International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Scholarly Publisher
RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

Dolna 17, Warsaw,
Poland 00-773
+48 226 0 227 03
editorial_office@rsglobal.pl

ARTICLE TITLE	LIVER FUNCTION AND LIPID METABOLISM MARKERS IN YOUNG ATHLETES FOLLOWING HIGH-PROTEIN DIETS
DOI	https://doi.org/10.31435/ijitss.3(47).2025.3573
RECEIVED	14 July 2025
ACCEPTED	05 September 2025
PUBLISHED	18 September 2025
LICENSE	The article is licensed under a **Creative Commons Attribution 4.0 International License.**

LIVER FUNCTION AND LIPID METABOLISM MARKERS IN YOUNG ATHLETES FOLLOWING HIGH-PROTEIN DIETS

Kacper Trząsalski *(Corresponding Author, Email: kacper.trzasalski1@gmail.com)*
Medical University of Wroclaw, Wroclaw, Poland
ORCID ID: 0009-0002-8425-6865

Katarzyna Oświeczyńska
Silesian Academy, Zbigniew Religa Faculty of Medical Sciences, Poland
ORCID ID: 0009-0000-8383-9175

Aleksandra Sowa
Medical University of Wroclaw, Wroclaw, Poland
ORCID ID: 0009-0009-3606-8756

Sebastian Kupisiak
Czerniakowski Hospital, Stępińska 19/25, 00-739 Warsaw, Poland
ORCID ID: 0009-0007-9631-2314

Patrycja Jędrzejewska-Rzezak
MD, The John Paul II Catholic University of Lublin, Lublin, Poland
ORCID ID: 0000-0003-2144-5810

ABSTRACT

Introduction: Metabolic syndrome (MetS) is an increasingly significant health issue among young adults, marked by the coexistence of visceral obesity, insulin resistance, dyslipidemia, and hypertension. A key component of its pathogenesis is chronic low-grade inflammation, reflected by elevated levels of biomarkers such as C-reactive protein (CRP), interleukin-6 (IL-6), and tumor necrosis factor-alpha (TNF-α). Recently, attention has turned to the potential of physical activity as a modifiable factor that can influence inflammatory status and reduce MetS risk.
Objective: This study aimed to review current scientific evidence on the impact of regular physical activity on selected inflammatory markers and the risk of MetS in young adults.
Methods: A systematic literature review was conducted covering publications from 2015 to 2024. Scientific databases including PubMed, Scopus, and ScienceDirect were searched using keywords such as "physical activity," "inflammatory markers," "cytokines," "CRP," "TNF-alpha," "IL-6," and "metabolic syndrome." Included studies were randomized controlled trials, systematic reviews, and prospective cohort studies involving individuals aged 18–35.
Results and conclusion: Findings revealed that regular physical activity- especially programs combining aerobic and resistance training- significantly lowered CRP, TNF-α, and IL-8 levels, while increasing anti-inflammatory cytokines. Participants with higher physical activity levels were consistently less likely to meet MetS diagnostic criteria, even after adjusting for BMI. Additional benefits included improved insulin sensitivity, reduced oxidative stress, and favorable changes in lipid profiles. The anti-inflammatory effects were dose-dependent, with the most significant outcomes observed in those performing at least 150 minutes of moderate-to-vigorous activity weekly. Physical activity should be regarded as a key preventive measure against MetS and long-term cardiovascular risk in young adults.

KEYWORDS

Physical Activity, Inflammatory Markers, Cytokines, CRP, Metabolic Syndrome, Young Adults, Prevention

CITATION

Kacper Trząsalski, Katarzyna Oświeczyńska, Aleksandra Sowa, Sebastian Kupisiak, Patrycja Jędrzejewska-Rzezak (2025) Liver Function and Lipid Metabolism Markers in Young Athletes Following High-Protein Diets. *International Journal of Innovative Technologies in Social Science*. 3(47). doi: 10.31435/ijitss.3(47).2025.3573

1. Introduction

In recent years, there has been a rapid increase in interest in high-protein diets (HPDs), particularly among athletes and recreationally active individuals. Epidemiological data indicate that protein intake ≥ 25-30% of total energy or >2 g/kg of body weight per day has become a standard in fitness and athletic communities [1]. Programs such as "protein pacing" or ketogenic diets rich in protein have gained popularity due to documented benefits in fat mass reduction, increases in lean body mass, and improvements in glycemic control demonstrated in interventional studies [2].

