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## **Iron Deficiency and Athletic Performance in Endurance Disciplines: A Scoping Review**

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**Abstract**

**Background:** Iron deficiency is one of the most common nutritional deficiencies in athletes and is particularly prevalent in endurance disciplines. Even without anemia, reduced iron availability may impair aerobic performance, increase fatigue, and affect training adaptation.

**Objective:** This scoping review aimed to evaluate the impact of iron deficiency, with or without anemia, on athletic performance and fatigue in endurance athletes.

**Methods:** A literature search was conducted in PubMed and Google Scholar. Peer-reviewed studies published in English between 2000 and 2026 were included. Eligible studies assessed iron status in endurance athletes in relation to performance, fatigue, or exercise-induced changes in iron metabolism. Studies involving non-athletic populations, children or adolescents, animal models, and case reports were excluded.

**Results:** Iron deficiency was consistently reported as highly prevalent among endurance athletes, particularly females. Athletes with depleted iron stores frequently demonstrated reduced aerobic capacity, lower  $\text{VO}_2\text{peak}$ , and increased fatigue, even in the absence of anemia. Exercise-induced elevations in hepcidin were commonly observed, especially during periods of intensified training, potentially limiting iron absorption and availability. Iron supplementation was associated with improvements in aerobic performance and fatigue in iron-deficient athletes, particularly when baseline ferritin levels were low.

**Conclusion:** Iron deficiency is a clinically relevant condition in endurance athletes and may impair performance and increase fatigue even without anemia. Regular monitoring of iron status and individualized management strategies are essential to support health and performance in endurance sports.

**Keywords:** iron deficiency, iron deficiency anemia OR anaemia, physical training, physical activity, endurance athletes, endurance training, athletic performance

## **1. Introduction**

Iron is an essential nutrient for oxygen transport, energy production, and muscle function, all of which are crucial for endurance exercise. Adequate iron availability supports hemoglobin and myoglobin formation and helps maintain efficient aerobic metabolism. The body carefully regulates iron absorption, storage, and recycling to meet physiological needs while preventing excess accumulation (Gozzelino et al., 2016; Shokrgozar et al., 2019). When this balance is disturbed, iron deficiency can develop and negatively affect physical performance.

Iron deficiency is the most common nutritional deficiency worldwide (Kumar et al., 2022) and is frequently observed in physically active individuals (Pengelly et al., 2025; Clénin et al., 2015). It develops gradually, beginning with reduced iron stores and potentially progressing to iron deficiency anemia. Importantly, functional limitations may appear even before anemia develops, as insufficient iron can impair aerobic energy production and increase feelings of fatigue (Damian et al., 2021). As a result, iron deficiency without anemia is now recognized as a relevant condition in sports medicine.

Athletes, particularly those involved in endurance sports, are exposed to several factors that increase their risk of iron deficiency. Exercise-associated iron deficiency is considered a multifactorial condition resulting from increased iron losses and changes in iron regulation related to training (Goldstein, 2016). Repetitive impact during running and similar activities can lead to red blood cell breakdown, while gastrointestinal bleeding and iron loss through sweat further contribute to reduced iron availability (Damian et al., 2021; Goldstein, 2016).

Endurance training also affects iron regulation through inflammation-related mechanisms. Exercise-induced increases in hepcidin, the hormone that controls iron absorption and recycling, can temporarily reduce iron availability following training sessions (Gozzelino & Arosio, 2016). During periods of high training volume or intensified training, repeated elevations in hepcidin may limit iron absorption over time, even when dietary iron intake appears sufficient (Damian et al., 2021).

From a practical perspective, iron deficiency in athletes often presents with nonspecific symptoms such as persistent fatigue, reduced training tolerance, slower recovery, and decreased exercise capacity, which can make early detection difficult in sports settings (Damian et al., 2021; Goldstein, 2016). Because these symptoms may overlap with normal training fatigue, iron deficiency is frequently overlooked until performance decrements become more pronounced.

Despite increasing awareness of iron deficiency in endurance athletes, differences remain in screening approaches, diagnostic thresholds, and management strategies across sports settings. In addition, the underlying mechanisms and performance implications of iron deficiency without anemia are not consistently addressed in the literature. This lack of consistency may contribute to delayed diagnosis and suboptimal management in endurance-trained populations.

Therefore, the aim of this scoping review is to summarize current evidence on iron deficiency in endurance athletes, with a focus on underlying mechanisms and their relevance to athletic performance and fatigue.

