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Beyond Performance Fuel: Could Carbohydrate Intake Contribute to Bone Stress Injury Prevention in Endurance Athletes? A Narrative Review

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Abstract

Introduction. Bone stress injuries (BSIs) occur when repetitive skeletal loading exceeds the capacity of bone to repair accumulated microdamage. Low energy availability is an established risk factor, but the independent contribution of carbohydrate availability remains uncertain.

Aim. This narrative review examines whether carbohydrate-based sports foods could contribute indirectly to BSI prevention by helping endurance athletes meet carbohydrate requirements.

Material and methods. A targeted search of PubMed/MEDLINE was supplemented by citation tracking and searches of publishers' and journal websites, including the Journal of Education, Health and Sport, Quality in Sport, and Pedagogy and Psychology of Sport. The search was updated between April and July 2026. Human studies of endurance exercise, carbohydrate feeding or restriction, fasted training, bone turnover, and bone injury were prioritized.

Results. Carbohydrate ingestion during prolonged running can attenuate acute changes in selected bone-turnover markers, whereas severe short-term carbohydrate restriction has been associated with lower bone-formation markers and a less favorable turnover profile. In one observational study, current fasted training, but not self-reported carbohydrate restriction, was associated with a higher incidence of bone injury. The evidence is derived mainly from small, short-term studies in men and relies on surrogate biomarkers. No randomized trial has shown that sports drinks, gels, chews, bars, or powders reduce imaging-confirmed BSI.

Conclusions. Carbohydrate-based sports foods should not be presented as bone-protective supplements or established preventive interventions. However, they may be useful as practical fuelling options during prolonged or high-volume training.

Keywords: bone stress injury; stress fracture; carbohydrate availability; endurance athletes; sports drinks; sports gels; bone turnover; low energy availability

1. Introduction

Bone stress injuries (BSIs) form a continuum of overuse-related skeletal pathology in which repeated loading generates microdamage faster than bone can remodel and repair it. Current consensus terminology includes stress reactions and stress fractures within this continuum [1]. This fatigue-failure model is particularly relevant to endurance sports, in which thousands of loading cycles may occur during a single training session [2].

Mechanical workload is central to BSI development, but there is no universal mileage threshold at which bone failure occurs. Risk depends on the magnitude, rate, direction, and novelty of loading, the athlete's previous exposure, and the biological capacity of bone to adapt [3]. A recent review of endurance athletes integrates training load, previous injury, skeletal health, nutrition, endocrine function, and recovery within one risk model [4]. A review published in *Quality in Sport* likewise summarizes established stress-fracture risk factors [5]. The clinical course varies with anatomical site and the natural history of the injury [6], while MRI grade and underlying bone health help predict time to return to sport [7].

Nutrition is one modifiable component of this risk profile. In exercising girls and women, the accumulation of Female Athlete Triad risk factors is associated with a progressively higher

incidence of BSI [8]. The Relative Energy Deficiency in Sport (REDs) framework likewise identifies low energy availability (LEA) as a cause of impaired physiological function, including adverse skeletal outcomes [9]. Restrictive eating practices and eating disorders also remain clinically relevant in athletic populations [10]. Nutritional assessment should therefore address total energy availability, reproductive and endocrine health, calcium and vitamin D status, and other identifiable deficiencies.

Carbohydrate has traditionally been considered primarily as an exercise fuel and a determinant of glycogen availability. Sports drinks, gels, chews, bars, and powders are used mainly to provide carbohydrate in a form that is easy to consume during training and competition. The IOC REDs consensus nevertheless recognizes low carbohydrate availability as a potentially relevant exposure within the broader context of under-fueling [9]. This raises a more specific question: can carbohydrate availability influence the skeletal recovery environment sufficiently to affect BSI risk?

The evidence must be interpreted according to study design. An acute change in a bone-turnover marker is not equivalent to a reduction in stress-fracture incidence. Likewise, an observational association between fasted training and injury does not show that consuming a gel prevents injury. This review therefore treats laboratory findings, biomarker studies, observational data, and clinical outcomes as distinct levels of evidence. Sports foods are treated as ways of providing carbohydrate, not as products with a direct skeletal effect.

2. Aim of the Review

This review evaluates whether carbohydrate availability and the use of carbohydrate-based sports foods could contribute indirectly to BSI prevention in endurance athletes. It summarizes the relevant biological mechanisms, examines studies of carbohydrate feeding and restriction, assesses evidence on fasted training, distinguishes nutrient effects from product-specific claims, and identifies priorities for clinical research.