Protein plays a fundamental role in muscle fiber synthesis, post-exercise recovery, and metabolic adaptations. Meta-analyses have shown that intake levels between 1.6-2.2 g/kg/day (sometimes reaching as high as 3.2 g/kg in short-term interventions) significantly enhance strength and muscle mass gains in resistance and endurance-trained individuals [3]. These effects are further amplified by physical activity, leading to improved body composition, enhanced glucose tolerance, and increased insulin sensitivity [3].

Despite these benefits, HPDs may be associated with elevated liver enzyme levels (ALT, AST, GGT). An intervention involving 3.2 g/kg/day of protein intake over 16 weeks in trained males resulted in significant increases in ALT, AST, and GGT, although still within normal laboratory ranges, highlighting the need for regular monitoring [4]. Cross-sectional and crossover studies also suggest that excessive protein intake may stimulate hepatic de novo lipogenesis, leading to increased levels of triglycerides and VLDL [5].

Regarding lipid profiles, some studies report reductions in triglycerides and fat mass with HPDs [4], while others indicate increases in LDL or total cholesterol, especially when diets are high in animal-derived proteins and saturated fats [6].

Young adults (aged 18-30), whether recreationally or professionally active, often use high-protein supplements (e.g., powders, isolates) without professional dietary supervision. This may result in daily intakes exceeding >3 g/kg, posing a risk of nitrogenous metabolite accumulation (urea, creatinine) and potential hepatic or renal strain, even in the absence of underlying chronic kidney disease [4]. Persisting in this practice without regular monitoring of hepatic and lipid parameters represents a significant gap in sports health prevention strategies.

2. High-protein diets – characteristics

A high-protein diet is defined as a dietary pattern in which daily protein intake exceeds the recommended levels for the general adult population, which amount to 0.8 g of protein per kilogram of body weight per day [7]. In the context of individuals engaged in regular physical activity, particularly resistance or endurance training, optimal protein intake ranges from 1.4 to 2.0 g/kg body weight/day [2]. Under conditions of increased metabolic demand, such as negative energy balance or intense resistance training, protein intake as high as 2.3-3.1 g/kg body weight/day has been advocated to preserve lean body mass and support training adaptations [2].

It is recommended that the sources of protein in such diets possess high biological value and contain adequate amounts of essential amino acids, including leucine, a key stimulator of the mTOR signaling pathway, which initiates muscle protein synthesis (MPS) [2]. An effective distribution of protein intake involves consuming regular portions every 3-4 hours, each containing approximately 0.25 g of protein per kilogram of body weight, or 20-40 g of total protein, to maximize the anabolic response [8].

Traditional protein sources in athletes' diets include lean meats (poultry, veal, beef, fish) and eggs. These foods provide a complete profile of essential amino acids: leucine, isoleucine, valine, lysine, methionine, threonine, phenylalanine, tryptophan, and histidine. Branched-chain amino acids (BCAAs) are of particular metabolic significance, especially leucine, which activates the mechanistic target of rapamycin complex 1 (mTORC1) signaling pathway, regulating the rate of muscle protein synthesis and post-exercise metabolic adaptations [7].

A common supplementation strategy among athletes includes protein powders, most often derived from whey and casein (milk-based), as well as soy protein isolate or proteins from peas, rice, and other legumes. Whey protein supplements are highly regarded due to their superior nutritional value and rapid absorption rate. A post-workout dose of 20–25 g of whey protein is sufficient to reach the leucine threshold and maximize MPS [2]. Casein is digested more slowly due to the formation of a gel-like structure in the stomach, which delays amino acid release. Studies have demonstrated that ingesting ~40 g of casein before sleep ensures a sustained supply of amino acids overnight, supporting muscle regeneration and protein synthesis even during sleep [8].

Plant-based protein sources also play an important role in the diets of active athletes, as legumes, seeds, nuts, and pseudocereals provide substantial amounts of high-quality protein, including all essential amino acids. Legumes such as lentils, chickpeas, beans, and soy products (edamame, tofu, tempeh) contain between 17%

and 40% protein by dry weight and are particularly rich in lysine and leucine [9]. Although many plant sources are relatively low in methionine, appropriate combinations with cereal-based foods (e.g., quinoa, oats, whole grains) allow for a complete amino acid profile across the daily energy intake [10].

However, the selection of protein sources in an athlete's diet should consider not only amino acid quality and absorption kinetics but also long-term metabolic effects, particularly with respect to liver function and lipid profile. Current research suggests that insufficient fiber intake in high-protein diets, especially those dominated by animal-derived components, may limit intestinal fermentation and the production of short-chain fatty acids (SCFAs), thereby promoting hepatic lipogenesis and increasing LDL cholesterol concentrations. These changes may contribute to the progression of non-alcoholic fatty liver disease (NAFLD) and elevate the risk of atherosclerosis due to chronic dyslipidemia and low-grade systemic inflammation [11][12]. Conversely, diets rich in plant-derived proteins, even when they constitute a high percentage of total intake, appear to exert hepatoprotective effects and support improvements in lipid parameters, including reductions in LDL cholesterol and triglyceride levels [13].

