

UCI Sports Nutrition Project: Does Cycling Create a “Perfect Storm” for Bone Health? Cycling-Specific Challenges to Bone and Nutritional Strategies to Overcome These

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As a group, cyclists tend to have lower bone mass compared with other athletes, and nonathlete controls which may have negative consequences for fracture risk and longer term bone health. There are several cycling-specific factors that may contribute to this finding. These include, the low-impact, repetitive load nature of cycling which provides limited stimulus for bone metabolism; metabolic perturbations that occur following prolonged cycling that may lead to a transient increase in the rate of bone resorption; and nutritional factors, including low energy availability or nutrient inadequacy. Furthermore, many endurance cyclists are naturally lean and light, which may result from both genetic predisposition and long-term training adaptations. In turn, they may also have lower bone mass. None of these factors stand out as the primary cause of the low bone mass reported in cyclists but, instead, may combine to create a “perfect storm” to challenge cyclist bone health. Given these multiple potential challenges to bone health, a multifaceted approach may be required to combat them. On an individual level, nutritional strategies, including ensuring adequate energy, carbohydrate, protein, calcium, vitamin D, and other important micronutrients may be key to protecting cyclist bone health. Integrating brief bouts of high-impact loading within the training regimen and ensuring adequate sleep and recovery are also recommended. The onus should not remain solely on the individual, however, and cycling teams and organizational bodies have a key role to play in providing screening and educational strategies to support cyclists bone health.

Keywords: bone density, low energy availability, mechanical loading

High-level cyclists particularly those in endurance disciplines such as road cycling tend to have lower bone mass and compromised bone microarchitecture compared with athletes in higher impact sports and healthy nonathlete controls (Hilkenes et al., 2021; Olmedillas et al., 2012). This is concerning, as reduced bone mass and quality may increase risk for both stress and traumatic fracture, prolong recovery time from bone-related injuries, and potentially predispose cyclists to osteoporosis in later life. Several cycling-specific factors may contribute to diminished bone health, including characteristics of cycling particularly the low-impact, repetitive nature of applied loading cycles, along with acute metabolic perturbations that occur during prolonged cycling, such as disruptions in calcium levels, pH balance, inflammatory cytokines, and redox homeostasis (Dolan et al., 2020, 2022). Nutritional factors, such as low energy availability (LEA), or nutrient inadequacies (Dolan et al., 2024; Papageorgiou et al., 2018; Sale & Elliott-Sale, 2019), and the potential impact of medications, such as glucocorticoids or nonsteroidal anti-inflammatories (Seibel et al., 2013) may further increase these risks. Furthermore, a high power-to-mass ratio may provide performance advantages in some terrains, meaning that naturally lighter and leaner riders may have an advantage.

Given that bone mass closely correlates with body mass index, body, and muscle mass (Kirk & Duque, 2022; Song et al., 2020), it is likely that naturally light or lean individuals will also have lower bone masses. Together, these factors may combine to create a “perfect storm” to challenge cyclist bone health. The aim of this article is to explore these challenges and to consider their likely influence on cyclist bone health; to provide pragmatic recommendations to protect cyclist bone health; and to identify important gaps in current understanding of this topic area, along with suggested research avenues to fill these.

Cycling-Specific Challenges to Bone

Table S1 (see [Supplementary Material](#) [available online]) summarizes data from 34 studies on cyclists bone health, showing that as a group, cyclists tend to have less robust bone than other athletes or nonathlete controls. As described in the introduction, no single cycling-related factor stands out as the primary explanation for these findings (see Figure 1). Instead, multiple factors likely interact to create a “perfect storm” to challenge cyclist bone health, and each of these are discussed in turn herein. The impact of these factors likely depends on cycling modality and level, with higher level athletes following more intense and voluminous training programs most affected. Furthermore, while these factors may be relevant to varying degrees to all cyclists, road cyclists are likely most affected due to the prolonged and low-impact nature of training and competition and focus on leanness. In contrast,

