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The influence of iron deficiency on athletic performance – a narrative review

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Abstract

Background: Iron deficiency represents one of the most prevalent nutritional disorders among athletes. Iron plays a crucial role in oxygen transport, energy production, and the proper functioning of muscles. A deficiency in iron can lead to a reduction in physical performance, an increase in fatigue, and complications in recovery.

Objective of the Study: The primary objective of this research was to conduct an analysis of contemporary literature concerning the impact of iron deficiency on the physical performance of athletes. Additionally, the study aimed to discuss risk factors, diagnostic strategies, and potential supplementation options related to this issue.

Materials and Methods: A narrative literature review was conducted encompassing the years 2015 to 2024. A comprehensive analysis was performed on review articles, clinical studies, and experimental research identified through the PubMed and Google Scholar databases. The selected publications focused on iron metabolism, exercise performance, and supplementation among physically active individuals.

Results: Contemporary research indicates that iron deficiency can significantly affect aerobic capacity, increase the sensation of fatigue, and impair recovery. Endurance athletes and women are particularly vulnerable to this deficiency. Adequate diagnostic measures and the administration of supplements may enhance performance parameters and reduce the risk of decreased athletic endurance.

Keywords: iron deficiency, iron metabolism, athletes, athletic performance, supplementation

Content

1.Introduction

Iron is a crucial microelement essential for the proper functioning of the human body. It plays a significant role in numerous metabolic processes, including oxygen transport, energy production, and DNA synthesis. Iron is a fundamental component of hemoglobin and myoglobin, thereby facilitating oxygen delivery to tissues and ensuring optimal muscle function. Furthermore, it is involved in the activity of mitochondrial enzymes that participate in cellular respiration and ATP production [3,7,35]. Consequently, maintaining adequate iron levels is paramount for ensuring physical endurance and effective recovery within the body [5,35]. Athletes, particularly those engaged in endurance training, are at an elevated risk of iron deficiency [3,11]. Regular physical exercise can lead to increased iron requirements and greater losses of this micronutrient [6,35]. Among the factors contributing to the development of iron deficiency in athletes are increased sweating, microtraumas to the gastrointestinal tract, exercise-induced hemolysis, urinary iron loss, and elevated hepcidin activity post-exercise [1,2,8,17,21]. Additional contributors include restrictive dietary practices and low consumption of iron-rich foods [12,29,38]. This issue is notably prevalent among female athletes [11,14,16]. Iron deficiency can manifest as both anemia and a latent deficiency without a reduction in hemoglobin concentration [5,16]. Even minor deviations in iron homeostasis can result in diminished physical performance, increased feelings of fatigue, impaired recovery, and reduced exercise capacity [5,31,35]. A decreased iron level negatively impacts oxygen transport, mitochondrial function, and the energy processes occurring in muscles [7,13,35]. As a consequence, this can lead to a decline in sports performance and an increased risk of overtraining and injuries [5,35].In recent years, there has been a growing emphasis on the importance of adequate iron diagnostics and supplementation in athletes [4,10,35]. Research indicates that appropriately selected supplementation can enhance performance and support the body's recovery [25,34,35]. Adhering to a balanced diet, ensuring the availability of vitamin C, and minimizing factors that inhibit iron absorption are also critical considerations [6,12,29].The aim of this study is to analyze current literature regarding the impact of iron deficiency on the physical performance of athletes, elucidate the mechanisms leading to disturbances in iron metabolism, and explore supplementation strategies.