Insufficient fiber intake in high-protein diets (particularly those of animal origin) may reduce intestinal fermentation and the synthesis of SCFAs, which favors hepatic lipogenesis and elevated LDL-C concentrations [12]. Concurrently, low fiber consumption contributes to intestinal pro-inflammatory states, which may accelerate the progression of NAFLD [11].

Dietary recommendations (WHO, EFSA, ACSM, ISSN)

The World Health Organization (WHO) recommends that saturated fats comprise less than 10% of daily energy intake, and that daily fiber intake in adults exceed 25 g [14]. The European Food Safety Authority (EFSA) has established the population reference intake (PRI) for protein at 0.83 g/kg body weight/day for the general population, while recommending higher intakes for athletes (1.2-2.0 g/kg), depending on exercise intensity [14].

The American College of Sports Medicine (ACSM) and the International Society of Sports Nutrition (ISSN) recommend daily protein intakes of 1.2-2.0 g/kg for athletes. In specific situations, such as strength training or caloric restriction, intakes of ≥3.0 g/kg may be warranted. According to recent studies (e.g., Antonio et al.), such high intakes do not result in adverse hepatic or lipid-related outcomes when energy balance is maintained [15].

3. High protein intake and liver function

3.1. Liver function in amino acid catabolism and nitrogen homeostasis

The liver plays a central role in amino acid catabolism, including transamination, oxidative deamination and ammonia detoxification via the urea cycle. High protein intake increases the availability of amino acids, thereby enhancing transamination reactions and glutamate synthesis. Subsequently, glutamate is deaminated by glutamate dehydrogenase (GDH), producing ammonia, which serves as a substrate for the urea cycle [16]. Additionally, the liver cooperates with skeletal muscles in nitrogen transfer, mainly through the glucose-alanine cycle and glutamine transport. Muscle tissue synthesizes glutamine and alanine, which are then taken up by hepatocytes and converted into substrates for gluconeogenesis and the urea cycle [17].

In the context of a high-protein diet, the activity of urea cycle enzymes such as carbamoyl phosphate synthetase I (CPS1), ornithine transcarbamylase (OTC) and arginase increases adaptively. These changes are regulated by transcription factors including FoxO1, enabling effective detoxification of excess nitrogen without the accumulation of toxic ammonia [18].

In physically active individuals, the catabolism of branched-chain amino acids (BCAAs) primarily occurs in skeletal muscle, reducing the burden on the liver. Nonetheless, hepatic metabolic adaptations, including increased perfusion, enzymatic activity and the expression of genes involved in nitrogen utilization, allow effective maintenance of nitrogen homeostasis despite increased protein intake [19].

3.2. Effects of a high-protein diet on liver enzymes - a review of the evidence

A high-protein diet may cause a moderate increase in the activity of hepatic aminotransferases, especially alanine aminotransferase (ALT) and aspartate aminotransferase (AST). However, in healthy, physically active young individuals, these changes are most often transient and adaptive. Among athletes, mild elevations above reference values are observed, but they typically normalize after cessation of intense training or supplementation, suggesting no lasting hepatocyte damage and the presence of efficient hepatic compensatory mechanisms [20]. Long-term consumption of high levels of protein, even above 2.5 g/kg body weight per day, does not lead to sustained liver dysfunction or pathological elevation of liver enzymes, as confirmed by interventional studies in healthy trained men [3].

The type of protein consumed should also be taken into account. Compared to plant-based protein, animal protein intake may be associated with enhanced pro-inflammatory processes in the liver and increased ALT and AST levels, especially in individuals with a metabolic predisposition to non-alcoholic fatty liver disease (NAFLD). A particularly high intake of amino acids such as methionine, arginine and glycine, typical of meat-rich diets, is associated with exacerbated histopathological changes in the liver and elevated levels of cytolytic enzymes including ALT and AST, which are released into the bloodstream as a result of hepatocyte membrane injury [14].

When interpreting elevated ALT and AST levels in athletes, physical exercise itself must be considered as an independent confounding factor. Intensive resistance or endurance training alone can cause elevations in these enzymes, regardless of protein intake, due to release from damaged muscle cells rather than hepatocytes. Therefore, ALT and AST activity in this population is not liver-specific but may reflect a physiological response to muscle microtrauma and metabolic stress [21]. Moreover, cross-sectional studies indicate that the use of high-protein supplements, often containing creatine and branched-chain amino acids, may lead to a mild increase in liver stress markers, though without evidence of structural damage. These changes are interpreted as temporary metabolic adaptations to the increased protein and training load, without signs of hepatotoxicity. Even after adjustment for variables such as age, body weight and lifestyle, supplement users exhibited significantly higher AST and urea levels compared to non-users, suggesting a synergistic effect of intensive training and protein excess on laboratory indicators [19].