3. Materials and Methods

This article was designed as a narrative review of a clinically defined question. Searches of PubMed/MEDLINE were supplemented by backward and forward citation tracking and by searches of publishers' and journal websites, including the Journal of Education, Health and Sport, Quality in Sport, and Pedagogy and Psychology of Sport. The search was updated between April and July 2026.

Search terms covered the injury phenotype, nutritional exposure, skeletal physiology and the sporting context. Additional searches addressed LEA, REDs, athlete bone health, and sports-nutrition guidance.

Human studies were prioritized when they manipulated carbohydrate feeding or carbohydrate availability and reported bone-turnover outcomes, or when they examined carbohydrate-related practices in relation to bone injury. Consensus statements, prospective studies, and clinically relevant reviews were used to provide context. Animal studies, traumatic fractures, and carbohydrate interventions unrelated to exercise were excluded from the core synthesis.

Bone-turnover markers were treated throughout as surrogate physiological outcomes rather than as evidence of injury prevention.

4. Clinical and Nutritional Context

4.1. Fatigue failure and endurance-sport vulnerability

Repetitive loading is necessary for skeletal adaptation, but injury develops when microdamage accumulates faster than targeted remodeling can replace damaged tissue. Current consensus places stress reactions and stress fractures on the same BSI continuum [1]. A detailed biological review explains this process as fatigue failure under repeated loading [2]. The natural-history literature describes progression from an early stress response to a fracture line when recovery is inadequate [6]. MRI grade and anatomical site are clinically important because they affect prognosis and time to return to sport [7].

Endurance athletes accumulate many loading cycles and may also have high energy expenditure. Reviews published in the Journal of Education, Health and Sport describe

systemic metabolic disturbances and broader musculoskeletal and medical risks associated with marathon and ultramarathon participation [11,12]. Changes in pace, hills, running surface, competition density, or training frequency can alter skeletal strain even when weekly distance changes little [3]. A previous BSI, low bone mineral density, and impaired recovery are among the factors considered in endurance-athlete risk assessment [4]. Accumulating Female Athlete Triad risk factors is associated with a higher incidence of BSI in exercising girls and women [8]. REDs may further impair skeletal health through low energy availability and related endocrine disturbances [9]. Carbohydrate availability is therefore unlikely to act in isolation; any effect is most plausible when low availability is repeated, recovery is inadequate, or baseline skeletal risk is already elevated.

4.2. Low energy availability and carbohydrate availability

Evidence linking LEA with adverse skeletal outcomes is stronger than evidence linking carbohydrate availability with BSI. Controlled studies have shown dose-related changes in bone turnover when energy availability is reduced in exercising women [13], and short-term responses may differ between women and men [14]. Guidance on athlete bone health consequently emphasizes adequate total energy intake, calcium, vitamin D, and overall dietary quality [15].

Carbohydrate availability refers to carbohydrate supply relative to the demands of training and recovery. It is related to, but not synonymous with, energy availability. An athlete may maintain total energy intake while replacing carbohydrate with fat, or may consume a carbohydrate-rich diet that is still insufficient in total energy. Carbohydrate availability is also influenced by glycogen status, nutrient timing, exercise duration and intensity, and the interval between sessions. Frequent overnight-fasted training, prolonged sessions begun with low glycogen, delayed carbohydrate replacement, or sustained ketogenic intake may therefore produce a different metabolic exposure from an isolated low-carbohydrate meal.

5. Why Carbohydrate Availability May Matter to Bone

5.1. Bone-turnover markers and their limitations

Bone resorption is commonly assessed using β -C-terminal telopeptide of type I collagen (β -CTX), whereas the N-terminal propeptide of type I procollagen (P1NP) is used as a marker of bone formation. Osteocalcin provides additional information about osteoblast-related activity. Acute endurance exercise can alter these markers [16], which makes them useful in short laboratory studies. However, they neither measure bone strength nor diagnose BSI. A lower β -CTX response after a single run or a transient change in P1NP cannot be assumed to improve bone mineral density or reduce fracture risk.

Accordingly, the expression “more favorable bone-turnover profile” is used in this review only to describe the direction of biomarker changes. Current studies show that bone metabolism responds to nutritional manipulation; they do not show that altering a biomarker prevents injury.