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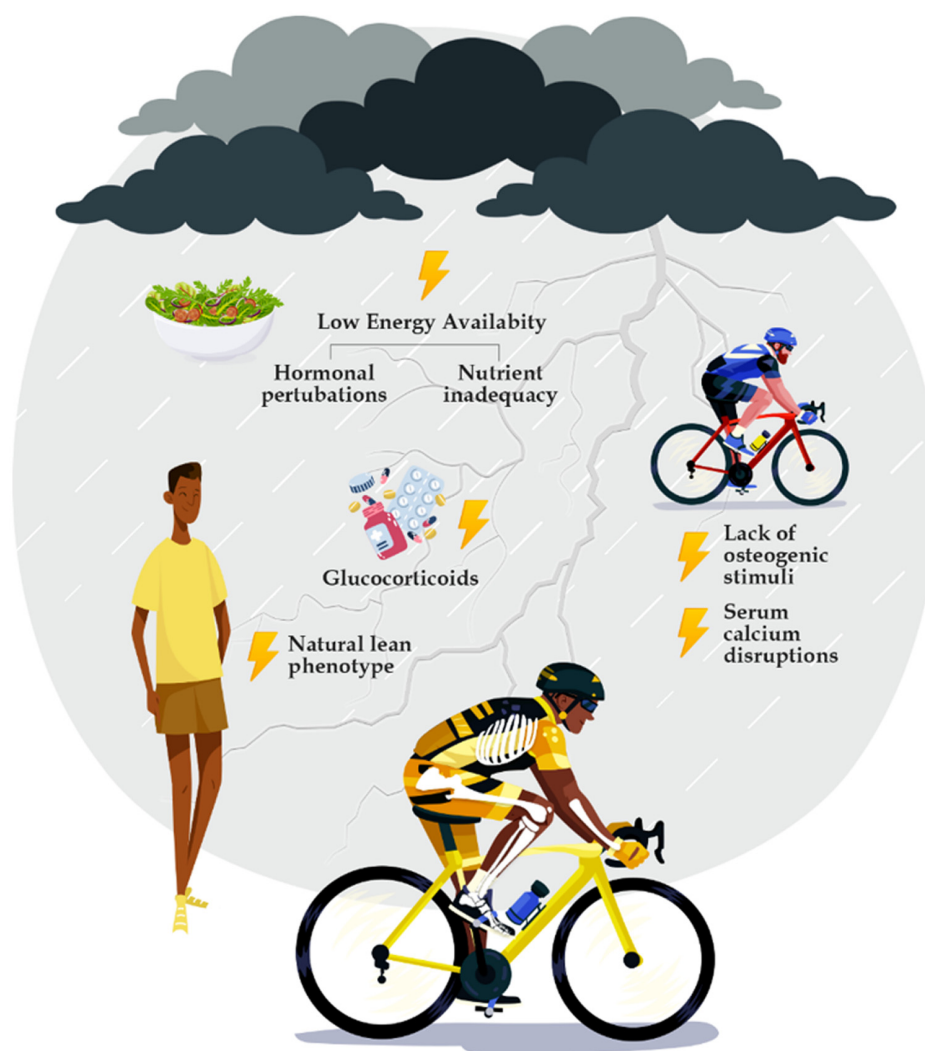


Figure 1 — Cycling-specific challenges to bone health.

disciplines like track cycling, BMX, MTB, or cyclo-cross, which often prioritize power over endurance and involve greater mechanical loading, may be less affected. To date, most research has focused on road cyclists, however, highlighting the need for further investigation across other cycling modalities.

Challenge 1: Lack of Adequate Mechanical Loading

Assuming the nutritional, metabolic, and endocrine environment is adequate, bone adapts to withstand the habitual load to which it is exposed (Frost, 2004), with activity induced mechanical loading the primary determinant of bone mass and strength. This load can arise from ground reaction or muscular forces (Kohrt et al., 2009), with high-impact, multidirectional, and intermittent activities generating the greatest osteogenic stimulus. Cycling is a prime example of a sport that provides minimal osteogenic stimulus, as it is weight-supported, and conveys low to no-impact repetitive loading cycles. As such, a lack of adequate mechanical loading is likely to contribute, at least in part, to the low bone mass and less robust microarchitecture observed in cyclists (see Table S1 in [Supplementary Material](#) [available online]).

Cycling modality is an important factor to consider here, given that different modalities convey different loading patterns and, as such, exert varying levels of osteogenic stimulus. Loading in cycling comes from three interactive sources: the cyclist's action (pedaling and body movements), control mechanisms (e.g., steering and braking), and road-surface interactions. Although the basic pedaling movement is similar between modalities, the control mechanisms and road-surface interactions are not. For example, road cycling typically occurs on paved surfaces, with predictable loading patterns. In contrast, mountain biking involves varied surfaces, such as rocks, gravel, sand, logs, and slopes at different inclines and, as such, may potentially offer an increased osteogenic stimulus compared with road cycling. In support of this hypothesis, two studies reported higher bone mineral density (BMD), and greater radial bone size and strength in mountain bikers compared with road cyclists (McVeigh et al., 2015; Warner et al., 2002). In contrast, Zamboni et al. (2024) reported that body mass-adjusted lumbar spine BMD was lower in both road and mountain biking (MTB) cyclists compared with noncyclist controls but similar between the two cycling groups (Zamboni et al., 2024), implying that the loading differences between MTB and road cycling were insufficient to lead to observable changes in bone mass.

Furthermore, it is plausible that cyclists from shorter distance and more power-based disciplines, such as track cycling or BMX, may have higher bone mass than road cyclists (Wilks et al., 2009). Disciplines such as cyclo-cross, which includes varying terrains and obstacles, some of which may necessitate the rider to dismount and run or climb while carrying their bike, have been reported to convey larger ground reaction forces and osteogenic index than disciplines such as road cycling (Tolly et al., 2014). Engagement in multiple cycling disciplines, or in other sports, may also influence the riders' bone health, depending on the combined load conveyed. Ultimately, the attributes of each individual discipline, including the muscular and gravitational loads conveyed, physique requirements, and extent of engagement in resistance training, may all contribute to determining the riders bone profile.