4. The impact of a high-protein diet on the lipid profile, with particular emphasis on the group of athletes

Protein, a fundamental macronutrient, is essential for both the preservation and development of muscle mass, as well as for the regulation of metabolic processes, including lipid metabolism. Alterations in dietary protein proportions can markedly influence the lipid profile in both healthy persons and those with metabolic disorders. In athletes, distinguished by heightened energy demands and a distinct metabolic profile relative to the general population, the implications of high-protein diets may hold significant clinical relevance.

Current research indicates that dietary protein content may influence levels of HDL cholesterol (HDL-C), LDL cholesterol (LDL-C), triglycerides (TG), and total cholesterol (TC), contingent upon energy intake, the intensity and type of physical activity, as well as the sources of protein and associated macronutrients, particularly fats and carbohydrates.

Elevated dietary protein influences lipid metabolism via three primary processes. Under conditions of limited carbohydrate consumption, elevated protein intake may facilitate fat metabolism as a substitute energy source. This results in diminished adipose reserves and decreased plasma triglyceride levels. Moreover, a high-protein diet restricts the conversion of surplus carbohydrates into fatty acids, potentially decreasing triglyceride and VLDL levels. Moreover, protein, especially its origin (e.g., plant versus animal), may influence LDL receptor expression and cholesterol reabsorption. Protein promotes insulin release, which may limit lipolysis; but, in the context of a low-carbohydrate diet, insulin levels stay low, facilitating effective fat oxidation.

A high-protein diet may positively influence some lipid profile metrics, particularly triglyceride levels and, in some instances, the HDL fraction. The impact on TC and LDL-C is varied and contingent upon factors like the protein source, the proportion of other macronutrients in the diet, and the length of the intervention. Clifton's investigation suggests that a high-protein diet may enhance the lipid profile by lowering triglyceride levels and elevating HDL-C, however it is advisable to concurrently monitor fat quality and LDL parameters [22].

A 2021 systematic review indicates that higher-protein diets exhibit a modest nevertheless advantageous impact on weight loss, fat mass reduction, systolic blood pressure, and certain lipid and insulin parameters, in comparison to lower-protein diets [23]. A total of 41 studies with 2303 participants submitted data on total cholesterol, 42 trials with 2452 participants on HDL-C, 42 trials with 2516 participants on LDL-C, and 43 trials comprising 2530 participants on TG. A meta-analysis revealed a decrease in total cholesterol with high-protein diets compared to low-protein diets. No notable variations in HDL-C or LDL-C levels were detected between the diets. A notable decrease in TG was observed with high-protein meals compared to low-protein diets. A clinical analysis revealed a more significant decrease in TC of 0.08 mmol/l (3.09 mg/dl) and a more pronounced reduction in TG of 0.12 mmol/l (10.63mg/dl) with high-protein meals compared to low-protein diets. Marked intervention effects on TC were noted in persons aged 50 years or older when the study length was less than 12 weeks. The intervention effects on TG were significant in female participants when the trial period was less than 12 weeks or between 12 and 24 weeks, but not when it exceeded 24 weeks.

Recent research suggest that the specific kind of dietary protein is notably significant [24]. A recent meta-analysis published in 2025, encompassing 20 randomized controlled trials involving 1638 participants, demonstrated that whey protein supplementation led to a substantial reduction in TG of 0.14 mmol/l (12.2 mg/dl) and an elevation in HDL-C of 0.07 mmol/l (2.6 mg/dl), with no significant alterations in LDL-C and TC.

A 2025 meta-analysis by Yao et al. demonstrated that a plant protein-based diet resulted in reductions in TC of 0.12 mmol/l (4.64 mg/dl), TG of 0.05 mmol/l (4.43 mg/dl), and LDL-C of 0.11 mmol/l (4.25 mg/dl), alongside a rise in HDL-C of 0.03 mmol/l (1.16 mg/dl), when compared to an animal protein-based diet [25]. The efficacy of high-protein diets was observed to improve when formulated as high-carbohydrate, low-fat.

Animal protein, present in red meat, dairy products, and eggs, is frequently consumed alongside saturated fat and dietary cholesterol. A substantial cross-sectional study conducted in China revealed that a diet rich in animal proteins correlated with a less advantageous lipid profile compared to a plant-based diet. The molecular foundation for this phenomena encompasses variations in amino acid composition: animal proteins are abundant in methionine and lysine, which may induce hypercholesterolemia, whereas plant proteins are higher in arginine, an amino acid with lipid-lowering properties.