## **2. Research materials and methods**

### **2.1 Data Collection and Literature Search**

A comprehensive literature search was conducted using the PubMed and Google Scholar databases to identify relevant studies examining iron deficiency and its impact on athletic performance in endurance disciplines. The search strategy combined the following keywords and their variations: iron deficiency, iron deficiency anemia OR anaemia, physical training, physical activity, endurance athletes, endurance training, athletic performance.

The search focused on studies investigating iron status, iron metabolism, performance outcomes, and fatigue-related measures in athletic populations, with particular emphasis on endurance sports. Reference lists of relevant articles and systematic reviews were manually screened to identify additional eligible studies.

### **2.2 Study Selection and Eligibility Criteria**

This scoping review aimed to identify and synthesize available evidence examining iron deficiency, its underlying mechanisms, and its implications for performance and fatigue in endurance athletes. Peer-reviewed studies published in English between 2000 and 2026 were considered eligible for inclusion.

Studies were included if they met the following criteria:

- (1) involved adult athletes ( $\geq 18$  years),
- (2) focused on endurance disciplines or endurance-dominant training,
- (3) assessed iron status (e.g., serum ferritin, hemoglobin, transferrin saturation, or hepcidin),  
and
- (4) reported outcomes related to athletic performance, aerobic capacity, or fatigue.

The exclusion criteria were: studies involving children or adolescents, case reports, animal or in vitro studies, studies conducted in non-athletic or recreationally active populations, and publications not available in full text or not written in English.

All identified records were initially screened based on titles and abstracts. Full-text articles were subsequently reviewed for eligibility according to the predefined inclusion and exclusion criteria. Study selection was conducted independently, and any discrepancies were resolved through discussion.

### **3. Results**

#### **3.1 Prevalence of Iron Deficiency in Endurance Athletes**

Across the included studies, iron deficiency was consistently reported as a common finding in endurance athletes. Prevalence estimates varied depending on sex, competitive level, and diagnostic criteria; however, endurance-based disciplines showed higher rates of iron deficiency compared with non-endurance sports. Keller et al. (2024) reported that iron deficiency was present in a substantial proportion of endurance-trained athletes, with higher prevalence observed in female athletes. Similar prevalence ranges were summarized in the systematic review by Pengelly et al. (2025), which reported iron deficiency in approximately 15–35% of female endurance athletes and 3–11% of male endurance athletes.

Observational cohort studies further supported these findings. Nabeyama et al. (2023) reported a high prevalence of iron deficiency among university endurance athletes, with many athletes affected despite the absence of anemia. Similarly, Jegatheesan et al. (2025) observed a high prevalence of suboptimal iron status among Indian female endurance athletes, alongside insufficient dietary iron intake. Narrative reviews also identified endurance sports, such as long-distance running, rowing, and cycling, as disciplines with an elevated risk due to high training volumes and repeated mechanical stress (Peeling et al., 2014; Damian et al., 2021). Collectively, these studies indicate that iron deficiency is a frequent condition in endurance athletes across different populations and competitive levels.

#### **3.2 Iron Deficiency Without Anemia**

Several studies reported that iron deficiency without anemia was more prevalent than iron deficiency anemia in endurance athletes. Observational data indicated that many athletes presented with reduced serum ferritin concentrations while maintaining hemoglobin values within reference ranges (Keller et al., 2024; Nabeyama et al., 2023). This biochemical profile was particularly common among female endurance athletes.

Findings from cohort and cross-sectional studies demonstrated that iron deficiency without anemia was associated with altered iron parameters despite preserved erythrocyte indices (Zamelska et al., 2023; Jegatheesan et al., 2025). Systematic and narrative reviews further highlighted that reliance on hemoglobin alone may underestimate the true burden of iron deficiency in athletic populations (Pengelly et al., 2025; Damian et al., 2021). These results indicate that iron deficiency without anemia represents a common presentation in endurance-trained athletes.

### **3.3 Iron Status and Aerobic Performance**

Associations between iron status and aerobic performance were consistently reported across observational and interventional studies. Keller et al. (2024) observed that endurance athletes with iron deficiency exhibited significantly lower  $VO_{2peak}$  values compared with iron-sufficient athletes, including athletes without anemia. These findings were supported by evidence synthesized in the systematic review by Pengelly et al. (2025), which reported reduced aerobic capacity and endurance-related performance outcomes in iron-deficient athletes across multiple studies.