2.1 Iron Metabolism and Its Biological Role

Iron plays a crucial role in oxygen transport, aerobic metabolism, and energy production within cells. It is an essential component of hemoglobin, myoglobin, and mitochondrial enzymes, all of which are necessary for the proper functioning of oxidative phosphorylation and adenosine triphosphate (ATP) synthesis [3,7,35]. A deficiency of iron can lead to impaired mitochondrial functions, consequently resulting in a reduction in aerobic capacity [13,35]. Furthermore, diminished iron availability may also result in decreased ATP production, accelerated fatigue, and a decline in maximum oxygen uptake (VO_2 max) [5,13,35]. Dietary iron is primarily absorbed in the duodenum and the proximal segment of the small intestine [39]. It exists in two forms: heme and non-heme iron. Heme iron is predominantly found in animal products and exhibits higher bioavailability [6,38]. In contrast, non-heme iron is mostly derived from plant sources and requires reduction to Fe^{2+} to be adequately absorbed [12]. Once internalized by enterocytes, iron may either be temporarily stored as ferritin or transported into the bloodstream [39,40]. The export of iron from cells is mediated by ferroportin [39]. Subsequently, iron binds to transferrin, which is responsible for its transportation to various tissues, including the bone marrow, where it plays a vital role in erythropoiesis [40]. Hepcidin is a key regulator of the body's iron homeostasis, as it modulates iron availability by binding to ferroportin and inducing its degradation [39,40]. During physical activity, hepcidin levels transiently increase, which may restrict intestinal iron absorption [1,2,9]. Iron deficiency adversely affects the body's performance while also heightening feelings of fatigue [5,11,35]. Individuals engaged in endurance sports are at an increased risk of depleting their iron reserves [3,13,35].

2.2 Causes of Iron Deficiency in Athletes

Intensive physical exertion increases the body's demand for iron, placing athletes at an elevated risk of experiencing deficiencies in this essential micronutrient [3,6,35]. Physical activity leads to an increase in the concentration of interleukin-6, which stimulates the production of hepcidin [1,2]. Elevated levels of hepcidin can result in reduced intestinal absorption of iron [9,18,39]. Another contributing factor is the hemolysis of erythrocytes induced by micro-traumas occurring during physical exertion [8,13]. This phenomenon is particularly relevant in endurance sports, where mechanical forces can compress capillaries and damage erythrocytes within the vessels [13,21]. Damaged erythrocytes undergo lysis, releasing their iron content. While a portion of this iron may be reabsorbed, repeated injuries can gradually deplete these stores [8,21]. Furthermore, intense physical activity also results in the loss of iron through perspiration and urine [3,6]. Prolonged training may lead to micro-injuries in the gastrointestinal tract [17], potentially resulting in diminished blood flow, which disrupts the integrity of the intestinal mucosa [24]. The lifestyle of athletes often necessitates a specific, restrictive diet, which may frequently supply inadequate amounts of iron [12,38]. Vegetarians and vegans are particularly vulnerable in this regard [12,38]. Additionally, certain compounds such as calcium and polyphenols have been identified as inhibitors of iron absorption [29]. It is imperative to consider the menstrual cycle in female athletes, as the loss of menstrual blood is one of the most significant risk factors for iron deficiency in women, making them a particularly susceptible group to this micronutrient deficiency [11,14,16].

2.3 The Impact of Iron Deficiency on Physical Performance

Iron is a fundamental component of hemoglobin, which is present in erythrocytes. Hemoglobin is responsible for the binding of oxygen in the lungs and its subsequent transport to tissues [3, 35]. A deficiency in iron leads to a reduction in hemoglobin levels, thereby significantly impairing the transport of oxygen to muscles during physical exertion [5, 13]. Additionally, iron is an integral part of cytochromes, iron-sulfur proteins, and mitochondrial enzymes that play crucial roles in the electron transport chain and oxidative phosphorylation [7, 13]. Consequently, a lack of iron disrupts electron transport within mitochondria, resulting in diminished ATP production, which is a critical energy source for active muscles [13, 35]. This ultimately leads to accelerated muscle fatigue, a decline in aerobic capacity, and reduced exercise efficiency [5, 35]. Moreover, the decreased energy production coupled with tissue hypoxia contributes to a persistent sensation of weakness, fatigue, and lower exercise tolerance [11, 31, 35]. An additional significant aspect is the impairment of recovery processes associated with iron deficiency. This deficiency may hinder the repair of muscle damage and prolong the recovery time required [31, 35]. Furthermore, there are scenarios in which hemoglobin levels may be normal, yet ferritin levels are reduced. This indicates diminished iron reserves, which may adversely affect mitochondrial function, energy production, and exercise capacity [5, 16]. Thus, low ferritin levels, even in the presence of normal hemoglobin levels, can result in decreased physical performance and increased fatigue [5, 16, 35].