Elevated protein consumption in an athlete's diet influences lipid homeostasis, contingent upon the composition of other macronutrients and the type of physical activity undertaken. The dietary composition of macronutrients greatly influences the body's metabolic response. A high-protein, low-carbohydrate diet, commonly adopted by athletes in bodybuilding or strength training, may result in elevated TC and LDL-C levels, particularly when coupled by a higher intake of saturated fats. Consequently, high-protein, isocaloric diets derived from plant sources, coupled with a modest consumption of complex carbohydrates, may diminish LDL-C levels and enhance HDL metabolism [26].

Secondly, the nature of physical activity significantly influences the lipid response to a high-protein diet. Endurance exercise decreases TG levels and enhances the HDL profile, irrespective of protein consumption. In strength-training athletes, a neutral or even detrimental impact of a high-protein diet on the lipid profile is occasionally noted, particularly with excessive consumption of animal fats [3].

Ultimately, the athlete's unique metabolic traits (age, body fat, insulin resistance, genetic polymorphisms) may influence the metabolic impact of a high-protein diet. A high-protein diet may positively influence certain lipid markers, particularly TG and HDL-C, while its effects on TC and LDL-C remain ambiguous. The quality and origin of protein, along with the overall dietary context, are essential. Additional long-term studies are required to definitively evaluate the safety and efficacy of this nutritional paradigm for cardiovascular risk in both the general population and athletes.

5. Review of studies on high protein diet in young athletes

A 2022 study by Liu et al. [27] investigates the effects of high-protein meal intake on athletes' physical performance, specifically on metabolism, endurance, and recovery. The research focused on the observational analysis of physical performance in athletes engaged in rigorous training. The study focused on maintaining protein balance, water, and electrolyte levels, which constituted around 71% of their overall dietary requirements. The authors propose that high-protein diets can enhance strength, endurance, and recovery in athletes, especially during rigorous training. Table 1 encapsulates the key elements of the investigation.

A study conducted by Witard et al. [28], published in 2025, examines the significance of protein in the dietary regimen of endurance athletes. The authors examine the impact of sufficient protein consumption on recovery, training adaptation, and the preservation of muscle mass. The discussion encompasses daily protein requirements, the significance of consumption timing (e.g., post-training), protein-carbohydrate interactions, and the necessity for additional research in women. The article offers pragmatic suggestions for ideal protein consumption across diverse training contexts. Table 2 presents a concise overview of the key elements of this investigation. Table 3 delineates our comparative analysis of the aforementioned studies.

Table 1. Summary of Dietary Intake Study in Young Basketball Players – 2022

Parameter	Description / Value
Number of subjects	30 young male basketball players
Study duration	5 days
Data collection method	Weighing method (raw weight, cooked weight, and leftovers)
Diet type	Daily diet of athletes; detailed classification and nutrient content analysis
Software used	Nutritional value analysis software
Energy contribution ratio	
– Carbohydrates	48.6% (recommended: 50%–55%)
– Fats	28% (recommended: 30%–35%)
– Proteins	**23.4%** (recommended: 12%–15%) → ***High-protein diet***
Carbohydrate-to-fat energy ratio	Lower than recommended
Meal-based energy distribution	
– Breakfast	20%
– Lunch	38%
– Dinner	42%

Table 2. Protein Requirements in Endurance Athletes – IAAO-Based Studies – 2025

Parameter	Description / Result
Number of subjects	Endurance-trained male athletes (exact number not specified)
Diet type / conditions	Habitual diet vs. low carbohydrate (CHO) availability
Research method	IAAO (Indicator Amino Acid Oxidation) technique
Training day	20-km treadmill run
Protein requirement	1.83 g·kg body mass⁻¹·day⁻¹
Training day – low CHO availability	10-km treadmill run under low carbohydrate conditions
Protein requirement (low CHO)	1.95 g·kg body mass⁻¹·day⁻¹
RDA for non-active adults	0.8 g·kg body mass⁻¹·day⁻¹ (i.e., 2.3 times lower than the athletes' training-day requirement)
Habitual protein intake in endurance athletes	~1.5 g·kg body mass⁻¹·day⁻¹
Conclusions	Endurance exercise significantly increases protein needs due to BCAA oxidation and muscle remodeling. Protein requirements rise further under low carbohydrate availability.

