International Journal of Current Research and Review
DOI: https://doi.org/10.31782/IJCRR.2025.171502

Review Article

IJCRR
Section: Healthcare

The Impact of Iron Deficiency in Professional Endurance Athletes - A Review

Anna Zdziebło[1], Anna Bieniasz[2], Katarzyna Zdziebło[3], Maria Sitko[4], Dominika Stolarczyk[5], Aleksandra Bąk[6], Igor Biernacki[7], Katarzyna Agopsowicz[8], Katarzyna Blicharz[9], Piotr Mojżesz[10]

[1]Student, Medical University of Rzeszów Faculty of Medicine, al. mjr Wacława Kopisto 2a, 35-315 Rzeszów, Poland; [2]Student, Jagiellonian University Medical College, ul. Świętej Anny 12, 31-008 Kraków, Poland; [3]Medical Doctor, Specialist Hospital of Edmund Biernacki in Mielec, ul. Żeromskiego 22, 39-300 Mielec, Poland; [4]Student, Jagiellonian University Medical College, ul. Świętej Anny 12, 31-008 Kraków, Poland; [5]Student, Jagiellonian University Medical College, ul. Świętej Anny 12, 31-008 Kraków, Poland; [6]Student, Jagiellonian University Medical College, ul. Świętej Anny 12, 31-008 Kraków, Poland; [7]Student, Medical University of Lodz, al. Tadeusza Kościuszki 4, 90-419 Łódź, Poland; [8]Medical Dentistry Doctor, Medical University of Warsaw Faculty of Dentistry, Żwirki i Wigury 61, 02-091 Warszawa, Poland; [9]Student, Medical University of Silesia, Faculty of Medical Sciences in Zabrze, plac Traugutta Street 2, 41-800 Zabrze, Poland; [10]Medical Dentistry Doctor, Medical University of Silesia Faculty of Dentistry, Plac Akademicki 17, 41-902 Bytom, Poland.

ABSTRACT

Iron plays a crucial role in oxygen transport and energy production processes, making it an especially important micronutrient for endurance athletes. Iron deficiency, both overt (iron-deficiency anemia) and latent (low ferritin levels with normal hemoglobin), can lead to impaired physical performance, decreased maximal oxygen uptake (VO_2 max), fatigue, and prolonged recovery time. Athletes—especially women, long-distance runners, and those undergoing intense training are particularly vulnerable to iron deficiency due to increased losses (e.g., via sweat, gastrointestinal microbleeds, menstruation) and insufficient dietary intake. This paper is a review of the latest journals and scientific articles and discusses the mechanisms by which iron deficiency affects athletic performance, diagnostic methods, as well as prevention and treatment strategies. The importance of individualized approaches and monitoring of iron levels is emphasized in the context of optimizing athletic performance and health.

Key Words: “Iron,” “Iron deficiency,” “Iron deficiency in endurance athletes,” “Iron metabolism” ,” ‘Iron deficiency treatment”, athletic performance and health

INTRODUCTION

Iron (Fe) is one of the most important trace elements in the human body. It plays a key role in many biological processes, including oxygen transport, energy metabolism, and the functioning of the immune system. Iron is a fundamental component of hemoglobin and myoglobin—proteins responsible for oxygen binding and transport. This ensures oxygen delivery to all cells, which is essential for their proper functioning. Iron deficiency may cause anemia, defined as a decrease in hemoglobin concentration in the blood. It has been shown that both anemia and iron deficiency without anemia lead to a reduction in mitochondrial count and decreased activity of respiratory enzymes. Iron deficiency without anemia negatively affects the oxidative capacity of muscles, while anemia primarily impairs oxygen transport. [30]

Iron is also essential in metabolic processes such as the Krebs cycle, which leads to the production of ATP—the primary energy carrier in cells. Without adequate iron levels, the body cannot efficiently produce energy, which may result in fatigue and reduced physical performance. Iron is also a component of enzymes such as catalase and peroxidase, which protect cells from oxidative stress. Additionally, it is involved in detoxification processes in the liver, supporting the removal of toxins from the body.

The total iron content in an adult human body is approximately 3.5–4.5 g—around 4 g in men and 3–3.5 g in women. Daily iron losses are approximately 1–2 mg. [2]

Iron exists in the human body in two primary forms:

- **Heme iron** – found in animal-derived foods, mainly in hemoglobin and myoglobin. It is more bioavailable and efficiently absorbed in the digestive tract.
- **Non-heme iron** – present mainly in plant-based products. Its absorption is less efficient and depends on the presence of enhancing or inhibiting factors.