The available evidence clearly shows that road cyclists often have lower bone mass than athletes in higher impact sports, but this does not necessarily mean that their BMD is low—only that other athlete groups have higher values. Therefore, it is also important to compare cyclist bone to nonathlete controls and reference data. As described in Table S1, Part B (see [Supplementary Material](#) [available online]), several studies have reported lower bone mass in trained road cyclists compared with nonathlete controls (Campion et al., 2010; Gonzalez-Aguero et al., 2017; Nichols et al., 2003; Nichols & Rauh, 2011; Olmedillas et al., 2011; Smathers et al., 2009; Stewart & Hannan, 2000; Warner et al., 2002). Reported cyclist Z- and T-scores are summarized in Figure 2, clearly demonstrating that a disproportionately high number of cyclists are classified as having lower bone mass than would be expected from a random sample of the general population. For example, a recent study reported that 65% of advanced career cyclists had lumbar spine BMD values comparable to the lowest 16% of the reference population (Z-score < -1; Hilken et al., 2023). While cycling's low-impact nature may provide insufficient osteogenic stimulus, this alone is unlikely to explain lower BMD than nonathlete controls, suggesting other contributory factors, as described in the next sections.

Challenge 2: Acute Metabolic Responses to Prolonged Cycling Bouts

When considering the impact of exercise on bone, the focus is typically on habitual mechanical loading. Acute exercise also triggers a cascade of transient metabolic and endocrine changes, however, that may also influence bone (Dolan et al., 2020, 2022). Many exercise-induced metabolic signals, such as alterations in calcium, or redox balance, or pH can stimulate bone resorption, at least for the short term. Consequently, the net impact of exercise on bone ultimately depends upon the balance between anabolic and catabolic signals.

A recent systematic review and meta-analysis on the bone biomarker response to acute exercise reported that prolonged cycling bouts consistently induce a substantial increase in the bone resorption marker C-terminal telopeptide of Type I collagen (Dolan et al., 2022). Further investigation is required to elucidate the underlying mechanisms that drive this response, but potential candidates include redox imbalance (Wauquier et al., 2009), inflammatory cytokines (Epsley et al., 2021), acid-base imbalances (Arnett, 2008), or disruptions to calcium homeostasis. Of these, calcium homeostasis is the most investigated and may be particularly relevant to cyclists. Approximately 99% of the body's calcium is stored in bone, with the rest circulating in the blood and other tissues. During prolonged cycling, circulating calcium concentrations decline (Kohrt et al., 2019), likely triggering an increase in

parathyroid hormone. In turn, parathyroid hormone stimulates bone resorption to release stored calcium and restore circulating homeostasis. This physiological response, while necessary and likely harmless in the short term, has the potential to be problematic if frequently repeated across the long-term, as may be the case with high-level cyclists with intensive training programs, although further investigation is necessary to investigate this hypothesis.

Challenge 3: Dietary Factors

Nutritional factors, including energy availability, and nutrient adequacy are essential for athlete bone health (Papageorgiou et al., 2018; Sale & Elliott-Sale, 2019). Energy availability refers to the energy remaining for physiological processes after the demands of exercise are met. As described in another article within this series, cyclists may have high risk of LEA, due to the high-energy cost of training and competition, combined with a frequent desire to restrict calories in pursuit of reduced body mass and improved power-to-mass ratio (Burke et al., 2025). Prolonged LEA can be detrimental to bone, potentially leading to reduced bone mass, compromised micro-architecture, metabolic disturbances, and increased fracture risk (Papageorgiou et al., 2018), and is a likely contributory factor to the less robust bone commonly observed in cyclists, as summarized in Table S1 ([Supplementary Material](#) [available online]) and Figure 2.

Prolonged LEA could potentially impact bone via three interconnected pathways: (a) energy conservation, (b) suppression of reproductive and metabolic hormones, and (c) nutrient inadequacy. When energy intake is insufficient to simultaneously support both exercise training and all physiological processes, available energy is preferentially allocated to more immediately essential processes, potentially resulting in suppression of others (Shirley et al., 2022). Studies suggest that just 3–5 days of LEA reduces circulating levels of Procollagen Type 1 N-terminal propeptide, a bone formation biomarker (Dolan et al., 2024; Ihle & Loucks, 2004; Papageorgiou et al., 2017, 2018; Zanker & Swaine, 2000), potentially representing an energy conservation mechanism.

