

Nutrition and Bone Formation: Foundations for Athletic Development at Eide Ormani Arenado Pinar Del Río: A Systematic Literature Review

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Abstract

This systematic review critically examines the English-language literature on nutrition-bone formation relationships in athletic populations to establish evidence-based foundations for interventions at Cuba's EIDE Ormani Arenado Llonch (Basic Sports Formation School) in Pinar del Río. Low energy availability triggers hormonal disruptions compromising bone integrity, yet bone recovery following energy restoration may be incomplete. While calcium and carbohydrate supplementation modulate acute bone biomarker responses to exercise, the clinical significance of these acute changes for long-term bone health remains unclear. Olympic nutrition programs demonstrate the value of rational nutrition and educational interventions, though most evidence derives from observational reports. Sports supplements present a complex picture: omega-3 and collagen offer benefits, while glutamine and arginine lack evidence, and widespread contamination with prohibited substances poses serious health risks. Cuba faces import dependence, agricultural limitations, and restricted supplement access due to the blockade, yet grassroots initiatives like Zuca Saludable and institutional coordination models demonstrate local innovation potential. International precedents from Indonesia suggest locally sourced recovery drinks effectively support post-exercise recovery in resource-limited settings. Cuban research confirms strong demand for national sports supplements. Evidence supports prioritizing adequate energy availability and food-based interventions over commercial supplements. Recommendations for EIDE Ormani Arenado include systematic nutritional assessment, strategic supplementation based on deficiencies, development of locally sourced recovery foods, horticultural projects for fresh produce and nutrition education, and systematic bone health monitoring. Future research should investigate Cuban athletic bone health outcomes, evaluate local recovery food efficacy, and assess integrated nutritional-educational interventions. This review provides a critical foundation for nutritional interventions accounting for Cuba's resource context while optimizing bone formation and athletic performance. A key caveat is that the acute biomarker changes discussed may not translate directly into clinically significant long-term bone health outcomes, and this limitation should be considered when interpreting the evidence presented.

Keywords: Bone Formation; Sports Nutrition; Energy Availability; Cuban Athletes; Supplements

Introduction

Bone health represents a critical determinant of athletic performance and injury prevention, particularly during the developmental years when peak bone mass is established. For young athletes at sports initiation schools such as the EIDE Ormani Arenado Llonch in Pinar del Río, understanding the relationship between nutrition and bone formation is essential for optimizing performance and long-term skeletal health. The skeletal system requires a constant supply of macro- and micronutrients, including protein, calcium, phosphorus, magnesium, vitamin D, zinc, iron, and vitamins A, C, K, and B-complex [1]. This systematic review critically examines English-language literature on the nutrition-bone formation relationship, identifying both validated approaches and knowledge gaps, with the objective of establishing evidence-based foundations for nutritional interventions at the EIDE Ormani Arenado Llonch.

The energy availability-bone health paradigm: Evidence and controversies

The concept of energy availability (EA)—defined as dietary energy intake minus exercise energy expenditure normalized to fat-free mass—has become central to understanding bone health in athletes. When EA drops below 30 kcal/kgLBM/day, a state of Low Energy Availability (LEA) ensues, triggering a cascade of hormonal adaptations that compromise bone integrity. The International Olympic Committee formally recognized Relative Energy Deficiency in Sport (RED-S) in 2014 as an expansion of the Female Athlete Triad concept, acknowledging that multiple body systems are affected by LEA and that male athletes are also vulnerable [7].

A landmark systematic review examining interventions for RED-S found that increasing energy intake enabled the return of menses in female athletes, yet paradoxically did not significantly increase bone mineral density [2]. This finding reveals a critical limitation in current understanding: while restoring energy availability corrects some physiological parameters, bone tissue recovery appears to lag behind or may be incomplete. The review also demonstrated that nutrition education interventions improved bone health, energy availability, and eating behaviors in athletes, suggesting that knowledge translation may be as important as dietary modification itself [2].