5.2. Plausible pathways

Potential mechanisms include feeding-related insulin secretion and changes in the exercise-induced inflammatory response. Insulin can suppress bone resorption, while alterations in cytokine signaling may influence post-exercise bone metabolism. In the study by Sale et al., carbohydrate ingestion attenuated the immediate responses of both bone-turnover markers and interleukin-6, although the study did not identify a single causal mediator [17]. Exercise-related calcium balance, parathyroid hormone, gut-derived peptides, and other feeding responses may also contribute [16].

Behavior may be as important as any endocrine mechanism. Athletes who restrict carbohydrate may also consume too little total energy, train in a fasted state more often, or follow broader restrictive eating patterns. During prolonged exercise, a drink, gel, chew, or other compact carbohydrate source may help increase carbohydrate and energy intake when solid food is unavailable or poorly tolerated. Practical fueling may also be limited by exercise-associated gastrointestinal symptoms, which are common in endurance athletes and may depend partly on feeding strategy and carbohydrate composition [18,19]. Any skeletal relevance may therefore

arise partly from reducing repeated under-fueling rather than from a carbohydrate-specific hormonal effect.

6. Direct Experimental Evidence

6.1. Carbohydrate feeding and early recovery

Sale et al. studied ten men in a crossover trial involving a 120-minute treadmill run. Participants consumed either an 8% glucose solution or placebo before, during, and immediately after exercise; carbohydrate was provided at approximately 0.7 g/kg/h. Carbohydrate ingestion attenuated the immediate responses of β -CTX, P1NP, and interleukin-6, but the differences were not sustained during the following three days [17]. The study demonstrates an acute effect on bone metabolism, but both resorption and formation markers were attenuated, and no structural or injury outcome was assessed.

Townsend et al. compared immediate carbohydrate-plus-protein ingestion, delayed ingestion, and placebo after exhaustive treadmill running. Immediate feeding altered the post-exercise response of bone-turnover markers [20]. Because the intervention combined carbohydrate and protein, the contribution of carbohydrate cannot be isolated; the findings are more relevant to mixed recovery nutrition than to a carbohydrate-only product claim.

6.2. Carbohydrate restriction

Fensham et al. compared a control diet, an energy-matched ketogenic low-carbohydrate/high-fat diet, and an LEA condition in elite male race walkers. The ketogenic diet reduced several bone-formation markers and increased the exercise-associated CTX response despite adequate energy availability [21]. In a separate study, Heikura et al. reported higher CTX and lower P1NP and osteocalcin after approximately three and a half weeks of ketogenic feeding during intensified training [22]. These findings suggest that severe carbohydrate restriction can alter bone-turnover markers even when total energy intake is controlled. Both interventions were short and involved highly trained, predominantly male samples, so the results should not be generalized to ordinary day-to-day variation in carbohydrate intake.

Panik et al. examined recovery after fasted, glycogen-depleting exercise in twelve men. An energy-matched recovery condition providing 6.0 rather than 1.5 g/kg/day of carbohydrate was associated with lower β -CTX at selected time points and higher P1NP after 24 hours [23]. This study extends the evidence to the recovery period, but it remains a small, acute secondary analysis based on surrogate outcomes.

Table 1. Key studies linking carbohydrate availability and related practices with bone outcomes

Study	Population and design	Exposure/intervention	Main finding and principal limitation
Sale et al. [17]	10 men; crossover; 120-min treadmill run	8% glucose before, during, and after exercise; ~0.7 g/kg/h vs placebo	Lower immediate β -CTX, P1NP, and IL-6 responses; no sustained difference. Small male sample; surrogate outcomes.
Townsend et al. [20]	10 men; exhaustive treadmill running	Immediate vs delayed carbohydrate + protein vs placebo	Immediate feeding modified bone-turnover recovery. Combined macronutrient intervention; carbohydrate effect cannot be isolated.
Fensham et al. [21]	28 elite male race walkers; controlled diet	Control vs energy-matched ketogenic diet vs LEA	Severe restriction impaired formation markers and exercise responses. Short intervention; extreme diet.
Heikura et al. [22]	World-class race walkers; intensified training	Energy-matched high-carbohydrate vs ketogenic diet	Ketogenic diet increased CTX and reduced P1NP/osteocalcin. Predominantly male; no BSI endpoint.
Panik et al. [23]	12 men; randomized crossover after depleted exercise	Recovery with 1.5 vs 6.0 g/kg/day carbohydrate	Adequate carbohydrate improved selected turnover markers. Small acute study; secondary outcomes.