LEA also suppresses key reproductive and metabolic hormones, including estrogen, testosterone, and triiodothyronine (Elliott-Sale et al., 2018). Many of these play important roles in bone metabolism, meaning that the negative influence of LEA on bone may be an indirect consequence of reproductive or metabolic suppression. Supporting this, triiodothyronine—a primary indicator of problematic LEA (Stellingwerff et al., 2023), was one of the main factors associated with low BMD in elite cyclists (Hilken et al., 2023). Furthermore, male competitive cyclists identified as high risk for LEA using a sport-specific questionnaire and clinical interview had lower lumbar spine BMD Z-scores compared with those deemed as being at lower risk of LEA (Keay et al., 2018).

Food comprises both macronutrients from which we derive energy, and micronutrients that are essential for adequate physiological function. A key challenge in investigating the effects of LEA on bone is distinguishing the direct consequences of LEA per se from those caused by inadequacies in bone-important nutrients, such as carbohydrate, protein, calcium, vitamin D, and other micronutrients (e.g., phosphorus, magnesium, potassium, and vitamin K; Sale & Elliott-Sale, 2019). Deficiencies in any of these nutrients may be detrimental to bone, regardless of energy status; however, cyclists who restrict calorie intake may have increased risk of both LEA and nutrient inadequacy. Therefore, the composition and quality of a cyclist's diet may be just as, if not more, important than the total energy intake.

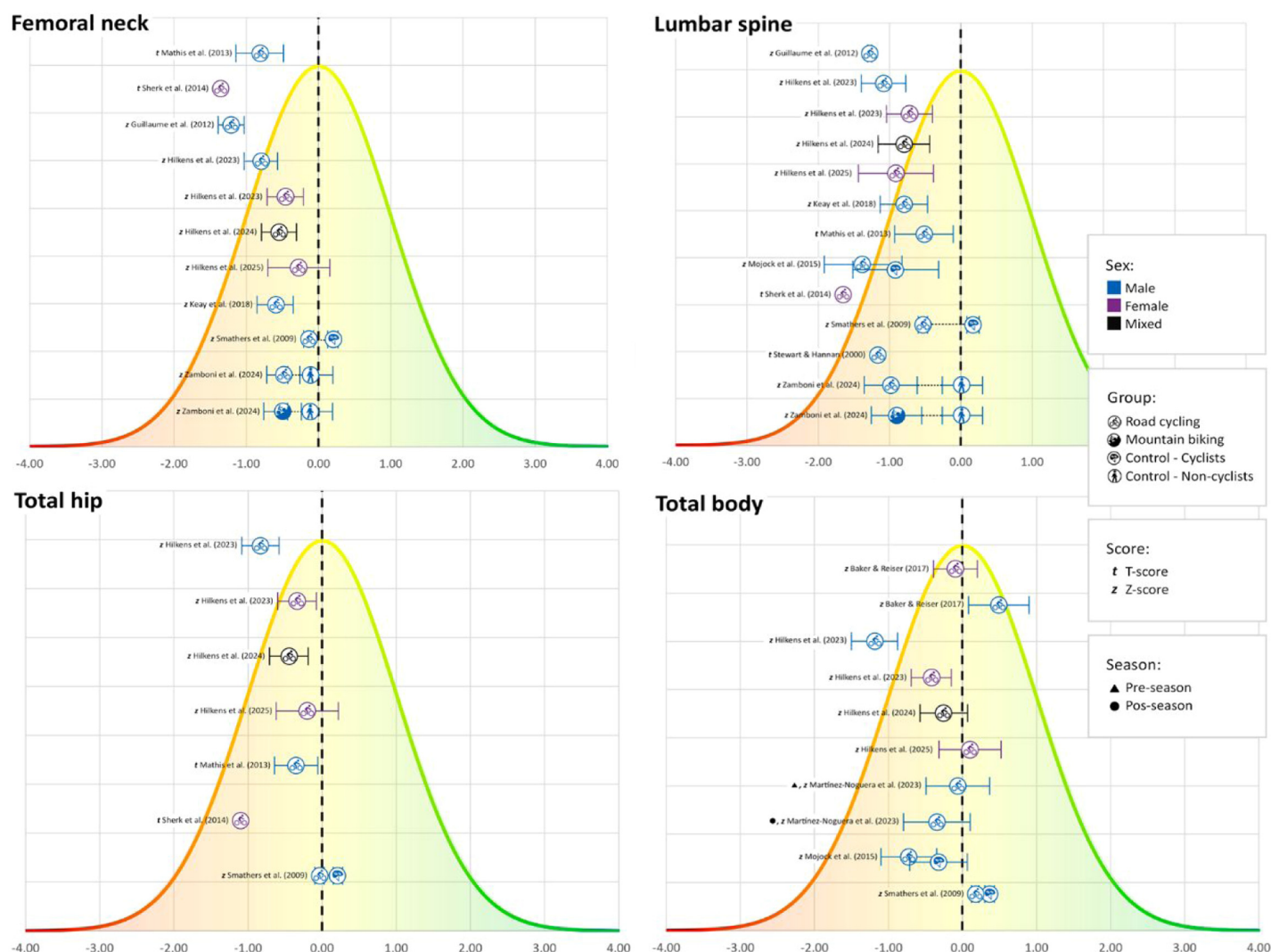


Figure 2 — Cyclist Z-scores and comparisons with nonathlete controls. Legend: Data represent the mean and 95% confidence interval of Z-scores reported in articles evaluating cyclist bone health (Table S1, Part B in [Supplementary Material](#) [available online]). If Z-scores were not reported, T-scores were used. Control groups comprised either recreational cyclists or noncyclists compared with high-level cyclists.

