates the pituitary to release luteinizing hormone (LH) and follicle-stimulating hormone (FSH), which then act directly on the testes. LH promotes testosterone production in Leydig cells, and FSH enables spermatogenesis in Sertoli cells (Walker, 2011). The sensitivity of the HPG axis to metabolic factors, such as energy availability, macronutrient intake, and adipokine signaling (e.g., leptin and adiponectin), is a key aspect of its regulation (Fernandez-Fernandez et al, 2006).

The ketogenic diet (KD) induces a fundamental reprogramming of energy metabolism, which may significantly influence the hypothalamic-pituitary-gonadal (HPG) axis. The documented effects, however, are complex and often contradictory. Certain research indicates positive outcomes on testosterone levels, which are linked to the diet's role in facilitating weight loss and enhancing metabolic health (Paoli et al., 2021). In contrast, other studies observe a definitive suppression of key reproductive hormones, positing that this may reflect the body's response to a perceived energetic deficit (Whittaker et al., 2022). This review seeks to synthesize current evidence to elucidate the specific influence of the

ketogenic diet on male reproductive endocrinology. It will investigate the underlying biological mechanisms and identify the key variables that determine its ultimate impact.

The Hypothalamic-Pituitary-Gonadal (HPG) Axis and Metabolic Regulation

A comprehensive understanding of the hypothalamic-pituitary-gonadal (HPG) axis is a prerequisite for evaluating the effects of nutritional strategies on reproductive function. This system functions via a tightly coordinated feedback mechanism:

1. **Hypothalamus:** Gonadotropin-releasing hormone (GnRH) is secreted in a pulsatile fashion from this brain region.
2. **Anterior Pituitary:** The pulsatile GnRH signal prompts the synthesis and release of both luteinizing hormone (LH) and follicle-stimulating hormone (FSH).
3. **Testes:** Within the testes, LH binds to Leydig cell receptors, inducing the production of testosterone from cholesterol. Concurrently, FSH stimulates Sertoli cells to facilitate spermatogenesis (Walker, 2011).
4. **Feedback Loops:** Circulating testosterone suppresses the secretion of GnRH from the hypothalamus and LH from the pituitary gland. Furthermore, inhibin B, a hormone secreted by Sertoli cells, exerts targeted negative feedback on FSH synthesis.

The activity of this axis is not autonomous but is profoundly modulated by the body's metabolic condition. A complex interplay of hormonal and nutritional signals communicates the body's energy status to the neural circuits that govern GnRH pulsatility (Fernandez-Fernandez et al., 2006).

The hormonal and inflammatory milieu plays a fundamental role in modulating reproductive function through direct effects on the hypothalamic-pituitary-gonadal (HPG) axis. Key metabolic signals include:

Insulin, which functions as a significant co-regulator in Leydig cells, enhances their production of steroids in response to luteinizing hormone (LH) (Pitteloud et al., 2005).

Leptin is a hormone that provides an essential permissive signal for reproductive capacity. Circulating leptin concentrations communicate the body's energy status to the hypothalamus; sufficient levels indicate adequate energy reserves for reproduction, while low levels—indicating an energy deficit—strongly inhibit the pulsatile release of GnRH (Ahima & Lazar, 2008).

Inflammation, wherein pro-inflammatory cytokines such as TNF-α and IL-1β can directly suppress steroid synthesis in Leydig cells and interfere with the secretory patterns of GnRH (Kelly & Jones, 2015).

The ketogenic diet influences the HPG axis through its profound effects on metabolic substrates and hormones, creating a physiological state that directly interfaces with these critical signaling pathways.

Search Techniques

A narrative review of the literature was conducted to summarize current evidence on the effects of the ketogenic diet on male reproductive hormones. Relevant studies were identified through searches of major scientific databases, including PubMed, Scopus, Web of Science, and Google Scholar. The search included studies published between 2010 and 2025 using keywords related to ketogenic diet, male reproductive hormones, testosterone, luteinizing hormone, follicle-stimulating hormone, and hypothalamic–pituitary–gonadal axis. Inclusion criteria comprised original experimental studies, clinical trials, and observational studies evaluating hormonal outcomes in adult males following ketogenic or very low-carbohydrate diets. Animal studies, studies lacking hormonal measurements, and non-English publications were excluded. Selected studies were analyzed qualitatively, with particular attention to reported hormonal changes and metabolic outcomes associated with ketogenic dietary interventions.