Table 3. Comparison: Young Basketball Players vs. Endurance Athletes – own compilation

Category	Young Basketball Players	Endurance Athletes
Type of activity	Strength-speed discipline with endurance elements	Pure endurance effort (e.g., 20-km treadmill run)
Number of participants	30	Not specified; trained males
Study method	Weighed food intake and nutritional software analysis	IAAO (Indicator Amino Acid Oxidation) technique
Protein in diet (%)	23.4% of total energy from protein	Quantitatively: 1.83–1.95 g·kg body mass⁻¹·day⁻¹
Observed vs. recommended intake	Protein well above recommended range (12–15%) → **high-protein diet**	Protein needs exceed both RDA and habitual intakes in endurance athletes
Dominant energy source	High protein, moderate carbs (48.6%), fat 28%	Increased protein demand due to BCAA oxidation and muscle remodeling
Special conditions studied	Normal habitual diet	Also studied under **low carbohydrate (CHO) availability**
Local study conclusions	High protein intake may exceed actual needs	Athletes often need more protein than they consume, especially with low CHO

6. Discussion and conclusion

Based on the review of current literature, it can be concluded that in healthy, physically active young adults, consumption of a high-protein diet (HPD), even at intake levels of up to ~3.3 g/kg of body weight per day over several months, rarely causes clinically significant liver dysfunction. In most crossover studies conducted on resistance-trained individuals, no significant changes were observed in liver enzymes such as ALT, AST, or GGT, even with protein intake exceeding 3 g/kg/day [3] [29]

In some intervention studies combining HPD with intensive resistance training (e.g., 16 weeks, ~3.2 g/kg/day), transient, non-pathological elevations in liver enzyme levels have been reported, most likely reflecting a physiological metabolic adaptation rather than hepatocellular injury [4]. Moreover, exercise modalities such as aerobic and resistance training have been shown to reduce hepatic fat content and liver enzymes in patients with non-alcoholic fatty liver disease (NAFLD), underscoring the protective role of physical activity on liver health [30].

The impact of HPD on the lipid profile and metabolic markers is highly dependent on the quality and source of dietary proteins and accompanying fats. Meta-analyses show that replacing animal-based proteins with plant-based sources can lead to significant improvements in lipid parameters -namely reductions in LDL-C and triglycerides, as well as increases in HDL-C [26][31]. Conversely, diets high in red meat and saturated fats may be associated with poorer metabolic outcomes and increased risk of NAFLD.

However, most existing studies are short-term (≤16 weeks), with relatively small sample sizes and limited analysis of inflammatory biomarkers (e.g., CRP, IL-6), insulin resistance, or long-term metabolic syndrome risk. Prospective cohort data further suggest that long-term consumption patterns of protein sources are linked to the incidence of metabolic syndrome in general populations [32]. Thus, well-designed randomized controlled trials (RCTs) are needed to assess the safety and metabolic effects of long-term HPD in combination with exercise in healthy young populations.

From a practical standpoint, regular monitoring of biochemical parameters (e.g., ALT, AST, GGT, creatinine, urea, inflammatory markers) is recommended for individuals adhering to prolonged HPD, especially when combined with high training loads and protein supplementation. This approach enables early identification of potentially adverse effects and distinguishes between physiological adaptations and pathological responses, particularly at protein intakes exceeding 3 g/kg/day [3].

In conclusion, high-protein diets can be metabolically safe in young, active adults, provided that protein sources are of high quality (preferably plant-based or lean animal proteins), and that regular biochemical monitoring is implemented. Further research is necessary to develop targeted guidelines and optimize nutritional strategies for athletic performance and prevention of metabolic disorders.

Disclosure

Author's contribution: Aleksandra Sowa, Kacper Trząsalski, Conceptualisation: Patrycja Jędrzejewska-Rzezak, Katarzyna Oświeczyńska; Methodology: Sebastian Kupisiak, Katarzyna Oświeczyńska; Software: Patrycja Jędrzejewska-Rzezak, Sebastian Kupisiak; Check: Katarzyna Oświeczyńska; Formal: Patrycja Jędrzejewska-Rzezak; Investigation: Aleksandra Sowa; Resources: Kacper Trząsalski, Patrycja Jędrzejewska-Rzezak; Data curation: Katarzyna Oświeczyńska, Patrycja Jędrzejewska-Rzezak; Writing-Rough Preparation: Aleksandra Sowa, Kacper Trząsalski; Writing-Review and Editing: Sebastian Kupisiak, Aleksandra Sowa; Visualisation: Kacper Trząsalski, Sebastian Kupisiak; Supervision: Sebastian Kupisiak, Aleksandra Sowa; Project Administration: Kacper Trząsalski, Katarzyna Oświeczyńska