Challenge 4: Self-Selection of People With a Naturally Lean Phenotype to the Sport

As a group, cyclists tend to be light and lean—characteristics that may reflect not only training and nutritional strategies aimed at optimizing power-to-mass ratio but also inherent predisposition and phenotype. Given that bone mass is closely linked to both muscle mass and body mass index (Kirk & Duque, 2022; Song et al., 2020), it is plausible that naturally lighter, leaner cyclists may also have lower BMD simply due to their size and genetic predisposition. Conversely, naturally larger cyclists may experience greater pressure to restrict calories and reduce body mass and as such to be at greater risk of the negative consequences of prolonged LEA described above, compared with their naturally lighter counterparts.

To date, limited research has examined how genetic factors and the riders' natural physique predisposition may influence bone health. Although it does seem plausible that these factors may be relevant, they are unlikely to be the primary drivers of the low bone mass commonly observed in cyclists. As described in Table S1, Part C ([Supplementary Material](#) [available online]), longitudinal

studies have reported larger declines in cyclist bone mass over time (or smaller increases for adolescent athletes) when compared with expected age-related changes (see Table S1, Part C; [Supplementary Material](#) [available online]). Furthermore, a larger prevalence of low BMD (Z-score < 1) was recently reported in advanced, compared with early-career, male cyclists, suggesting that more time in the sport may lead to more detrimental bone outcomes (Hilkens et al., 2023). These findings suggest that the cycling-specific factors discussed throughout this review—including the low-impact and repetitive nature of cycling, metabolic perturbations after long rides, LEA, or bone-important nutrient inadequacies—may also contribute to low bone mass in this population.

Pragmatic Recommendations to Support Cyclist Bone Health

As described throughout this article, multiple cycling-specific factors could challenge cyclist bone health, necessitating a multi-faceted approach to mitigation. Bone protective nutritional

strategies are particularly relevant, and key recommendations are summarized in Table 1. These recommendations are based on current evidence but should be interpreted with two caveats: (a) Bone-specific nutritional recommendations are limited, so most nutrient recommendations align with recommended nutrient targets for cycling, as described in other articles within this series, and (b) Individual requirements will vary widely, meaning that these recommended ranges should be used as a start point, with individual targets tailored to each cyclist's goals, requirements, and progress.

Although the main focus of this series is nutrition, other lifestyle factors are essential for bone health, including incorporation of load-bearing exercise into the training regimen, and ensuring adequate sleep and recovery. At an organizational level, systematic approaches to regularly screen for bone health and associated risk factors may facilitate early intervention. Furthermore, fostering a healthier cultural approach to bone health, weight management, and fueling strategies may further support cyclists' long-term skeletal integrity.

Exercise and Other Lifestyle Recommendations to Improve Cyclist Bone Health

While this article focuses on nutritional strategies to address cycling-specific challenges to bone health, it would be remiss not to mention the importance of other lifestyle factors that are also fundamental to supporting bone. Bone-loading exercise is key, and the incorporation of activities that provide multidirectional, high-impact, and varied loading patterns within the training regimen should be considered. Examples include jumping, kicking, or punching-type activities, or heavier load resistance exercises. In support of this recommendation is evidence that elite cyclists with a history of osteogenic activity (e.g., soccer or gymnastics) had higher BMD during their active cycling career than their counterparts with a less-varied sporting history (Hilkens et al., 2023). This is particularly pertinent for young cyclists, given that adolescence is a critical period for bone development, with approximately 90–95% of peak bone mass estimated to accumulate by the age of 20 years (Baxter-Jones et al., 2011).

Adequate sleep and stress management may also be important to support cyclist bone health. Sleep and circadian disruption has been reported to disrupt bone metabolism and contribute to reduced BMD (Swanson, 2022), highlighting the importance of strategies to optimize sleep. Furthermore, psychological stress has been linked to poor bone health, which may be due both to direct mechanisms, including increased glucocorticoids, low grade inflammation, and hyper activation of the sympathetic nervous system or to indirect behavioral changes, such as altered dietary patterns, or disrupted sleep (Ng & Chin, 2021). As such, prioritizing sleep and stress management may be useful strategies to protect bone health, in addition to the myriad other benefits that these approaches bring.