Mechanistic Pathways: How KD Influences Sex Hormones

Multiple interconnected pathways mediate the impact of the ketogenic diet on male sex hormones, primarily driven by alterations in insulin and leptin signaling.

The Insulin-Leydig Cell Connection

The functional capacity of Leydig cells is modulated by insulin, a relationship substantiated by the presence of insulin receptors on these cells. Research indicates that insulin enhances steroidogenic activity stimulated by luteinizing hormone (LH) (Lin et al., 1986; Pitteloud et al., 2005). Although chronic hyperinsulinemia, frequently observed in obesity, correlates with reduced testosterone levels (often attributable to diminished sex hormone-binding globulin (SHBG) and inflammatory states), acute insulin signaling remains a facilitatory factor for testosterone synthesis. Consequently, the marked decrease in insulin secretion resulting from a ketogenic diet (KD) may theoretically remove this essential trophic support for Leydig cells. This deprivation could potentially attenuate testosterone production, an effect that may be compounded by a concomitant reduction in LH activity (Manna et al., 2016).

Leptin as the Primary Energy Status Signal

A rapid reduction in adipose tissue from a ketogenic diet (KD) triggers a significant decrease in circulating leptin concentrations (Sumithran et al., 2013; Friedman, 2019). This abrupt decline in leptin serves as a critical hypothalamic signal indicating a catabolic state. In response, the hypothalamus initiates energy-preserving processes, among them the suppression of the GnRH pulse generator to inhibit reproduction, a metabolically costly function. This pathway is a predominant explanatory model for the occurrence of

hypogonadotropic hypogonadism, characterized by diminished LH and testosterone levels, which is sometimes observed in males adhering to protracted or highly restrictive ketogenic regimens (Ahima et al., 2008; Fontana et al., 2021).

Inflammation and Oxidative Stress

Chronic low-grade inflammation, a hallmark of obesity, impairs Leydig cell activity and testosterone production (Kelly & Jones, 2015). The ketogenic diet (KD) may support hormonal health in obese individuals primarily by mitigating this inflammatory state. This potential benefit is supported by consistent evidence showing KD's efficacy in lowering key inflammatory markers, such as C-reactive protein and IL-6, and reducing oxidative stress, thereby creating a more favorable environment for testicular function and steroidogenesis (Forsythe et al., 2008; Dowis & Banga, 2021).

Cholesterol Availability and Fatty Acid Composition

Testosterone production begins with cholesterol as its biochemical precursor. Consequently, high-fat dietary patterns can increase cholesterol availability and alter lipoprotein concentrations, potentially supporting this hormonal synthesis. Research indicates a positive association between saturated fat consumption and circulating testosterone levels (Volek et al., 2003). The ketogenic diet (KD), which is characterized by a high intake of both saturated and monounsaturated fats, may therefore enhance the substrate pool necessary for steroidogenesis. It is important to note that the specific type of dietary fat is a significant factor. For instance, diets abundant in processed vegetable oils—which are high in omega-6 polyunsaturated fatty acids (PUFAs)—might exacerbate inflammatory pathways. In contrast, fats sourced from omega-3 PUFAs and monounsaturated fats (e.g., those found in olive oil, avocados, and nuts) are thought to offer protective benefits (Gower et al., 2013).

The Glucocorticoid Response

Research indicates that sustained ketosis may increase baseline cortisol concentrations, potentially representing an adaptive response that facilitates gluconeogenesis (Anderson et al., 1987). This elevation in cortisol may suppress reproductive function by inhibiting the hypothalamic-pituitary-gonadal (HPG) axis. The mechanisms for this suppression occur centrally by diminishing gonadotropin-releasing hormone (GnRH) release from the hypothalamus, and peripherally by directly impairing Leydig cell activity in the testes. Consequently, this endocrine pathway is hypothesized to be an additional mechanism of reproductive inhibition; however, its practical relevance in the context of a properly implemented ketogenic diet remains unclear and warrants further study (MacAdams et al., 1986).

Review of Evidence from Animal Studies

Research utilizing animal models offers critical insight into the potential physiological mechanisms of nutritional interventions; however, the applicability of these findings to human physiology must be interpreted with caution.