2.4 Iron Supplementation in Athletes

Appropriately selected iron supplementation may enhance physical performance and athletic outcomes [5,10,35]. Its primary objective is to replenish iron stores and improve oxygen transport [5]. Iron supplements are commonly utilized by individuals engaged in training who exhibit iron deficiency or low ferritin levels [10,25]. Addressing such deficiencies has been shown to enhance aerobic capacity, reduce feelings of fatigue, improve exercise tolerance, and support recovery following microtrauma [11,34,35]. Moreover, athletes with normal hemoglobin levels but reduced ferritin levels might also benefit from supplementation, as latent iron deficiency can similarly impair physical performance [5,16]. The most prevalent form of supplementation is oral intake [25]. The presence of vitamin C positively influences iron absorption by increasing the bioavailability of iron; it accomplishes this by reducing ferric ions Fe^{3+}

to a more absorbable ferrous form Fe^{2+} [6,12]. Additionally, vitamin C forms soluble complexes with iron, preventing its precipitation and facilitating absorption within the gastrointestinal tract. The optimal timing for supplement intake is in the morning on an empty stomach, as food can hinder iron absorption [6,29]. Furthermore, certain dietary components, such as calcium, polyphenols, and dietary fiber, can bind iron within the gastrointestinal system, thereby diminishing its bioavailability [29,38]. Oral supplementation may elicit adverse effects, with the most common being gastrointestinal disturbances, including nausea, abdominal pain, and constipation [4,6]. An alternative to oral administration is intravenous supplementation, which is indicated in cases of substantial deficiencies or lack of efficacy from oral therapy [5,36]. Intravenous administration rapidly replenishes iron stores; however, it must be performed under medical supervision [36]. When determining the type and dosage of supplementation, it is crucial to tailor the therapy to individual characteristics, including sex, the specific sport practiced, the degree of deficiency, and training load [4,35].

2.5 Factors Influencing Iron Absorption

The absorption of iron is influenced by a multitude of factors that are both dietary and physiological in nature. A notable enhancer of iron bioavailability is vitamin C, which reduces Fe^{3+} ions to the more readily absorbable Fe^{2+} form [6,12]. Furthermore, vitamin C forms soluble complexes with iron, facilitating its absorption within the gastrointestinal tract [12]. The presence of ascorbic acid may significantly increase the absorption of non-heme iron, which is characterized by lower bioavailability compared to heme iron [6,12]. Heme iron is predominantly found in animal-derived products; therefore, athletes adhering to plant-based diets may be at a heightened risk for deficiencies in this essential micronutrient [12,38]. Conversely, certain compounds can inhibit iron absorption in the gastrointestinal tract. These include calcium, polyphenols, and phytic acid, which form insoluble complexes with iron, as well as dietary fiber [29,38]. Consequently, it is recommended to supplement iron on an empty stomach to prevent food from impeding absorption [6,29]. Another critical aspect is the level of hepcidin, a key regulator of iron homeostasis in the body [39,40]. Hepcidin concentrations tend to increase following physical exertion, resulting in the degradation of ferroportin and a subsequent reduction in iron absorption [1,2,9]. Additionally, gender plays a significant role, with women being considerably more susceptible to iron deficiency due to cyclical menstruation [11,16].

Dietary restrictions also represent an important factor, as they often lead to inadequate iron intake [12,38].