Recommendations for Screening and Monitoring

Considering that LEA may be a risk factor for impaired bone health in cyclists, regular screening for indicators of problematic LEA is recommended. In 2023, an International Olympic Committee working group published an updated risk stratification tool for problematic LEA, that is, the Relative Energy Deficiency in Sport Categorization Tool Version 2 (REDs-CAT2; Stellingwerff et al., 2023). This tool proposes a series of primary and secondary indicators of REDs risk and uses a traffic light system to categorize individuals within one of four risk categories (green, yellow,

orange, and red). Further details on the application of this tool and screening for LEA risk in cyclists can be found in the original REDs-CAT2 (Stellingwerff et al., 2023) and in the energy availability and body composition review within this special issue (Burke et al. 2025). Although the original tool recommends a three-stage assessment process, with Stage 1 comprising initial screening via questionnaire or clinical interview, we recommend that this stage could be skipped and that Stage 2, that is, risk stratification based on any identified primary or secondary indicators, could be routinely implemented, considering that cyclists may be a group with inherently high risk for prolonged LEA.

Primary indicators of REDs risk include menstrual status in females, testosterone levels in males, free or total triiodothyronine concentration, history of high-risk bone stress injuries, evidence of disordered eating (assessed by validated questionnaires), deviation from typical growth trajectories (for pediatric or adolescent athletes), and BMD Z-score. BMD Z-scores can be obtained from dual energy X-ray absorptiometry scans, with preferred measurement sites being the hip and lumbar spine (Lewiecki et al., 2006). Wrist scans may also be considered, as the wrist is particularly vulnerable to fractures in cycling-related falls. For adults under 50, dual energy X-ray absorptiometry results are reported in absolute terms (in grams/square centimeter) and as a Z-score, which compares an individual's BMD to a reference population of similar age, sex, and ethnicity (LeBoff et al., 2022). A Z-score < -1 at the lumbar spine, total hip, or femoral neck, or a decrease in Z-score from previous tests, is considered high risk and may warrant further investigation and potentially intervention (LeBoff et al., 2022; Mountjoy et al., 2023).

Regular assessment of body mass and composition is commonplace among cyclists and may have utility in planning nutritional analyses and assessing progress toward performance goals, for example, by monitoring power-to-mass ratio. Some degree of caution is, however, warranted in terms of the frequency and focus of body composition assessment. Survey data indicate that cyclists are a weight-conscious group who often consciously strive to maintain low body mass to enhance their power-to-mass ratio or due to cultural beliefs about the "ideal" cycling physique (Haakonssen et al., 2015; Hoon et al., 2019). While this emphasis on body composition can be beneficial under specific conditions, overemphasizing it may be detrimental to both health and performance. For a comprehensive discussion on body composition's role in cyclist health and performance, see Mathisen et al. (2023) and Burke et al. (2025).

Recommendations for Organizations and Policy Makers

The above recommendations are targeted at the individual cyclist; however, cycling associations, organizing bodies and cycling team management also have an important role to play in protecting cyclist bone health through supporting initiatives and promoting cultures that emphasize long-term health. Key educational messages to share with cyclists' support staff, coaches, and younger athletes' carers about the importance of bone health are summarized in Table 2. Potential actions that policymakers and organizational bodies may take to protect cyclists bone health include mandating BMD and risk assessment of problematic LEA within annual health screens for Union Cycliste Internationale world, pro, continental, and developmental teams while recommending similar screening protocols for all cycling teams, prioritizing athlete safety when designing and preparing cycling events, to minimize risk of falls and crashes that can result in fractures and by providing