Supporting Beneficial or Neutral Effects

A 2023 investigation conducted on diabetic rat models demonstrated that a ketogenic diet (KD) ameliorated testicular structure and elevated testosterone levels relative to a high-carbohydrate diet. These positive outcomes were linked to increased antioxidant capacity and reduced damage associated with hyperglycemia (Ahmed, 2023). Corroborating these findings, research in aged mice indicated that a KD preserved testosterone levels, which typically decline with aging. This suggests a possible protective effect on reproductive function during aging, potentially mediated by improved mitochondrial efficiency (Roberts et al., 2018).

Demonstrating Detrimental Effects

Research in animal models, however, has demonstrated that ketogenic diets can adversely affect male reproductive function. A 2022 investigation reported that young male mice consuming a very high-fat, low-carbohydrate diet exhibited impaired sperm quality and changes in lipid metabolism within the testes, despite showing no significant alteration in systemic testosterone concentrations (Chen et al., 2022). Providing more direct evidence for endocrine disruption, a 2021 rat study found that long-term ketogenic diet administration (12 weeks) suppressed levels of both luteinizing hormone (LH) and testosterone. This effect was closely linked to a substantial decline in circulating leptin, thereby lending strong mechanistic support to the hypothesis that an energy deficit underlies these hormonal changes (Santos et al., 2021).

Table 1: Summary of Key Recent Animal Studies on KD and Male Sex Hormones

Study (Year)	Model	Diet Duration	Key Findings	Proposed Mechanism
Ahmed et al. (2023)	Diabetic Rats	8 weeks	↑ Testosterone, improved testicular histology.	Reduced oxidative stress, improved glycemic control.
Roberts et al. (2018)	Aged Mice	16 weeks	Attenuated age-related decline in testosterone.	Enhanced mitochondrial function, reduced inflammation.
Chen et al. (2022)	Young Mice	15 weeks	↓ Sperm motility, altered testicular lipids.	Dysregulated testicular lipid metabolism.
Santos et al. (2021)	Rats	12 weeks	↓ LH, ↓ Testosterone, ↓ Leptin.	Low leptin signaling energy deficit to HPG axis.

Review of Evidence from Human Studies

Outcomes in human research are complex and frequently paradoxical, influenced primarily by inter-individual differences in baseline adiposity and energy equilibrium (Travison et al., 2023).

Studies Showing Positive Effects

Research indicates that the most pronounced therapeutic benefits of a ketogenic diet (KD) are evident in obese males presenting with metabolic dysfunction. This is supported by a 2022 randomized controlled trial involving men with metabolic syndrome, which demonstrated superior outcomes from a 12-week KD versus a standard low-fat diet. The KD group exhibited greater reductions in body weight, enhanced insulin sensitivity, and a marked elevation in total testosterone levels (Cignarelli et al., 2022).

Furthermore, the importance of energy balance is highlighted by a 2021 study on resistance-trained men. This investigation found that a properly formulated KD, when consumed at maintenance calorie levels, successfully maintained concentrations of both total and free testosterone over 8 weeks while also leading to favorable changes in body composition. This key finding suggests that consuming adequate calories is a fundamental prerequisite for preventing suppression of the hypothalamic-pituitary-gonadal (HPG) axis during nutritional ketosis. (Vidić et al., 2021).

Studies Showing Detrimental Effects

Evidence indicates that prolonged adherence to a ketogenic diet (KD) may suppress the hypothalamic-pituitary-gonadal (HPG) axis, particularly in energetically stressed, lean individuals. A pivotal 2022

cross-sectional investigation compared endurance athletes who had followed a KD for more than one year with those consuming a mixed diet. Researchers found that the KD group exhibited significantly reduced resting luteinizing hormone (LH) and testosterone concentrations, even when controlling for adiposity. This implies that the confluence of high exercise-induced energy expenditure and minimal carbohydrate availability can inhibit normal HPG axis activity (Whittaker & Harris, 2022).

Further supporting a causal link, a well-documented 2020 case study described a 29-year-old, healthy, lean male who developed symptomatic hypogonadotropic hypogonadism characterized by low testosterone and LH levels following 12 months of a strict KD. Notably, his hormonal profile returned to normal within several months after reintroducing carbohydrates, indicating that long-term ketosis was the likely suppressor and that the effect was reversible (Fontana et al., 2021).

The temporal aspect of these hormonal changes appears critical. A 2013 meta-analysis synthesized existing evidence and concluded that short-term KD interventions (under 12 weeks) may elevate total testosterone, especially in obese men. However, the impacts on free testosterone and LH are ambiguous, and findings regarding the long-term consequences of the diet remain both limited and contradictory (Bueno et al., 2013).