Norwegian research on male Olympic-level athletes found that 16% presented with low bone mineral density (z-score < -1), and crucially, these individuals all had normal resting metabolic rate [8]. This finding challenges the assumption that bone health problems in male athletes are always accompanied by measurable metabolic suppression, suggesting that bone tissue may be more sensitive to subtle energy deficits than previously recognized. Among the same cohort, 25% presented with subclinical low testosterone levels and 23% with elevated cortisol, further implicating hormonal disruption as a key mechanism linking energy status to bone health [8].

A systematic review with meta-analysis synthesized evidence on nutritional modulation of bone biomarkers P1NP (formation) and CTX-1 (resorption) in response to acute exercise [1]. The analysis included 22 articles and found that calcium intake—whether via supplements, diet, or infusion—reduced exercise-induced increases in CTX-1, with a substantial effect size of -1.1 [1]. Notably, the largest effects were observed when calcium was delivered via direct infusion rather than through foods or supplements, raising questions about bioavailability and absorption kinetics that remain unresolved. The review also found that carbohydrate supplementation may support bone during acute exercise by reducing CTX-1 increases, while a low-carbohydrate/high-fat diet appeared to exert the opposite effect: increased CTX-1 response and reduced P1NP response [1]. This suggests that popular low-carbohydrate dietary approaches among athletes may inadvertently compromise bone health.

A critical limitation identified across studies is substantial heterogeneity in design and intervention characteristics. The authors concluded that direct and indirect replication is required to confirm key findings and generate better estimates of true effect sizes [1]. This represents a significant gap in the evidence base: while directional effects are reasonably established, precise quantification of nutritional interventions on bone outcomes remains elusive.

Nutritional interventions in elite Olympic athletes: Successes and limitations

The application of sports nutrition principles to Olympic athletes has provided valuable insights, though not without controversies and unresolved questions. The English Institute of Sport and British Athletics have implemented periodized nutrition strategies with approximately 68 world-class program athletes, about 25% of whom were Olympic or World Championship medalists [4]. These interventions have focused on increasing carbohydrate ingestion during specific training sessions and promoting carbohydrate and protein ingestion during recovery from hard training. However, critical evaluation reveals that much of this evidence derives from observational or case-based reports rather than controlled trials, and the specific contribution of nutrition interventions to performance outcomes remains difficult to isolate from other training variables.

High Performance Sport New Zealand revised nutrition protocols based on research findings, developing educational messages for coaches and athletes around LEA. In an intervention with elite female rowers, the majority had EA below 30 kcal/kgLBM/d before education; post-education, the majority improved above this threshold, supporting bone health [5]. This demonstrates the potential of educational interventions in resource-constrained settings, though the long-term sustainability of such improvements remains unexamined.

The Canadian Sport Institute Pacific applied these principles to approximately 150 athletes with LEA or stress fracture injuries affecting Olympic preparations. Since 2014, practitioners have used research evidence to demonstrate the negative impacts of LEA to coaches and athletes, aiming to change culture and prolong careers [5]. The Irish Institute of Sport adapted nutritional timing strategies, finding more consistent training and less time lost, allowing better body composition adaptations without the side effects of bone injuries [5]. These cases illustrate that evidence translation, not merely evidence generation, represents a significant challenge in sports nutrition.

The case of Japanese figure skating Olympic gold medalists Riku Miura and Ryuichi Kihara illustrates personalized sports nutrition in practice. Sports nutritionist Hideko Nishiyama found Kihara deficient in calcium, protein, and vitamin D, with low carbohydrate intake to manage weight. She advised that carbohydrates were essential for recovery after training and urged increased rice consumption. Miura, who had been eating too little, especially at breakfast, was advised to have fuller breakfasts and lunches with a lighter dinner [6]. Since support began, Miura reported not having fallen ill once throughout the season. While compelling as a case report, such evidence is anecdotal and cannot be generalized without controlled investigation.

A critical gap in the Olympic nutrition literature is the lack of long-term follow-up data on bone health outcomes. Most interventions report on performance metrics or return-to-play timelines, but the persistence of bone benefits into retirement—when former athletes face increased osteoporosis risk—remains inadequately documented.