Corresponding Author:
Anna Zdziebło, Student, Medical University of Rzeszów Faculty of Medicine, al. mjr Wacława Kopisto 2a, 35-315 Rzeszów, Poland.
Email: ania.zdzieblo@onet.pl

ISSN: 2231-2196 (Print) **ISSN:** 0975-5241 (Online)

Received: 02.07.2025 **Revised:** 31.07.2025 **Accepted:** 08.08.2025 **Published:** 15.08.2025

Enhancers of iron absorption include:

- Vitamin C
- Organic acids (e.g., citric acid, lactic acid)
- Peptides and amino acids from meat and fish

Inhibitors of iron absorption include:

- Phytates
- Polyphenols
- Calcium
- Phosphates and oxalates

Long-term use of proton pump inhibitors for acid reflux, *Helicobacter pylori* infection, or inflammatory conditions (e.g., celiac disease) may also reduce non-heme iron absorption.[6]

In a balanced diet, the average daily intake of elemental iron is about 5–15 mg and 1–5 mg of heme iron. Ultimately, only 1–2 mg is absorbed in the intestine, mainly in the duodenum and proximal jejunum. [3, 4]

Unlike most essential nutrients, humans have no active mechanisms for iron excretion. Small amounts are lost via shedding of skin and gastrointestinal cells, as well as in bile and urine. However, in athletes, primary iron losses occur through gastrointestinal microbleeds and intestinal ischemia during intense exercise, [7, 8] excessive sweating, [9] and potential losses through the urogenital tract. [10] Foot-strike hemolysis—mechanical destruction of red blood cells in long-distance runners—is another cause.[11] Recent studies also highlight the role of **hepcidin** in iron loss.[12]

Hepcidin, a liver-produced peptide hormone, plays a central role in iron metabolism. It regulates iron absorption and release by inhibiting intestinal absorption and iron release from macrophages during exercise or inflammation, reducing serum iron concentration. Its secretion is correlated with ferritin levels.[13]

The mechanism begins with iron being absorbed in enterocytes as ferritin. For iron to enter the plasma, it must be exported by **ferroportin**, a membrane protein on the basal side of enterocytes. Once in circulation, iron binds to **transferrin** and is transported to the liver for storage (as ferritin) or to iron-utilizing tissues, e.g., bone marrow.

All forms of physical activity trigger a certain level of inflammation in the body, which—along with repair mechanisms—form the basis of training adaptation. The magnitude of the inflammatory response depends on the type, intensity, and duration of exercise. Many markers of iron metabolism change as part of the acute-phase response.[26]

Intensive training has been shown to significantly increase hepcidin levels, [28, 29] that reduces iron absorption and interferes with its transport to erythroblasts, potentially leading to deficiency.

Interestingly, athletes with lower iron stores may have reduced hepcidin levels, promoting greater iron absorption.[28,29]

The aim of this review is to present and discuss the current state of knowledge regarding the causes, symptoms, diagnosis, and treatment of iron deficiency in professional athletes. The work seeks to compile the most recent findings from the scientific literature, identify existing research gaps, and highlight the importance of early detection and appropriate therapeutic interventions in preventing complications associated with iron deficiency.

Iron Status Diagnostics

The following laboratory tests are used to assess iron status:

- **Hemoglobin (Hb)** and **hematocrit (Hct)** – basic anemia indicators
- **MCV** – mean corpuscular volume
- **MCHC** – mean corpuscular hemoglobin concentration
- **Ferritin** – marker of iron stores
- **Serum iron concentration** – reflects circulating iron
- **TIBC** (Total Iron-Binding Capacity)
- **Transferrin** – iron transport protein

Iron deficiency can be divided into several types depending on its effect on hematopoiesis:

- **NAID (Non-Anemic Iron Deficiency)** – iron deficiency without changes in Hb or red blood cell indices
- **IDMH (Iron Deficiency Microcytosis with or without Hypochromia)** – normal Hb with decreased RBC volume (<82 fl) and hemoglobin content (<28 pg)
- **AID (Anemic Iron Deficiency)** – decreased Hb and red blood cell indices. Anemia is defined as Hb <130 g/L in men and <120 g/L in women. [16]

It is crucial to note that iron deficiency cannot be excluded based solely on normal Hb levels, as significant iron depletion must occur before Hb begins to decline. Thus, low MCH or high red cell distribution width (RDW) with normal Hb may suggest mild iron deficiency.[15]

Ferritin is the most commonly used parameter to assess iron status. Levels >30 mcg/L are considered normal. Values <30 mcg/L indicate low stores, while levels <15 mcg/L suggest total depletion. In elite endurance athletes, ferritin should exceed 30 mcg/L.[14, 16] However; ferritin is an acute-phase protein and may be elevated during inflammation, which is common in athletes undergoing intense training.