Raleigh et al. [24]	Elite endurance athletes; observational study	Self-reported carbohydrate reduction and fasted training	Self-reported carbohydrate reduction was not associated with bone injury; current fasted training was associated with 1.61-times higher injury incidence. Observational and non-causal.
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CHO, carbohydrate; CTX, C-terminal telopeptide of type I collagen; P1NP, N-terminal propeptide of type I procollagen; IL-6, interleukin-6; LEA, low energy availability; BSI, bone stress injury.

7. From Carbohydrate Availability to Sports Foods

Sports drinks, gels, chews, bars, and powders provide known amounts of carbohydrate in forms that may be easier to consume during exercise than a meal. The available evidence concerns carbohydrate availability, not a specific protective effect of any product type. Established performance guidance recommends matching carbohydrate intake to exercise duration, intensity, and training goals [25]. More recent guidance emphasizes individualization and discusses higher intakes during selected prolonged events [26]. These recommendations were developed for fueling and performance, not for bone protection.

The IOC classifies these products as sports foods: convenient sources of nutrients that can also be obtained from ordinary foods [27]. A food-first review similarly recommends selecting carbohydrate sources according to the demands of the session and the athlete's tolerance [28]. Several articles from the Journal of Education, Health and Sport provide supplementary context rather than direct evidence. Kalisz et al. discuss macronutrients in athletes' diets [29], while Kiciak et al. examine sensory preferences and carbohydrate-bar consumption among physically active adults [30]. Uzdicki et al. and Gondko et al. summarize metabolic disturbances and broader health risks associated with marathon and ultramarathon running [11,12]. Murawiec and Konert, and Jedlina et al., discuss gastrointestinal disorders and dietary strategies relevant to carbohydrate intake during endurance exercise [18,19]. None of these articles evaluated bone metabolism or BSI prevention.

No study identified in this review showed that a particular brand, formulation, or product type reduced BSI incidence. Sale et al. used an 8% glucose beverage during running [17]. Townsend et al. tested a combined carbohydrate-protein recovery drink [20]. Fensham et al. prescribed a ketogenic diet under controlled conditions [21], and Heikura et al. evaluated another ketogenic intervention during intensified training [22]. Panik et al. compared low- and adequate-carbohydrate recovery diets [23]. These studies show that carbohydrate availability can be manipulated; they do not show that a commercial product prevents BSI.

The main reason to use sports foods in this context is practical, not therapeutic. During prolonged sessions or twice-daily training, solid food may be unavailable or poorly tolerated. A drink, gel, chew, bar, or powder can help an athlete reach a planned carbohydrate target. This convenience should not be interpreted as an independent skeletal effect. Athletes who already meet their energy and carbohydrate needs through ordinary food should not expect additional bone protection from sports products.

8. Fasted Training and Bone Injury

Some endurance-training strategies deliberately involve exercise with low glycogen stores or after an overnight fast. Their proposed performance rationale should be considered separately from skeletal safety, particularly when low-carbohydrate sessions are frequent, prolonged, or combined with LEA.

Raleigh et al. reported that self-identified reduction of carbohydrate intake was not associated with radiographically confirmed bone injury in elite endurance athletes. In contrast, bone-injury incidence was 1.61 times higher among athletes who currently trained in a fasted state than among those who had never used, or no longer used, that practice [24]. The absence of an association with general carbohydrate restriction argues against a simple relationship between lower carbohydrate intake and injury risk. The fasted-training finding nevertheless warrants further investigation.

This observational association does not establish causation. Athletes who train fasted may differ in training volume, weight-control behavior, total energy availability, or previous injury, and the temporal relationship between the practice and injury was not established. The finding

is compatible with the less favorable marker responses reported during severe carbohydrate restriction by Fensham et al. [21] and Heikura et al. [22]. It is also compatible with the low-carbohydrate recovery findings reported by Panik et al. [23]. An occasional, supervised low-carbohydrate session in an otherwise adequately fueled athlete should not be equated with repeated prolonged fasted sessions combined with delayed eating and intentional weight loss.

9. Can Sports Foods Prevent Bone Stress Injuries?

The evidence progresses from physiology to clinical outcomes. Ihle and Loucks showed that reducing energy availability alters bone-turnover markers in exercising women [13]. Papageorgiou et al. subsequently demonstrated that short-term responses to reduced energy availability differ between women and men [14]. Reviews by Sale and Elliott-Sale [15] and by Wherry et al. [16] provide broader physiological context. During exercise, Sale et al. found that glucose ingestion altered acute bone-turnover responses [17].