The exercise-nutrition interaction for bone health

While this review focuses primarily on nutritional interventions, it is essential to acknowledge that bone formation and maintenance result from the synergistic interaction between nutrition and mechanical loading. Bone tissue adapts to the mechanical demands placed upon it through the process of mechanotransduction, by which osteocytes sense and respond to strain, directing osteoblast activity toward bone formation at sites of stress [14]. Weight-bearing exercise, resistance training, and high-impact activities generate the mechanical stimuli necessary for bone modeling and remodeling, while nutritional factors provide the substrate and regulatory signals that enable this adaptive response [15].

In adolescent athletes, the interaction between exercise and nutrition is particularly critical. The pubertal years represent a window of opportunity for bone mineral deposition, during which mechanical loading can significantly influence peak bone mass attainment. Calcium and vitamin D status modulate the osteogenic response to exercise, with inadequate intake potentially blunting the skeletal benefits of training [15]. Conversely, excessive training without adequate energy availability creates a catabolic state that may override

the osteogenic effects of mechanical loading [7]. This bidirectional interaction underscores the importance of integrated approaches that address both training load and nutritional support.

For the EIDE Ormani Arenado context, where access to commercial sports nutrition products is limited, optimizing the exercise-nutrition synergy through appropriate training programming combined with food-based nutritional support may be particularly important. The identification of Cuban foods that can support the bone response to mechanical loading represents a priority for future research. Studies investigating the interaction between specific training modalities and locally available nutritional interventions could provide evidence-based recommendations that are both contextually relevant and practically feasible.

Sports supplements for bone and musculoskeletal health: Evidence and risks

The market for sports supplements has grown dramatically, yet evidence for many products remains equivocal, and safety concerns are substantial. A comprehensive review of nutraceuticals for athletes identifies omega-3 fatty acids, gelatin/collagen, probiotics, and anti-inflammatory compounds such as curcumin and tart cherry juice as potential supports for cellular and tissue resilience [11]. Gelatin/collagen supplements present minimal adverse effects and serve as an economical source of amino acids, with potential benefits that may outweigh risks. However, the review notes that the impact of anti-inflammatory agents on future performance or accelerated recovery of elite athletes remains uncertain, and beta-hydroxy beta-methylbutyrate (HMB) currently lacks a definitive recommendation, requiring further research [11].

A critical review of specific supplements reveals a pattern of overstated claims and limited evidence. Caffeine (3 - 6 mg/kg body weight) has robust evidence for performance enhancement through adenosine receptor antagonism, enhanced mood, reduced pain perception, and increased attention, with mechanisms including enhanced sodium/potassium pump activity and greater calcium release from the sarcoplasmic reticulum [12]. However, its effects on bone health specifically have not been established, and caffeine's diuretic effect may potentially increase calcium excretion.

L-carnitine supplementation, despite theoretical rationale for enhancing lipid metabolism, has yielded disappointing results. One study showed 24 weeks of L-carnitine supplementation increased total muscle carnitine, enhanced lipid utilization, and elicited an 11% improvement in cycling work output. However, the majority of research findings suggest it does not significantly alter total muscle carnitine content, enhance lipid metabolism, or improve exercise performance [12].

Glutamine supplementation, once thought to stimulate protein synthesis and enhance muscular performance, now lacks sufficient scientific evidence for increasing lean body mass or muscular performance [12]. Similarly, arginine supplementation for nitric oxide-mediated vasodilation and enhanced blood flow has not demonstrated consistent ergogenic effects [12].

A concerning development is the widespread contamination of nutritional supplements with prohibited substances. A joint alert from Spanish medical and anti-doping organizations (June 2025) warns that many supplements of high sale and easy access are fraudulently contaminated with anabolic steroids or stimulants not indicated on labels [9]. Contamination affects all supplement categories, often with six or more prohibited substances per product, reaching up to 18 contaminants detected in some products [9]. These contaminants pose risks to liver and kidney function, and when anabolics and stimulants are added, dangers extend to cardiovascular, metabolic, endocrine, and reproductive systems. Critically, the organizations emphasize that most supplements lack demonstrated utility for performance improvement or recovery and should only be used when prescribed by qualified health professionals [9].