Table 1 Nutritional Recommendations to Support Bone Health in Cyclists

Nutritional recommendation	Supporting information
Energy availability: Strive for habitual energy availability of approximately 40–45 kcal·kg FFM·day ⁻¹ (Energy availability = energy intake – exercise energy expenditure, expressed relative to FFM).	• Cyclists should aim for the upper or lower levels of this recommended range based on their overall activity level outside of structured cycling training. • Individual energy requirements vary widely and accurately estimating energy intake, exercise expenditure and FFM in free-living conditions is challenging. Given large interindividual variability along with the potential for error in estimation, we recommend that these estimates should be used as guidelines and adjusted according to individual goals and progress. • Meeting these recommendations may be challenging during heavy training periods or competition; however, short periods of LEA are unlikely to be problematic if ample recovery time follows and the cyclist maintains habitual energy adequacy in the long term.
Carbohydrate: Intake should be adapted to training demand, for example: • Light training (~1 hr/day): 5–7 g/kg. • Moderate training (1–3 hr/day): 6–10 g/kg. • Intense training (>4 hr/day): >8 g/kg.	• Emerging evidence suggests that carbohydrate availability is important to support bone and that low carbohydrate availability, rather than LEA, may drive acute changes in bone biomarkers following short-term energy restriction (Dolan et al., 2024; Fensham et al., 2022). • As the primary fuel source for moderate- to high-intensity exercise, carbohydrate intake should be adjusted based on training volume to support performance and potentially to protect bone health. • Most daily carbohydrate should come from whole foods like pasta, rice, potatoes, fruits, and vegetables, which provide essential nutrients in addition to carbohydrates. Carbohydrate gels and sports drinks may be useful supplements, particularly while riding.
Protein: Consume 1.6–2.1 g·kg·day ⁻¹ , ideally spread across the day (Morton et al., 2025).	• Protein supports bone health by providing essential building blocks to support its organic matrix, promoting anabolic hormones and growth factors, and preserving muscle mass and function. • Intakes toward the upper end of this recommendation may be more appropriate if the cyclist is in a period of low energy or carbohydrate availability or to promote recovery on rest days following strenuous training.
Calcium and vitamin D: • 800–1,200 mg/day of calcium. • Maintain serum 25(OH)D levels > 75 nmol/L.	• Approximately 99% of body calcium is contained within the bone, and this calcium is required to ensure structural integrity by ensuring adequate bone mineralization. The bone also acts as a mineral reservoir, which can be released if required to support critical metabolic processes such as vascular contraction and vasodilation, muscle function, and nerve transmission. Inadequate dietary calcium intake necessitates increased calcium liberation from the bone, which can be detrimental if sustained. • Precise calcium requirements for cyclists are unknown; however, intakes toward the higher end of the recommended range may be prudent, considering that cyclists may have an increased dermal calcium loss due high sweat rates during prolonged rides. • Timing of daily calcium intake may be important, considering the cycling-induced increases in CTX-1 described in the “Challenge 2: Acute Metabolic Responses to Prolonged Cycling Bouts” section. Meta-analysis of eight studies, including five on cycling, indicates that calcium supplementation consumed before or during the cycling bout can attenuate, but not fully prevent, these cycling-induced increases in CTX-1 (Dolan et al., 2024). • Calcium should ideally come from the diet, with rich dietary sources including dairy products such as milk, cheese, or yogurt; green leafy vegetables such as kale, okra, and spinach; or fortified foods. • Vitamin D enhances calcium absorption from the intestine and is required for adequate bone mineralization. • Vitamin D can be sourced from sunlight exposure and dietary sources (e.g., fatty fish such as salmon or mackerel or fortified foods). • In the case of vitamin D insufficiency (serum 25(OH)D < 75 nmol/L) or difficulty in obtaining adequate dietary calcium, supplementation may be useful.
Other nutrients: Adequacy of various other micronutrients, including magnesium, phosphorous, vitamins C and K, and essential fatty acids.	• Diets that are primarily based in whole foods, from a variety of food groups, and that meet all above recommendations are likely to contain adequate amounts of all of these micronutrients. • If indicated via blood testing, or if there are concerns about nutrient inadequacy due to dietary restriction, then a multivitamin and mineral supplement may be useful to ensure micronutrient adequacy.

Note. FFM = fat-free mass; LEA = low energy availability; 25(OH)D = 25-hydroxyvitaminD; CTX-1 = C-terminal telopeptide of Type I collagen.

Table 2 Key Educational Messages for Promoting Bone Health in Cyclists

Key educational messages	Details and supporting references
Reducing fracture risk	Fractures can have devastating consequences for a cyclists’ career and are the most common reason for withdrawal from the Tour de France (Haeberle et al., 2018). Even when occurring outside of competition, the length of time lost in training while recovering from fracture can have severe performance implications (Ray Smith & Drew, 2016). Cyclists with low BMD tend to have a higher fracture incidence (Hilkens et al., 2023), and strengthening bones through targeted nutrition and exercise may potentially reduce risk for traumatic fractures, thus reducing injury related career setbacks.
Protect longer term bone health	Most adults reach their peak bone mass by approximately 30 years, with the majority of lifetime bone mass laid down during adolescence. Failure to accrue sufficient bone during adolescence and early adulthood can increase the risk for bone disorders such as osteoporosis in later life.
Small changes can lead to large gains	Small increases in BMD result in large increases in bone strength (Bouxsein et al., 2019). BMD can be improved through brief, targeted high-impact exercises that require minimal time and energy, such as jump training (Hilkens et al., 2024; Hutson et al., 2020). Furthermore, the nutritional recommendations summarized in Table 1 may bring numerous other health and performance benefits, in addition to protecting bone.

Note. BMD = bone mineral density.

educational materials and courses to promote awareness about bone health among cycling teams and individual cyclists.

Outstanding Questions and Potential Research Directions

Recognition of the importance of supporting cyclist bone health has started to gain traction, but much remains unknown about both the causes and consequences of reported low bone mass in cyclists. Substantial further investigation is required to fill important gaps in the current knowledge base and to test the feasibility and efficacy of potential bone-protective strategies. Specific research lines that may provide particularly useful information include the following.

Longitudinal Studies Across Cycling Careers

Long-term studies that track bone health from the start of a cycling career, through active competition, and postcareer could provide valuable insights. Including outcomes, such as participation in other modalities or sports; primary and secondary REDs indicators; and incidence, cause, severity, and duration of fractures would be beneficial. Due to the scope of data required to observe trends and contributing factors to bone mass and fracture risk, these studies would benefit from large, collaborative international consortiums that harmonize assessment and reporting strategies across jurisdictions.