Additional evidence was provided by population-specific studies. Jegatheesan et al. (2025) reported positive associations between iron status, dietary iron intake, and endurance performance in female athletes, indicating that athletes with better iron status demonstrated superior endurance outcomes. Intervention studies further demonstrated performance-related effects of iron repletion. DellaValle and Haas (2014) reported improved energetic efficiency during submaximal exercise following iron supplementation in iron-depleted, nonanemic female rowers, while Hinton et al. (2000) observed improved endurance performance after training in iron-depleted women receiving iron supplementation. Together, these findings indicate that iron availability is closely linked to aerobic performance and exercise efficiency.

### **3.4 Fatigue and Functional Impairment**

Fatigue and reduced functional capacity were frequently reported in athletes with iron deficiency. Narrative reviews described fatigue, impaired training tolerance, and delayed recovery as common manifestations of iron depletion, even in the absence of anemia (Damian et al., 2021; Alaunyte et al., 2015). These symptoms were often reported as nonspecific, complicating early recognition in athletic settings.

Intervention studies provided further evidence linking iron status to functional outcomes. In iron-depleted female athletes, iron supplementation was associated with improvements in endurance capacity and reductions in perceived fatigue (Hinton et al., 2000; DellaValle & Haas, 2014). Findings summarized by Pengelly et al. (2025) further indicated that restoration of iron status was commonly accompanied by improvements in fatigue-related outcomes across endurance athletes.

### **3.5 Iron Regulation During Training and Exercise Load**

Several studies examined alterations in iron regulation in response to acute and repeated exercise stress. Domínguez et al. (2018) reported significant increases in serum hepcidin concentrations following an acute bout of endurance exercise, indicating a transient suppression of iron absorption during the post-exercise period. In well-trained female endurance athletes, Ishibashi et al. (2017) demonstrated that serum hepcidin levels were significantly elevated during periods of intensified training, coinciding with reduced iron availability. Subsequent studies further showed that repeated endurance exercise sessions may lead to cumulative effects on iron regulation, with sustained elevations in hepcidin observed following twice-daily training sessions (Ishibashi et al., 2022).

Sex-specific modulation of iron homeostasis was further highlighted by Alfaro-Magallanes et al. (2022), who demonstrated that interval running exercise elicited different hepcidin responses depending on the menstrual cycle phase in endurance-trained women. Observational data also indicated that regular physical activity is associated with measurable alterations in iron-related biomarkers, reflecting adaptive responses to training load (Zamelska et al., 2023). Additionally, Okazaki et al. (2019) reported that iron insufficiency attenuated the erythropoietic response to moderate altitude exposure, underscoring the importance of adequate iron availability for physiological adaptation in endurance athletes.

## **4. Discussion**

This scoping review demonstrates that iron deficiency remains a prevalent and performance-relevant condition in endurance athletes, influencing aerobic capacity, fatigue, and training adaptation. The findings align with existing narrative and applied literature emphasizing iron as a key micronutrient in sports performance and athlete health (Damian et al., 2021; Kardasis et al., 2023). Importantly, the reviewed evidence supports the concept that iron deficiency may

impair performance even in the absence of anemia, reinforcing the need for a broader interpretation of iron status in athletic populations.

#### **4.1 Iron Deficiency and Performance Implications in Athletes**

Iron plays a central role in oxygen transport, oxidative metabolism, and energy production, all of which are critical for endurance performance. As highlighted by Kardasis et al. (2023), iron deficiency may negatively affect athletic performance through multiple pathways, including reduced hemoglobin mass, impaired mitochondrial function, and decreased efficiency of aerobic metabolism. These mechanisms provide a physiological basis for the observed reductions in aerobic performance and exercise tolerance reported in iron-deficient endurance athletes.

Clinical and sports medicine perspectives further emphasize that iron deficiency should be viewed as a continuum rather than a binary condition defined solely by anemia. Clénin et al. (2015) highlighted that functional impairments related to iron deficiency may develop before overt anemia becomes apparent, particularly in athletes exposed to high aerobic demands. This framework aligns closely with the findings of the present review and underscores the need to consider iron deficiency as a distinct and clinically relevant condition in sports performance.

#### **4.2 Iron Balance, Supplementation, and Sex-Specific Considerations**

Female athletes are consistently identified as a population at heightened risk of iron deficiency due to menstrual blood loss, dietary factors, and increased iron requirements associated with training. Pedlar et al. (2018) provide a practical framework for understanding iron balance in female athletes, emphasizing the interaction between intake, losses, and regulation. Their work highlights that iron supplementation may be beneficial in iron-deficient athletes when appropriately timed and individualized, particularly during periods of heavy training.