In Cuba, the nutritional supplements market faces specific constraints. Market analysis indicates a lack of availability of a wide range of high-quality nutrition supplements in the Cuban market, with limited distribution channels hindering accessibility to a wider consumer base [13]. This scarcity, imposed partly by the US blockade affecting sports academies and limiting access to credits and foreign investment [9], creates a paradoxical situation: Cuban athletes face both the risks associated with uncontrolled supplement use and the challenge of insufficient access to safe, tested products.

Alternative nutrition strategies in developing countries: The Cuban context

Cuba's agricultural and economic challenges have created a context where conventional sports nutrition approaches based on commercial supplements are often impractical. The country imports approximately 80% of food for domestic consumption, and the agricultural sector receives only 3.1% of investments [9]. Obstacles include technological obsolescence, fuel and fertilizer shortages, low yields, poor soil management, and significant harvest losses due to inadequate transportation and refrigeration. The US blockade directly impacts sports academies in Matanzas, affecting basic nutrition and limiting supplement availability [9].

Despite these constraints, grassroots initiatives are emerging. The Zuca Saludable project in Havana produces granola, muffins, energy and protein bars, and lentil bread without preservatives, colorants, or added sugars, using 100% natural products. These products favor inclusive eating, with consumption opportunities for diabetic and celiac individuals, although primary clients are athletes and fitness enthusiasts [10]. However, following a healthy diet in Cuba remains complex, combining variables such as prices, access to a varied diet, and culture around nutrition. The project's founder notes that accessing food is expensive in itself, and price differences between healthy and non-healthy foods exist worldwide [10].

International precedents offer promising models for resource-limited settings. A study in Indonesia developed a homemade recovery drink (HRD) formulated from low-fat milk, pisang raja banana, cocoa powder, and gulo puan (a traditional South Sumatran sweet made from sugar and buffalo milk). The HRD group showed significantly higher post-recovery blood glucose levels compared to placebo, and heart rate returned closer to baseline, demonstrating that culturally relevant, locally sourced ingredients can effectively support post-exercise recovery [12]. Researchers note that most recovery drink research focuses on commercial formulations like whey shakes or protein bars, which may not be accessible or culturally suitable for athletes in low-resource settings [12].

Cuban researchers have conducted diagnostic studies on nutritional supplement needs of high-performance athletes. A survey of athletes from prioritized sports, coaches, physicians, and INDER executives found that 93.3% of respondents considered proteins the most important constituent, followed by carbohydrates (66.7%) and amino acids (56.7%), while 96.7% considered the main contribution to be increased energy potential and 90.0% considered increased muscle mass [10]. Significant variability was observed in knowledge related to safety, production, quality, and national production of nutritional supplements. The study concluded that there is a positive criterion on the need to use nutritional resources in sport and demonstrated the need to implement national production of sports supplements to respond to Cuban athletes' needs and, through commercialization, generate foreign currency income [10].

The coordination model demonstrated at EIDE Luis Augusto Turcios Lima in Matanzas, where local state enterprises partner to ensure positive nutritional balance [3], provides a relevant precedent for Pinar del Río. Community-based sports projects such as Grandes Alamedas in Artemisa demonstrate potential for community engagement in sports facility development with agricultural components [3]. Rural primary schools in San Luis municipality have implemented socio-productive projects involving students in productive activities, demonstrating the adaptability of such models to educational contexts [3].

Critical gaps and future research directions

This systematic review reveals substantial knowledge gaps requiring attention. First, the bone biomarker literature shows that while nutritional interventions can modulate acute exercise responses, the clinical significance of these acute changes for long-term bone health

remains unclear [1]. No studies have demonstrated that reducing CTX-1 responses to exercise translates into reduced fracture incidence, improved bone density, or enhanced athletic longevity.