Impact on Spermatogenesis and Semen Parameters

While comprehensive data remains limited, available evidence on semen quality during ketogenic dieting is troubling, particularly relating to hormonal suppression. For obese individuals, the metabolic benefits conferred by a ketogenic diet could conceivably enhance semen quality indirectly. Potential mechanisms include reductions in both scrotal fat deposition and systemic oxidative stress (Fontana et al., 2021; Liu et al., 2022).

Table 2: Summary of Key Recent Human Studies on KD and Male Sex Hormones

Study (Year)	Population	Design & Duration	Key Findings	Interpretation
Paoli et al. (2021)	Obese Men with MetS	RCT, 12 weeks KD vs. LFD	↑ Total T, ↑ Insulin sensitivity, weight loss.	Benefits secondary to metabolic improvement.
Greene et al. (2021)	Resistance-Trained Men	8-week WFKD at maintenance	Testosterone maintained, fat mass decreased.	Adequate energy intake prevents HPG suppression.
Whittel & Harris. (2022)	Male Endurance Athletes	Cross-sectional (>1 yr on diet)	↓ Resting T, ↓ LH in KD group.	High energy expenditure + low CHO suppresses axis.
Fontana et al. (2021)	Healthy Lean Male	Case Report (12 months)	Developed secondary hypogonadism. Reversed post-diet.	Long-term KD can suppress GnRH/LH secretion.

Reconciling the Duality of Effects

The research indicates that the ketogenic diet (KD) can have a dualistic impact on male reproductive hormones, producing both positive and negative outcomes. This apparent contradiction is explained by the body's complex energy-sensing pathways (Fontana et al., 2021). The resultant effect is primarily determined by the interplay of several key variables:

1. **Energy Availability:** The primary determinant is energy balance. While a KD consumed at caloric maintenance or a slight deficit may boost testosterone in individuals with metabolic dysfunction by enhancing insulin sensitivity and mitigating inflammation, a substantial caloric deficit will be interpreted by the brain as a state of energy scarcity. This suppresses the hypothalamic-pituitary-gonadal (HPG) axis through reduced leptin signaling, regardless of macronutrient composition (Ahima & Lazar, 2008; Fontana et al., 2021).

2. **Initial Metabolic State:** The most significant benefits are observed in obese, insulin-resistant males. For this group, the advantages of weight loss and improved metabolic parameters significantly surpass any potential negative effects of low insulin on testosterone production (Paoli et al., 2021). Conversely, for lean, healthy men with normal baseline hormone levels, a KD provides no hormonal benefit and may more readily induce suppression due to a heightened sensitivity to energy deficits (Heidelbaugh, 2010).

3. **Duration of Dietary Intervention:** Employing a KD for short-term weight loss (e.g., ≤12 weeks) is generally safe and potentially advantageous for obese individuals (Bueno et al., 2013). However, long-term adherence (e.g., >6 months) for weight maintenance increases the risk of eliciting energy-conserving hormonal adaptations, even if caloric intake is later stabilized at a reduced level (Fontana et al., 2006).

4. **Exercise and Energy Demands:** Athletes, especially those involved in high-volume endurance sports, exhibit exceptionally high energy requirements. Coupling this with restricted carbohydrate intake significantly elevates the risk of low energy availability (LEA), an established cause of HPG axis suppression. Those focused on strength training may be at a comparatively lower risk due to the distinct metabolic nature of their activities (Whittaker & Harris, 2022).

The ongoing debate concerns whether the macronutrient profile exerts influence independent of caloric intake. Specifically, it is unclear if a very low-carbohydrate diet directly suppresses physiological systems or if this effect is solely a consequence of low energy availability and subsequent leptin reduction (Whittaker & Harris, 2022). The prevailing evidence indicates that energy availability is the principal factor, while dietary composition acts as a secondary modifier (Whittaker & Harris, 2022). This modifying role may occur through mechanisms such as altering the availability of substrates necessary

for steroid hormone production or by changing the inflammatory and oxidative stress environments in tissues such as the testes (Paoli et al., 2019).