Expanding Research Beyond Road Cycling, BMD Assessments, and Male Cyclists

To date, most research has focused on road cyclists. There is a need to better understand bone health and its determinants across other cycling modalities, such as MTB, cyclo-cross, BMX, and track cycling. Furthermore, most current research has focused on BMD, which is only one determinant of bone strength. Incorporation of other assessment modalities, including High-Resolution Peripheral Quantitative Computed Tomography will be useful to assess bone microarchitecture and to estimate bone strength. Finally, available evidence is primarily based on male cyclists, whereas females may have unique challenges when it comes to maintaining bone health. These include a tendency toward lower bone and muscle mass, a higher proportion of body fat, a potentially greater susceptibility to

the negative consequences of prolonged LEA (Nattiv et al., 2021), and additional hormonal influences, such as menstrual fluctuations, hormonal contraceptive use and menopause. Recently, impaired cortical and trabecular microarchitecture were reported for a group of elite female road cyclists (Hilkens et al., 2025). Furthermore, analysis of injury rates at a large off-road cycling competition indicated a higher fracture risk in female compared with male competitors (Kronisch et al., 2002). This was, however, based on a single race, and insufficient data are currently available to determine whether bone outcomes are comparatively worse in females. Further research is required to explore the influence of sex on bone health in cyclists.

Testing the Efficacy of Bone-Protective Interventions

Above, we proposed various nutritional, exercise, and lifestyle-related recommendations, as well as screening, education, and policy-based strategies. While these recommendations are based upon existing evidence, controlled research is needed to determine their effectiveness in safeguarding bone health among cyclists. Although fracture incidence would be the ideal endpoint to evaluate bone-protective interventions, this may not always be feasible, given the unpredictability and multiple potential contributors to cyclist fracture. Therefore, alternative endpoints, such as static bone measures (BMD or High-Resolution Peripheral Quantitative Computed Tomography) or bone biomarkers for more dynamic responses, may be appropriate for exercise and nutrition studies.

Summary and Conclusions

In summary, various factors, including the lack of mechanical loading, metabolic disruptions during prolonged cycling, nutritional challenges such as LEA or low nutrient availability and a potential predisposition toward a light lean phenotype may combine and interact to create a “perfect storm” to threaten cyclist bone health. Protecting bone health in cyclists requires a multifaceted approach involving nutritional, exercise, and lifestyle interventions, along with regular screening, education, and policy changes. By collaborating with healthcare professionals, and sport and exercise scientists and fostering a culture that prioritizes bone health, support teams and organizations can reduce fracture risks and support long-term athlete performance and well-being.

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Nontechnical Summary

Exercise and sports participation are usually considered beneficial for bone health, and it is often assumed that athletes have stronger, more resilient bones than nonathletes. This is not necessarily the case, however, and participation in some sports has been linked to reduced bone density. Cycling is one such example. Research shows that cyclists, particularly high-level road cyclists, tend to have lower bone mass than athletes in other sports, and even compared with nonathletes. This is concerning because less dense bones are more prone to fracture, and young adults with low BMD may also have an increased risk of developing longer term health problems, such as osteoporosis, later in life.

In this article, we discuss a number of factors that may contribute to low bone density in cyclists. Bone responds best to high-impact, multidirectional loads. In contrast, cycling, and particularly road cycling, is a low-impact activity involving repetitive movements, meaning it provides limited stimulus to strengthen bone. Long rides can also trigger short-term metabolic changes that increase bone breakdown. Adequate fueling is also critical, not only to support performance but also for bone health. Nutritional factors key to protecting bone include sufficient energy availability, along with adequate intakes of bone-important nutrients including calcium, vitamin D, carbohydrate, and protein. Yet, cyclists are considered a high-risk group for low energy availability and potentially for REDs (Relative Energy Deficiency in Sport). This

is partly due to the very high energy demands of cycle training and competition but also from the perception that a lower body mass can improve performance—a belief that can encourage restrictive eating behaviors and potential health problems if taken too far. Many competitive cyclists are also naturally quite lean and light—traits that may be useful when climbing but which are also linked with lower bone mass.

None of these factors on their own stand out as the sole, or even primary, reason for low bone mass in cyclists. Instead, we believe they may combine and interact to create a “perfect storm” for cyclist bone health.

Tackling these multiple challenges requires a multifaceted approach. At the individual level, cyclists should prioritize adequate energy intake and meet targets for key bone-supporting nutrients, including carbohydrate, protein, calcium, and vitamin D. Adding short bouts of high-impact activity to training and ensuring adequate sleep and recovery may also be important to protecting bone health. The onus should not remain solely on the individual, however, and cycling teams and organizational bodies have important roles to play in providing screening and educational strategies to support cyclist bone health. Fostering healthy cultures around body weight management and discouraging excessively restrictive eating behaviors could also go a long way in supporting rider well-being and performance, both now and in the future.