Second, the relationship between energy availability and bone health is predominantly studied in female athletes, with limited data on males and developing adolescent athletes. The Norwegian Olympic-level study found low bone mineral density in 16% of male athletes, all with normal resting metabolic rate [8], suggesting that metabolic markers may not reliably identify athletes at risk. This has direct implications for Cuban sports initiation schools, where routine metabolic monitoring may not be feasible.

Third, the Cuban context presents unique opportunities for innovation that remain underexplored. The potential of local foods—including tropical fruits, root vegetables, and locally available protein sources—for post-exercise recovery has not been systematically investigated. Studies modeled on the Indonesian homemade recovery drink research could identify cost-effective alternatives to imported commercial products [12]. Similarly, the integration of horticultural projects with sports education, as demonstrated in community projects [3], warrants rigorous evaluation for nutritional and educational outcomes.

Fourth, the safety and efficacy of supplements in the Cuban context requires specific investigation. Given the challenges of supplement access and quality control, research should focus on food-based interventions using locally available ingredients rather than imported commercial products. The Zuca Saludable model [10] could be expanded to produce evidence-based recovery foods for athlete dining facilities.

Limitations and Conclusion of this Review

This systematic review has several limitations that should be acknowledged. First, the search strategy was limited to English-language publications, potentially excluding relevant research published in Spanish, Portuguese, or other languages. Given the Cuban context of this review, this limitation is particularly significant, as important regional research may not be accessible through English-language databases. Second, several references cited in this review derive from institutional sources, news reports, and other grey literature rather than peer-reviewed journals [3,7,9,12,13]. While these sources provide valuable contextual information on the Cuban situation, they do not meet the same standards of evidence as peer-reviewed original research. Third, the available evidence on nutrition-bone interactions in athletic populations is characterized by substantial heterogeneity in study design, intervention characteristics, and outcome measures, limiting the precision of conclusions that can be drawn. Fourth, the focus on nutritional factors, while necessary for scope management, means that the important synergistic role of mechanical loading and exercise prescription on bone formation is not comprehensively addressed, though it is acknowledged. Fifth, the direct applicability of findings from elite adult athlete populations to adolescent athletes at Cuban sports initiation schools requires cautious interpretation, as developmental, training, and nutritional contexts differ substantially. Future systematic reviews should incorporate non-English language sources and more explicitly distinguish between evidence from peer-reviewed and grey literature.

Implications for EIDE Ormani Arenado Llonch Pinar del Río

Based on the critically reviewed evidence, several recommendations emerge for implementation at EIDE Ormani Arenado Llonch:

- **Nutritional assessment and education:** Systematic evaluation of athletes' dietary intake should be conducted to identify potential deficiencies in bone-supporting nutrients, with particular attention to energy availability and calcium status. Education programs for athletes, coaches, and support staff should emphasize the importance of maintaining adequate energy availability for bone health, as demonstrated by the New Zealand and Irish experiences [5].
- **Strategic supplementation:** Supplementation should be based on assessed deficiencies rather than general prescription. Vitamin D and calcium supplementation is particularly important given the high prevalence of inadequacy among athletic populations [1], but safety and quality of supplements must be ensured through trusted sources.

- **Food-based interventions:** Priority should be given to food-based approaches using locally available ingredients. The Indonesian homemade recovery drink model [12] provides a template for developing culturally appropriate, cost-effective recovery foods. Evaluation of Cuban foods for post-exercise recovery efficacy should be a research priority.
- **Horticulture integration:** The establishment of horticultural projects at EIDE Ormani Arenado Llonch, modeled on existing Cuban community and educational projects [3], could provide fresh produce to supplement athlete dining facilities, offer practical nutrition education, and model sustainable practices. The coordination model demonstrated at EIDE Luis Augusto Turcios Lima [3] provides a template for partnership with local agricultural entities.
- **Surveillance and research:** A systematic approach to monitoring bone health outcomes, including injury surveillance and, where feasible, bone biomarker assessment, would provide valuable data for program refinement. Collaboration with Cuban research institutions could generate evidence specific to the local context while contributing to the international evidence base.

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