After exercise, Townsend et al. observed marker changes after a combined carbohydrate-protein drink [20]. Fensham et al. reported adverse marker changes during an energy-matched ketogenic intervention [21]. Heikura et al. reported a similar pattern during a separate ketogenic study [22]. Panik et al. found differences in CTX and P1NP between low- and adequate-carbohydrate recovery conditions [23]. The only injury study was observational and concerned fasted training [24]. No prospective trial has shown fewer imaging-confirmed BSIs after a targeted carbohydrate intervention.

Evidence that does not support a protective effect must also be considered. A systematic review and meta-analysis of prospective cohort studies did not identify carbohydrate intake as a determinant of overall running-related injury risk [31]. Because the outcome included many injury types, the result does not rule out a bone-specific effect. It does, however, weaken any claim that higher carbohydrate intake is already an established injury-prevention strategy.

Research on calcium and vitamin D illustrates the distinction between laboratory findings and clinical evidence. In a randomized trial involving 5,201 female Navy recruits, daily supplementation with 2,000 mg of calcium and 800 IU of vitamin D reduced stress-fracture incidence by approximately 20% [32]. The carbohydrate literature contains no comparable

trial, no validated threshold for BSI risk that is independent of energy availability, and no comparison of food-based carbohydrate with commercial sports foods using skeletal endpoints.

Table 2. Evidence hierarchy for the possible role of carbohydrate-based sports foods in BSI prevention

Evidence level	What is supported	What is not supported	Research need
Biological plausibility	Bone turnover responds to exercise, feeding, energy availability, and related signals.	Carbohydrate as a direct bone-strengthening agent.	Controlled studies separating carbohydrate availability from total energy intake and other nutrients.
Acute experimental evidence	Carbohydrate availability can alter CTX, P1NP, and related markers in selected protocols.	That transient biomarker changes prevent BSI.	Repeated-session studies with structural and imaging outcomes.
Restriction evidence	Severe ketogenic exposure can produce a less favorable turnover profile during heavy training.	That moderate reduction or one missed feeding opportunity causes BSI.	Dose-response studies using realistic availability ranges.
Observational injury evidence	Current fasted training has been associated with bone injury in one elite cohort.	Causation or benefit from a commercial product.	Prospective cohorts with objective diet, workload, and imaging data.
Direct clinical evidence	No preventive randomized trial was identified.	That drinks, gels, chews, bars, or powders reduce BSI incidence.	Multicenter trials with adjudicated BSI and prespecified risk groups.

BSI, bone stress injury; CTX, C-terminal telopeptide of type I collagen; P1NP, N-terminal propeptide of type I procollagen.

10. Clinical and Sports-Nutrition Implications

Routine prescription of carbohydrate products for bone health is not justified. Assessment of carbohydrate availability is most relevant in athletes who combine high mechanical load with possible under-fueling, including those with previous or recurrent BSI, high-volume or twice-daily training, frequent fasted sessions, REDs indicators, or practical barriers to eating. Previous injury should prompt a comprehensive BSI risk assessment [4]. Accumulating Female Athlete Triad risk factors also requires attention [8], as do indicators of REDs [9]. Carbohydrate intake should be evaluated within that broader clinical picture rather than in isolation.

A focused dietary history should address the frequency and duration of fasted training, carbohydrate intake during prolonged sessions, the interval between exercise and the next meal, recovery between sessions performed on the same day, recent ketogenic or very-low-carbohydrate dieting, and the reasons for dietary restriction. Early-morning training, travel, gastrointestinal symptoms [18,19], limited access to food, post-exercise appetite suppression, and concerns about body mass may all reduce carbohydrate availability.

Carbohydrate provision should not replace established elements of BSI prevention. Consensus guidance emphasizes accurate diagnosis and risk classification [1], while endurance-athlete reviews stress training-load management and previous injury [4]. Female Athlete Triad risk factors require targeted assessment [8]. REDs-related energy and endocrine disturbances must also be addressed [9]. Adequate calcium, vitamin D, and overall dietary quality remain important components of athlete bone health [15]. A sports gel cannot correct chronic LEA, an eating disorder, or an inappropriate return-to-running program.

Frequent fasted training accompanied by fear of weight gain, persistent dietary restriction, poor recovery, or recurrent injury should prompt assessment for LEA and REDs [9]. Signs of disordered eating require separate evaluation [10]. In this setting, multidisciplinary medical, dietetic, and psychological care may be more important than recommending a specific sports product.