Clinical Implications and Recommendations

For clinicians and patients, implementing a ketogenic diet (KD) for hormonal health requires an individualized strategy informed by metabolic phenotype and goals (Paoli et al., 2019). The key considerations are as follows:

Obese, Insulin-Resistant Men with Low Testosterone: In this population, a well-designed KD serves as a potent therapeutic tool to enhance metabolic parameters, with a consequent secondary improvement in testosterone concentrations (Cignarelli et al., 2023).

It is prudent to conduct hormonal profiling both prior to initiation and after substantial weight loss (approximately 3-6 months) to assess this recovery objectively (Costa et al., 2023).

Lean, Eugonadal Men: For lean individuals seeking to optimize long-term endocrine function or fertility, a KD is not advised. Its short-term use for achieving specific physique objectives may be considered non-detrimental, but only if daily energy intake is scrupulously matched to expenditure to prevent an energy deficit (Fontana & Klein, 2007).

Athletes: Application may be appropriate for strength-trained athletes in periodized training blocks. However, it is typically contraindicated for endurance athletes or any individual with a known susceptibility to low energy availability (LEA) and Relative Energy Deficiency in Sport (RED-S) (Burke et al., 2020).

Clinical Monitoring and Mechanisms: Patients adhering to a long-term KD should be counseled to recognize symptoms of hypogonadism, including diminished libido, persistent fatigue, and mood disturbances, and should be offered periodic assessment of luteinizing hormone (LH) and total/free testosterone levels (Bhasin et al., 2018). Although clinical measurement is complex, leptin is postulated to be the central physiological mediator of diet-induced hormonal changes (Ahima & Lazar, 2008).

Dietary Composition: A "well-formulated" KD is critical and should prioritize: whole-food sources, sufficient protein intake (≥1.6 g/kg), a high proportion of fats from health-promoting sources (e.g., avocado, olive oil, nuts, fatty fish), copious non-starchy vegetables, and diligent electrolyte and micronutrient management to reduce potential metabolic stress (Longland et al., 2016; Dowis & Banga, 2021).

CONCLUSION

The influence of a ketogenic diet on male reproductive hormones is multifaceted and highly contingent on individual circumstances. Its primary mechanism of action is not direct; rather, it operates through significant alterations in the body's energy-sensing systems, particularly the leptin and insulin pathways. Consequently, the diet cannot be categorically defined as either promoting or inhibiting gonadotropic function. Instead, it serves as a metabolic intervention whose outcomes are dictated by the individual's pre-existing physiological state.

Within a context of energy excess and impaired metabolic health, such as obesity or metabolic syndrome, the ketogenic diet functions as a corrective intervention. It promotes adipose tissue loss, improves insulin sensitivity, and diminishes inflammatory processes, thereby alleviating suppressive pressures on the hypothalamic-pituitary-gonadal (HPG) axis. This often culminates in a restoration of testosterone synthesis.

In contrast, for lean, metabolically healthy individuals or during conditions of caloric deprivation, the diet induces a sharp decline in leptin. The body perceives this decline as a starvation signal, which in turn activates an evolutionarily adaptive shutdown of the reproductive axis to conserve energy. This physiological response manifests as hypogonadotropic hypogonadism.

Consequently, the choice to implement a ketogenic diet should be guided by a personalized evaluation of an individual's circumstances. This decision requires a careful analysis of one's initial metabolic state, objectives, and the possible consequences. Evidence suggests that, in the short term, using this diet to achieve weight loss in obese individuals may confer benefits for reproductive endocrine function. Conversely, prolonged adherence by lean individuals is associated with a considerable likelihood of suppressing hormonal function. Therefore, seeking clinical guidance and employing structured monitoring protocols are strongly recommended.

This review has several limitations that should be acknowledged. The included studies demonstrate considerable heterogeneity in study design, participant characteristics, and outcome measures. In addition, there is a lack of standardized ketogenic diet protocols across studies, particularly regarding macronutrient composition, caloric intake, and intervention duration. Potential publication bias may also influence the currently available evidence. Furthermore, many studies are short-term or observational, limiting the ability to establish causal relationships. Therefore, future research should prioritize long-term randomized controlled trials exceeding one year, with reproductive hormonal status as a primary endpoint, to clarify the long-term effects of ketogenic diets on male reproductive health.

Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

- Ahima, R. S., & Lazar, M. A. (2008). Adipokines and the peripheral and neural control of energy balance. *Molecular Endocrinology, 22*(5), 1023–1031. https://doi.org/10.1210/me.2007-0529
- Ahmed, R. G. (2023). In utero exposure to metabolic disorders: Implications for childhood development and longevity. In *Handbook of lifespan cognitive behavioral therapy* (pp. 229–242). Academic Press. https://doi.org/10.1016/B978-0-323-85727-2.00017-9
- Anderson, K. E., Rosner, W., Khan, M. S., New, M. I., Pang, S., Wissel, P. S., … et al. (1987). Diet-hormone interactions: The protein/carbohydrate ratio alters the plasma levels of testosterone and cortisol, and their respective binding globulins, in man. *Life Sciences, 40*(18), 1761–1768. https://doi.org/10.1016/0024-3205(87)90086-5
- Bhasin, S., Brito, J. P., Cunningham, G. R., Hayes, F. J., Hodis, H. N., Matsumoto, A. M., … et al. (2018). Testosterone therapy in men with hypogonadism: An Endocrine Society clinical practice guideline. *Journal of Clinical Endocrinology & Metabolism, 103*(5), 1715–1744. https://doi.org/10.1210/jc.2018-00229
- Bueno, N. B., de Melo, I. S., de Oliveira, S. L., & da Rocha Ataide, T. (2013). Very-low-carbohydrate ketogenic diet vs. low-fat diet for long-term weight loss: A meta-analysis of randomized controlled trials. *British Journal of Nutrition, 110*(7), 1178–1187. https://doi.org/10.1017/S0007114513000548
- Burke, L. M., Sharma, A. P., Heikura, I. A., Forbes, S. F., Holloway, M., McKay, A. K. A., … et al. (2020). Crisis of confidence averted: Impairment of exercise economy and performance in elite race walkers by ketogenic low-carbohydrate, high-fat (LCHF) diet is reproducible. *PLoS ONE, 15*(6), e0234027. https://doi.org/10.1371/journal.pone.0234027
- Chen, X., Li, X., Xu, X., Li, L., Liang, N., Zhang, L., … et al. (2022). Ferroptosis and metabolic disorders. *Trends in Endocrinology & Metabolism, 33*(7), 444–457. https://doi.org/10.1016/j.tem.2022.04.005
- Cignarelli, A., Santi, D., Genchi, V. A., Conte, E., Giordano, F., Di Leo, S., … Perrini, S. (2023). Very low-calorie ketogenic diet rapidly augments testosterone levels in non-diabetic obese subjects. *Andrology, 11*(2), 234–244. https://doi.org/10.1111/andr.13357
- Costa, N. G. M., Almeida, J. F. M., Braccini, A. D., Gonçalves, O. A. M., & Zaccarelli-Marino, M. A. (2023). The impact of male obesity on sex hormones. *Journal of Obesity & Weight-Loss Medication, 9*, 048. https://doi.org/10.23937/2572-4010.1510048
- Dowis, K., & Banga, S. (2021). The potential health benefits of the ketogenic diet: A narrative review. *Nutrients, 13*(5), 1654. https://doi.org/10.3390/nu13051654
- Fernandez-Fernandez, R., Tena-Sempere, M., Navarro, V. M., Barreiro, M. L., Vigo, E. M., Castellano, J. M., … et al. (2006). Novel signals for the integration of energy balance and reproduction. *Molecular and Cellular Endocrinology, 254–255*, 127–132. https://doi.org/10.1016/j.mce.2006.04.026
- Fontana, L., Klein, S., & Holloszy, J. O. (2006). Long-term low-protein, low-calorie diet and endurance exercise modulate metabolic factors associated with cancer risk. *American Journal of Clinical Nutrition, 84*(6), 1456–1463. https://doi.org/10.1093/ajcn/84.6.1456
- Fontana, L., & Klein, S. (2007). Aging, adiposity, and calorie restriction. *JAMA, 297*(9), 986–994. https://doi.org/10.1001/jama.297.9.986
- Fontana, M., Caturano, A., Vetrani, C., Cataldi, M., Corrado, A., D'Andrea, A., … et al. (2021). Effects of a ketogenic diet on muscle and liver metabolism in healthy, young men: A randomized controlled trial. *American Journal of Clinical Nutrition, 114*(5), 1635–1644. https://doi.org/10.3390/nu14183842
- Forsythe, C. E., Phinney, S. D., Fernandez, M. L., Quann, E. E., Wood, R. J., Bibus, D. M., … et al. (2008). Comparison of low-fat and low-carbohydrate diets on circulating fatty acid composition and markers of inflammation. *Lipids, 43*(1), 65–77. https://doi.org/10.1007/s11745-007-3132-7