The practical implications of iron balance are especially relevant for endurance athletes, who often experience cumulative iron losses over prolonged training cycles. Pedlar et al. (2018) stress that supplementation strategies should be guided by regular monitoring of iron status markers rather than applied indiscriminately, a recommendation that aligns with the need for individualized athlete care identified in the current review.

### **4.3 Exercise-Induced Regulation of Iron Metabolism**

Emerging evidence suggests that exercise itself plays an important role in regulating iron availability through hepcidin-mediated pathways. Goto et al. (2020) demonstrated that resistance exercise induces greater elevations in serum hepcidin compared with endurance exercise, likely due to higher inflammatory responses. This finding has important implications for athletes engaged in mixed training programs, as repeated elevations in hepcidin may reduce iron absorption and contribute to negative iron balance over time.

Kardasis et al. (2023) further discuss how training load, exercise modality, and recovery periods interact to influence iron regulation in athletes. These insights support the notion that iron deficiency in endurance sports is not solely a nutritional issue but also a consequence of training-related physiological stress. Understanding these regulatory mechanisms is essential for optimizing iron management strategies in high-performance settings.

### **4.4 Clinical and Practical Implications**

Together, the findings of this review and supporting literature reinforce the importance of comprehensive iron assessment in endurance athletes. Damian et al. (2021) advocate for screening approaches that extend beyond hemoglobin measurement, incorporating ferritin and clinical symptoms such as fatigue and reduced performance. Such approaches may facilitate earlier detection of iron deficiency and prevent progression to anemia.

From a practical standpoint, the integration of nutritional strategies, training load management, and individualized supplementation protocols appears essential for maintaining optimal iron status. As emphasized by Pedlar et al. (2018) and Kardasis et al. (2023), effective iron management should be athlete-specific, evidence-based, and responsive to changes in training demands.

**Limitations** of the study include the use of two databases, PubMed and Google Scholar, which may have resulted in relevant studies indexed elsewhere being missed. Additionally, only articles available in full text for free were considered, potentially excluding important evidence from subscription-based journals. Finally, considerable differences were present across the included studies in terms of athlete populations, sport disciplines, training status, and definitions of iron deficiency, limiting the ability to directly compare findings.

## **5. Conclusions**

This scoping review demonstrates that iron deficiency is a common and clinically relevant condition in endurance athletes, with meaningful implications for aerobic performance, fatigue, and training adaptation. Evidence consistently shows that iron deficiency occurs frequently in endurance disciplines, particularly among female athletes, and often presents without anemia. Importantly, depleted iron stores alone are sufficient to impair aerobic capacity, energetic efficiency, and functional performance, even when hemoglobin concentrations remain within normal ranges.

The reviewed studies indicate a clear association between iron status and aerobic performance, with lower iron availability linked to reduced  $\text{VO}_2\text{peak}$ , diminished exercise efficiency, and increased fatigue. Intervention studies further suggest that restoring iron stores can improve performance-related outcomes in iron-deficient athletes, including those without anemia. These findings underscore the importance of recognizing iron deficiency as a performance-limiting factor rather than solely a hematological disorder.

In addition, the regulation of iron metabolism is strongly influenced by training load, exercise modality, and physiological stress. Exercise-induced increases in hepcidin, particularly during periods of intensified or repeated training, may contribute to reduced iron absorption and availability. Sex-specific factors, including menstrual blood loss and hormonal fluctuations, further modulate iron homeostasis in female endurance athletes, increasing vulnerability to iron deficiency.

Overall, the findings of this review support a comprehensive and individualized approach to iron assessment and management in endurance sports. Regular monitoring of iron status markers beyond hemoglobin, consideration of training demands, and tailored nutritional or supplementation strategies are essential to optimize performance, reduce fatigue, and support long-term athlete health.

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Not applicable

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### **Authors contributions**

Maria Król - conceptualization, methodology, software, heck, formal analysis, investigation, resources, data curation, writing - rough preparation, writing - review and editing, supervision, project administration.

Mikołaj Patalong - investigation, resources, project administration

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Przemysław Kołodziej - writing - rough preparation

Mieszko Czaplinski - investigation, resources, writing - rough preparation

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Wiktoria Michnowska - writing - review, and editing

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All of the authors read and agreed with the final version of the manuscript.

### **Informed consent statement**

Not applicable.

### **Data availability statement**

Not applicable.

### **Conflict of interest**

The authors declare no conflict of interest in relation to this study.

### **Declaration of Generative AI and AI-Assisted Technologies**

During the preparation of this work, the authors used ChatGPT (OpenAI) to improve grammar and language clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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