All authors have read and agreed with the published version of the manuscript. Funding statement: The study did not receive special funding. Institutional review board statement: Not applicable. Informed consent statement: Not applicable. Data availability statement: Not applicable. Conflict of interest: The authors declare no conflict of interest

In preparing this work, the authors used ChatGPT (chatGPT.com) as a tool for translation, improving language and readability. After using the tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

REFERENCES

1. Carbone JW, Phillips SM, Weaver CM, Hughes JM, Pasiakos SM. Exploring Opportunities to Better Characterize the Effects of Dietary Protein on Health across the Lifespan. Advances in Nutrition 2025;16:100347. https://doi.org/10.1016/j.advnut.2024.100347.
2. Jäger R, Kerksick CM, Campbell BI, Cribb PJ, Wells SD, Skwiat TM, et al. International Society of Sports Nutrition Position Stand: protein and exercise. J Int Soc Sports Nutr 2017;14. https://doi.org/10.1186/s12970-017-0177-8.
3. Antonio J, Ellerbroek A, Silver T, Vargas L, Tamayo A, Buehn R, et al. A High Protein Diet Has No Harmful Effects: A One-Year Crossover Study in Resistance-Trained Males. J Nutr Metab 2016;2016:1–5. https://doi.org/10.1155/2016/9104792.
4. Bagheri R, Kargarfard M, Sadeghi R, Scott D, Camera DM. Effects of 16 weeks of two different high-protein diets with either resistance or concurrent training on body composition, muscular strength and performance, and markers of liver and kidney function in resistance-trained males. J Int Soc Sports Nutr 2023;20. https://doi.org/10.1080/15502783.2023.2236053.
5. Charidemou E, Ashmore T, Li X, McNally BD, West JA, Liggi S, et al. A randomized 3-way crossover study indicates that high-protein feeding induces de novo lipogenesis in healthy humans. JCI Insight 2019;4. https://doi.org/10.1172/jci.insight.124819.
6. Pasiakos SM, Cao JJ, Margolis LM, Sauter ER, Whigham LD, McClung JP, et al. Effects of high-protein diets on fat-free mass and muscle protein synthesis following weight loss: a randomized controlled trial. The FASEB Journal 2013;27:3837–47. https://doi.org/10.1096/fj.13-230227.
7. Weiler M, Hertzler SR, Dvoretskiy S. Is It Time to Reconsider the U.S. Recommendations for Dietary Protein and Amino Acid Intake? Nutrients 2023;15:838. https://doi.org/10.3390/nu15040838.
8. Kim J. Pre-sleep casein protein ingestion: new paradigm in post-exercise recovery nutrition. Phys Act Nutr 2020;24:6–10. https://doi.org/10.20463/pan.2020.0009.
9. Rehman SU, Ali R, Zhang H, Zafar MH, Wang M. Research progress in the role and mechanism of Leucine in regulating animal growth and development. Front Physiol 2023;14. https://doi.org/10.3389/fphys.2023.1252089.
10. Smith JW, Holmes ME, McAllister MJ. Erratum to "Nutritional Considerations for Performance in Young Athletes." Journal of Sports Medicine 2017;2017:1–1. https://doi.org/10.1155/2017/6904048.
11. 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;15:3511. https://doi.org/10.3390/nu15163511.
12. Nikparast A, Sohouli MH, Forouzan K, Farani MA, Dehghan P, Rohani P, et al. The association between total, animal, and plant protein intake and metabolic dysfunction-associated fatty liver disease in overweight and obese children and adolescents. Nutr J 2025;24:75. https://doi.org/10.1186/s12937-025-01142-4.
13. Luna F, Rossi EV, Arrieta EM. Nutritional considerations for vegetarian athletes: A narrative review. Human Nutrition & Metabolism 2024;37:200267. https://doi.org/10.1016/j.hnm.2024.200267.
14. Khazaei Y, Dehghanseresht N, Ebrahimi Mousavi S, Nazari M, Salamat S, Asbaghi O, et al. Association Between Protein Intake From Different Animal and Plant Origins and the Risk of Non-Alcoholic Fatty Liver Disease: A Case-Control Study. Clin Nutr Res 2023;12:29. https://doi.org/10.7762/cnr.2023.12.1.29.
15. Shariq A, Khan S, Usmani SUR. The Role of Dietary Protein in Mitigating the Risk of Nonalcoholic Fatty Liver Disease. Nutr Rev 2025;83:1537–9. https://doi.org/10.1093/nutrit/nuae229.
16. Paulusma CC, Lamers WH, Broer S, van de Graaf SFJ. Amino acid metabolism, transport and signalling in the liver revisited. Biochem Pharmacol 2022;201:115074. https://doi.org/10.1016/j.bcp.2022.115074.
17. Holeček M. Origin and Roles of Alanine and Glutamine in Gluconeogenesis in the Liver, Kidneys, and Small Intestine under Physiological and Pathological Conditions. Int J Mol Sci 2024;25:7037. https://doi.org/10.3390/ijms25137037.
18. Karkoutly S, Takeuchi Y, Mehrazad Saber Z, Ye C, Tao D, Aita Y, et al. FoxO transcription factors regulate urea cycle through Ass1. Biochem Biophys Res Commun 2024;739:150594. https://doi.org/10.1016/j.bbrc.2024.150594.
19. Schlickmann DS, Molz P, Brand C, dos Santos C, da Silva TG, Rieger A, et al. Liver and kidney function markers among gym users: the role of dietary supplement usage. British Journal of Nutrition 2022;128:704–11. https://doi.org/10.1017/S0007114521003652.
20. Čano Dedić L, Pašalić A, Šegalo S, Serdarević N, Vefić A. EFFECTS OF PROTEIN SUPPLEMENTS ON LIVER ENZYMES LEVELS IN ATHLETES. vol. 55. n.d.
21. Pettersson J, Hindorf U, Persson P, Bengtsson T, Malmqvist U, Werkström V, et al. Muscular exercise can cause highly pathological liver function tests in healthy men. Br J Clin Pharmacol 2008;65:253–9. https://doi.org/10.1111/j.1365-2125.2007.03001.x.
22. Clifton P. Effects of a high protein diet on body weight and comorbidities associated with obesity. British Journal of Nutrition 2012;108:S122–9. https://doi.org/10.1017/S0007114512002322.
23. Vogtschmidt YD, Raben A, Faber I, de Wilde C, Lovegrove JA, Givens DI, et al. Is protein the forgotten ingredient: Effects of higher compared to lower protein diets on cardiometabolic risk factors. A systematic review and meta-