3. Discussion

Iron deficiency constitutes a significant concern within the athletic population, particularly affecting individuals engaged in endurance sports and women [3,11,35]. Iron plays a critical role in oxygen transport and energy production; thus, disruptions in iron homeostasis can lead to decreased physical performance among athletes [3,7,35]. Research indicates that symptoms of iron deficiency may manifest even before the development of overt anemia [5,16]. One of the primary mechanisms influencing physical endurance is the impairment of mitochondrial function. Iron is an integral component of cytochromes and iron-sulfur proteins, which are involved in electron transport and oxidative phosphorylation [7,13]. A deficiency in iron results in a reduced ATP production, which consequently leads to accelerated fatigue and diminished performance [13,35]. Furthermore, inadequate oxygen transport contributes to lowered exercise tolerance and prolonged recovery times [31,35]. Prolonged and intense physical exertion has been associated with increased levels of interleukin-6, which stimulates the production of hepcidin [1,2]. Elevated hepcidin levels lead to the degradation of ferroportin and a reduction in intestinal iron absorption [9,39,40]. Athletes engaged in endurance training, particularly those subjected to frequent and intensive training loads, are especially vulnerable [3,35]. Another group at heightened risk for iron deficiency is women, particularly those who are active. Studies have shown that female athletes frequently exhibit lower ferritin levels [11,14]. Menstruation is one of the primary risk factors associated with iron deficiency in this population [16]. Additionally, the issue of latent iron deficiency remains significant. Despite normal hemoglobin levels, decreased ferritin can result in impaired physical performance [5,16]. This evidence suggests that the mere assessment of blood morphology may be insufficient for evaluating iron metabolism. Consequently, the importance of monitoring ferritin levels is emphasized [35]. In the context of iron deficiency, supplementation constitutes a pivotal component of therapy [5,25,35]. The most common form of supplementation is oral administration; however, in cases where this method proves ineffective or in instances of significant deficiencies, intravenous administration should be considered [25,36]. Such treatment must be conducted under the supervision of a qualified medical professional [36]. Therapy should be tailored to the individual patient [4,35]. Moreover, the concurrent use of vitamin C and the administration of supplements on an empty stomach are of considerable significance [6,12,29]. Appropriately implemented supplementation can support bodily recovery, enhance physical performance, and reduce feelings of fatigue [11,34,35]. It is important to note that current research varies significantly in terms of methodological approaches, the duration of supplementation, type of supplementation, and the characteristics of the studied populations [4,35]. This variability poses challenges in achieving a definitive assessment of the effectiveness of iron supplementation among athletes. There is a need for further studies involving larger groups of athletes, as well as standardization of methodologies for assessing iron metabolism. Despite existing limitations, it appears that appropriate diagnostics, prevention, and treatment of iron deficiency may play a critical role in enhancing aerobic performance, reducing recovery time, and mitigating the risk of deteriorating athletic results [35].

4. Conclusions

1. Iron deficiency is a prevalent issue among athletes, particularly those engaged in endurance training, as well as among women.
2. Iron plays a critical role in oxygen transport, mitochondrial function, and adenosine triphosphate (ATP) production; thus, disturbances in iron homeostasis may lead to diminished physical performance and hinder the body's recovery processes.
3. Subclinical iron deficiency, even in the absence of concurrent anemia, can adversely affect the exercise capabilities of athletes.
4. Regular monitoring of iron metabolism parameters, including ferritin levels, is essential for the prevention of declines in aerobic performance.
5. Appropriately tailored iron supplementation alongside a suitable diet can aid in the recovery of the body and enhance the physical performance of athletes.
6. Further research is necessary to evaluate the efficacy of iron supplementation and to establish standardized methods for assessing iron metabolism in athletes.

5. Declarations

Author's contribution

Conceptualization: Marcelina Malinowska

Software: Martyna Bartela

Formal analysis: Martyna Bartela, Marcelina Malinowska

Investigation: Marcelina Malinowska

Resources: Marcelina Malinowska

Data curation: Martyna Bartela

Writing-rough preparation: Martyna Bartela

Writing-review and editing: Marcelina Malinowska

Supervision: Martyna Bartela

Project administration: Martyna Bartela, Marcelina Malinowska

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