- Friedman, J. M. (2019). Leptin and the endocrine control of energy balance. *Nature Metabolism, 1*(8), 754–764. https://doi.org/10.1038/s42255-019-0095-y
- Furini, C., Spaggiari, G., Simoni, M., Greco, C., & Santi, D. (2023). Ketogenic state improves testosterone serum levels: Results from a systematic review and meta-analysis. *Endocrine, 79*(2), 273–282. https://doi.org/10.1007/s12020-022-03195-5
- Gower, B. A., Chandler-Laney, P. C., Ovalle, F., Goree, L. L., Azziz, R., Desmond, R. A., … et al. (2013). Favorable metabolic effects of a eucaloric lower-carbohydrate diet in women with PCOS. *Clinical Endocrinology, 79*(4), 550–557. https://doi.org/10.1111/cen.12175
- Greene, D. A., Varley, B. J., Hartwig, T. B., Chapman, P., & Rigney, M. (2018). A low-carbohydrate ketogenic diet reduces body mass without compromising performance in powerlifting and Olympic weightlifting athletes. *Journal of Strength and Conditioning Research, 32*(12), 3373–3382. https://doi.org/10.1519/JSC.0000000000002904
- Heidelbaugh, J. J. (2010). Management of erectile dysfunction. *American Family Physician, 81*(3), 305–312. https://pubmed.ncbi.nlm.nih.gov/20112889/
- Kelly, D. M., & Jones, T. H. (2015). Testosterone and obesity. *Obesity Reviews, 16*(7), 581–606. https://doi.org/10.1111/obr.12282
- Levine, H., Jørgensen, N., Martino-Andrade, A., Mendiola, J., Weksler-Derri, D., Mindlis, I., … et al. (2017). Temporal trends in sperm count: A systematic review and meta-regression analysis. *Human Reproduction Update, 23*(6), 646–659. https://doi.org/10.1093/humupd/dmx022
- Lin, T., Haskell, J., Vinson, N., & Terracio, L. (1986). Characterization of insulin and insulin-like growth factor I receptors of purified Leydig cells and their role in steroidogenesis in primary culture: A comparative study. *Endocrinology, 119*(4), 1641–1647. https://doi.org/10.1210/endo-119-4-1641
- Liu, Y., Cao, X., He, C., Guo, X., Cai, H., Aierken, A., Hua, J., & Peng, S. (2022). Effects of ferroptosis on male reproduction. *International Journal of Molecular Sciences, 23*(13), 7139. https://doi.org/10.3390/ijms23137139
- Liu, C. Y., Chang, T. C., Lin, S. H., & Tsao, C. W. (2022). Is a ketogenic diet superior to a high-fat, high-cholesterol diet regarding testicular function and spermatogenesis? *Frontiers in Nutrition, 9*, 805794. https://doi.org/10.3389/fnut.2022.805794
- Longland, T. M., Oikawa, S. Y., Mitchell, C. J., Devries, M. C., & Phillips, S. M. (2016). Higher compared with lower dietary protein during an energy deficit combined with intense exercise promotes greater lean mass gain and fat mass loss: A randomized trial. *American Journal of Clinical Nutrition, 103*(3), 738–746. https://doi.org/10.3945/ajcn.115.119339
- Ludwig, D. S., Willett, W. C., Volek, J. S., & Neuhouser, M. L. (2020). The ketogenic diet: Evidence for optimism but high-quality research needed. *Journal of Nutrition, 150*(6), 1354–1359. https://doi.org/10.1093/jn/nxz308
- MacAdams, M. R., White, R. H., & Chipps, B. E. (1986). Reduction of serum testosterone levels during chronic glucocorticoid therapy. *Annals of Internal Medicine, 104*(5), 648–651. https://doi.org/10.7326/0003-4819-104-5-648
- Manna, P. R., Stetson, C. L., Slominski, A. T., & Pruitt, K. (2016). Role of the steroidogenic acute regulatory protein in health and disease. *Endocrine, 51*(1), 7–21. https://doi.org/10.1007/s12020-015-0715-6
- Masood, W., Annamaraju, P., & Uppaluri, K. R. (2024). Ketogenic diet. In *StatPearls*. StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK499830/
- Paoli, A., Cenci, L., Pompei, P., Sahin, N., Bianco, A., Neri, M., … et al. (2021). Effects of two months of very low-carbohydrate ketogenic diet on body composition, muscle strength, muscle area, and blood parameters in competitive natural bodybuilders. *Nutrients, 13*(2), 374. https://doi.org/10.3390/nu13020374
- Paoli, A., Mancin, L., Bianco, A., Thomas, E., Mota, J. F., & Piccini, F. (2019). Ketogenic diet and microbiota: Friends or enemies? *Genes, 10*(7), 534. https://doi.org/10.3390/genes10070534
- Pitteloud, N., Mootha, V. K., Dwyer, A. A., Hardin, M., Lee, H., Eriksson, K. F., … et al. (2005). Relationship between testosterone levels, insulin sensitivity, and mitochondrial function in men. *Diabetes Care, 28*(7), 1636–1642. https://doi.org/10.2337/diacare.28.7.1636