analysis of randomised controlled trials. Atherosclerosis 2021;328:124–35. https://doi.org/10.1016/j.atherosclerosis.2021.05.011.
24. Gataa IS, Abdullah Z, González Cabrera MV, S R, Verma S, Arora I, et al. Impact of whey protein on lipid profiles: A systematic review and meta-analysis. Nutrition, Metabolism and Cardiovascular Diseases 2025;35:103858. https://doi.org/10.1016/j.numecd.2025.103858.
25. Yao Y, Huang V, Seah V, Kim JE. Impact of Quantity and Type of Dietary Protein on Cardiovascular Disease Risk Factors Using Standard and Network Meta-analyses of Randomized Controlled Trials. Nutr Rev 2025;83:e814–28. https://doi.org/10.1093/nutrit/nuae086.
26. Li SS, Blanco Mejia S, Lytvyn L, Stewart SE, Viguiliouk E, Ha V, et al. Effect of Plant Protein on Blood Lipids: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. J Am Heart Assoc 2017;6. https://doi.org/10.1161/JAHA.117.006659.
27. Liu S, Wen N, Su H. Influence of High-Protein Food on Physical Function of Athletes. J Food Qual 2022;2022:1–8. https://doi.org/10.1155/2022/4447061.
28. Witard OC, Hearris M, Morgan PT. Protein Nutrition for Endurance Athletes: A Metabolic Focus on Promoting Recovery and Training Adaptation. Sports Medicine 2025;55:1361–76. https://doi.org/10.1007/s40279-025-02203-8.
29. Antonio J, Ellerbroek A, Silver T, Vargas L, Peacock C. The effects of a high protein diet on indices of health and body composition – a crossover trial in resistance-trained men. J Int Soc Sports Nutr 2016;13. https://doi.org/10.1186/s12970-016-0114-2.
30. Bacchi E, Negri C, Targher G, Faccioli N, Lanza M, Zoppini G, et al. Both resistance training and aerobic training reduce hepatic fat content in type 2 diabetic subjects with nonalcoholic fatty liver disease (the RAED2 randomized trial). Hepatology 2013;58:1287–95. https://doi.org/10.1002/hep.26393.
31. Naghshi S, Sadeghi O, Willett WC, Esmaillzadeh A. Dietary intake of total, animal, and plant proteins and risk of all cause, cardiovascular, and cancer mortality: systematic review and dose-response meta-analysis of prospective cohort studies. BMJ 2020:m2412. https://doi.org/10.1136/bmj.m2412.
32. Hajihashemi P, Hassannejad R, Haghighatdoost F, Mohammadifard N, Sadeghi M, Roohafza H, et al. The long-term association of different dietary protein sources with metabolic syndrome. Sci Rep 2021;11:19394. https://doi.org/10.1038/s41598-021-98688-0.