Performance-oriented carbohydrate targets should not be presented as bone-health doses. Established performance guidance discusses carbohydrate intake during prolonged exercise [25]. More recent work considers higher intakes in selected trained athletes [26]. No intake of 60, 90, or 120 g/h has been validated for BSI prevention. The IOC framework can guide the appropriate use of sports foods [27], while food-first guidance emphasizes tolerance and the demands of the session [28]. Consumer-preference data may help explain adherence to carbohydrate bars [30], but they provide no evidence of skeletal benefit. Educational messages should remain proportionate: missing a single gel does not damage bone, but repeatedly undertaking high-load training with inadequate energy and carbohydrate availability may create an unfavorable recovery environment in susceptible athletes.

11. Research Gaps and Future Directions

The principal research gap is the absence of clinical trials with BSI as the primary outcome. Future studies should randomize endurance athletes to clearly defined carbohydrate-availability strategies and confirm incident BSI using standardized clinical and imaging criteria. The current international consensus provides terminology for consistent outcome reporting [1]. Injuries should also be classified by anatomical location, clinical risk, and MRI severity because these features affect prognosis [7].

Interventions must extend beyond a single exercise bout. Studies conducted over training blocks or competitive seasons should measure dietary exposure and training load repeatedly and should include bone mineral density, appropriate measures of bone microarchitecture or estimated strength, and follow-up of sufficient duration for BSI to develop [6].

Women must be adequately represented. The prospective Female Athlete Triad literature identifies a clinically important risk structure in exercising girls and women [8]. The REDs consensus also emphasizes reproductive and endocrine variables [9]. Controlled work indicates that the bone-metabolic response to reduced energy availability may differ by sex [14]. Several carbohydrate-bone experiments enrolled only men: the running study by Sale et al. [17], the recovery study by Townsend et al. [20], the race-walking study by Fensham et al. [21], and the recovery study by Panik et al. [23]. The ketogenic study by Heikura et al. included a predominantly male sample [22]. Future studies should therefore record menstrual status,

hormonal-contraceptive use, reproductive function, energy availability, and Triad or REDs risk.

Carbohydrate exposure should be quantified relative to the demands of each training session and separated analytically from total energy availability. Energy- and protein-matched designs could test carbohydrate timing, the frequency of low-glycogen sessions, and recovery provision. Product studies should compare equivalent carbohydrate doses delivered as ordinary food, drinks, gels, chews, or bars to determine whether format primarily affects adherence and gastrointestinal tolerance.

12. Conclusions

Current evidence suggests that carbohydrate availability may acutely modify bone-turnover responses to endurance exercise and recovery, whereas severe carbohydrate restriction and fasted training may be associated with a less favorable skeletal environment [17, 20–24]. However, these findings are based largely on small, short-term studies, predominantly conducted in men, and rely mainly on surrogate biomarkers rather than clinically confirmed bone stress injuries. No randomized trial has demonstrated that carbohydrate-containing sports foods reduce BSI incidence, and prospective evidence on overall running-related injury does not support carbohydrate intake as an established protective factor [31].

Accordingly, sports drinks, gels, chews, bars, and powders should be regarded as practical means of supporting carbohydrate and energy intake during prolonged or high-volume training rather than as bone-protective interventions. Their potential value lies in helping athletes avoid repeated under-fuelling when ordinary food is impractical or poorly tolerated. Whether maintaining adequate carbohydrate availability can reduce BSI risk remains uncertain and requires prospective studies using clinically or imaging-confirmed injury outcomes. Carbohydrate-based sports foods should therefore be regarded as practical fueling options rather than as bone-protective supplements. They may help athletes meet carbohydrate requirements when prolonged or high-volume training makes ordinary meals difficult to consume. Whether this approach reduces BSI incidence requires direct prospective testing.

Disclosure Section

Author Contribution

Conceptualization: P.Z.Z., M.A.Ł.T., D.I.S., M.De., I.O.Ż.; methodology: P.Z.Z., K.J.Ł., M.Z., Ł.K.S., M.Dr.; investigation and literature search: P.Z.Z., Ł.K.S., M.Dr., M.De., I.O.Ż.; writing - original draft preparation: P.Z.Z., P.B.N., M.A.Ł.T., D.I.S.; writing - review and editing: P.Z.Z., K.J.Ł., M.Z., P.B.N.; supervision: P.Z.Z.

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