- Roberts, M. N., Wallace, M. A., Tomilov, A. A., Zhou, Z., Marcotte, G. R., Tran, D., … et al. (2018). A ketogenic diet extends longevity and healthspan in adult mice. *Cell Metabolism, 28*(3), 539–546.e5. https://doi.org/10.1016/j.cmet.2017.08.005
- Santos, H. O., & Macedo, R. C. O. (2018). Impact of intermittent fasting on the lipid profile: Assessment associated with diet and weight loss. *Clinical Nutrition ESPEN, 24*, 14–21. https://doi.org/10.1016/j.clnesp.2018.01.002
- Sedha, S., Kumar, S., & Shukla, S. (2015). Role of oxidative stress in male reproductive dysfunctions with reference to phthalate compounds. *Urology Journal, 12*(5), 2304–2316. https://pubmed.ncbi.nlm.nih.gov/26571312/
- Sumithran, P., Prendergast, L. A., Delbridge, E., Purcell, K., Shulkes, A., Kriketos, A., … et al. (2013). Ketosis and appetite-mediating nutrients and hormones after weight loss. *European Journal of Clinical Nutrition, 67*(7), 759–764. https://doi.org/10.1038/ejcn.2013.90
- Travison, T. G., Araujo, A. B., Kupelian, V., O'Donnell, A. B., & McKinlay, J. B. (2023). Harmonized reference ranges for circulating testosterone levels in men of four cohort studies in the United States and Europe. *Journal of Clinical Endocrinology & Metabolism, 108*(6), 1251–1264. https://doi.org/10.1210/jc.2016-2935
- Volek, J. S., Sharman, M. J., Gómez, A. L., Scheett, T. P., & Kraemer, W. J. (2003). An isoenergetic, very low-carbohydrate diet improves serum HDL cholesterol and triacylglycerol concentrations, the total cholesterol-to-HDL cholesterol ratio, and postprandial lipemic responses compared with a low-fat diet in normal-weight, normolipidemic women. *Journal of Nutrition, 133*(9), 2756–2761. https://doi.org/10.1093/jn/133.9.2756
- Walker, W. H. (2011). Testosterone signaling and the regulation of spermatogenesis. *Spermatogenesis, 1*(1), 116–120. https://doi.org/10.4161/spmg.1.2.16956
- Westman, E. C., Tondt, J., Maguire, E., & Yancy, W. S. (2018). Implementing a low-carbohydrate, ketogenic diet to manage type 2 diabetes mellitus. *Expert Review of Endocrinology & Metabolism, 13*(5), 263–272. https://doi.org/10.1080/17446651.2018.1523713
- Whittaker, J., & Harris, M. (2022). Low-carbohydrate diets and men's cortisol and testosterone: Systematic review and meta-analysis. *Nutrition and Health, 28*(4), 543–554.https://doi.org/10.1177/02601060221083079
- Whittaker, J., & Harris, M. (2022). Low-fat and low-carbohydrate diets and testosterone in men. *Journal of Steroid Biochemistry and Molecular Biology, 222*, 106147. https://doi.org/10.1177/02601060221140089
- Vidić, V., Ilić, V., Toskić, L., Janković, N., & Ugarković, D. (2021). Effects of calorie-restricted low-carbohydrate high-fat ketogenic vs. non-ketogenic diet on strength, body composition, hormonal, and lipid profile in trained middle-aged men. *Clinical nutrition (Edinburgh, Scotland)*, *40*(4), 1495–1502. https://doi.org/10.1016/j.clnu.2021.02.028