Serum iron concentration is **not** recommended for assessing iron status due to its daily fluctuations and possible false elevation due to hemolysis during blood collection.[18]

Treatment of Iron Deficiency

Diet is the first-line approach, as it is a natural and safe method for replenishing iron without the side effects associated with supplementation. A well-balanced diet also provides vitamins (e.g., C, B12, folate) that aid in iron absorption and red blood cell production, helping to maintain long-term iron

balance. In mild deficiencies, dietary changes alone may be sufficient. The recommended daily intake is approximately 14 mg of iron.[20, 21]

Best-absorbed sources of iron include:

- **Heme iron** from red meat, offal, poultry, and fish (bioavailability: 15–35%)
- **Non-heme iron** from legumes, whole grains, and leafy vegetables (bioavailability: 2–20%)

Absorption promoters:

- Vitamin C – reduces non-heme iron to Fe^{2+}
- Lactic and organic acids – found in fermented foods
- Meat, fish – the "MFP factor" that enhances absorption

Absorption inhibitors:

- Polyphenols – in coffee, tea, cocoa
- Phytates – in seeds, nuts, grains
- Calcium – competes with iron for absorption
- Phosphates and oxalates – in spinach, rhubarb

It is advisable to limit coffee or tea consumption for 1–2 hours before and after iron-rich meals and replace them with, for example, a glass of orange juice.[23]

Iron Supplementation

Iron supplementation is recommended in cases of diagnosed iron deficiency or anemia, especially when dietary modifications prove insufficient or the deficiency is advanced. Iron should not be taken without recommendation, an excess of it in the body can lead to serious health issues such as liver, heart, or pancreas damage. Iron supplementation is necessary only in cases of confirmed deficiency. Supplementation can be oral or in selected cases, intravenous. Oral supplementation is generally considered first-line treatment due to its lower cost and fewer risks, although it often causes gastrointestinal side effects such as nausea, constipation, or abdominal discomfort.

Types of oral supplements:

- **Ferrous iron salts** – e.g., ferrous sulphate, gluconate, fumarate – the most common and best absorbed
- **Ferric iron preparations** – less efficiently absorbed
- **Polysaccharide-iron complexes** – better tolerated but may be less effective

It is generally recommended to take iron on an empty stomach, but due to gastrointestinal side effects, taking it with food is acceptable, although this slightly reduces absorption. Co-administration with vitamin C is advised, as it significantly improves absorption.

Recommended doses:

- For iron-deficiency anemia: 100–200 mg elemental iron per day in divided doses
- For latent deficiency or prevention in at-risk individuals (e.g., female athletes, vegetarians): 30–60 mg/day

Research shows that alternate-day supplementation (e.g., every other day) may be more effective and better tolerated than daily dosing, especially in women with low iron stores. [24] This is due to the regulation of hepcidin levels, which rise after oral iron intake and can block further absorption if supplements are taken too frequently.

Intravenous iron supplementation is used in more severe cases, in those with intolerance to oral preparations, or when rapid replenishment of iron stores is required. It is usually performed under medical supervision and carries a risk of allergic reactions.[17]

Table 1: Iron deficiency treatment

Treatment method	Advantages	Disadvantages	Recommendation
Oral supplementation	- Easy to use - Low price - Over-the-counter availability	• Common side effects (nausea, constipation, abdominal pain) • Slower onset of action	• Mild to moderate deficiency • No gastrointestinal contraindications
Intravenous supplementation	• Rapid therapeutic effect • Bypasses the digestive system	• Requires medical supervision • Risk of allergic reactions • Higher cost	• Severe deficiency • Intolerance to oral preparations • Gastrointestinal diseases
Dietary modification	• Natural sources of iron • Supports overall health	• Requires time and consistency • Difficulty meeting demand during severe shortages	• Prevention • Complementary pharmacological treatment

Iron Deficiency in Endurance Athletes

Endurance athletes, particularly women, long-distance runners, and adolescents, are at high risk of iron deficiency due to several overlapping mechanisms:

- **Increased iron losses:**
  - o Through sweat
  - o Gastrointestinal microbleeding caused by ischemia during prolonged exercise
  - o Hematuria (blood in urine) after long runs
  - o Foot-strike hemolysis in runners
  - o Menstruation in female athletes
- **Increased demand:**
  - o For red blood cell production during training adaptation

  - For muscle myoglobin
  - Due to muscle microdamage
- **Dietary insufficiency:**
  - Low intake of iron-rich foods (e.g., in vegetarians or individuals with restricted caloric intake)
  - Inhibitors of absorption in diet
- **Hepcidin elevation:**
  - Training-induced inflammation increases hepcidin secretion
  - Elevated hepcidin reduces iron absorption and release from stores

Studies have shown that up to **50% of female endurance athletes** may have depleted iron stores (ferritin <30 µg/L), and iron deficiency anemia is diagnosed in up to 15% of them.[24] Iron deficiency, even without anemia, has been associated with reduced endurance performance, lower VO_2 max, increased perception of fatigue, and prolonged recovery time.[17, 25]

Recommendations for Monitoring and Prevention

Monitoring frequency:

- At least once a year in amateur athletes
- 2–3 times a year in professional endurance athletes
- Immediately if symptoms such as chronic fatigue, poor performance, or paleness occur

Recommended lab tests:

- Hemoglobin
- Hematocrit
- MCV, MCH
- Ferritin
- CRP (C-reactive protein – to assess inflammation, which may affect ferritin interpretation)

Prevention strategies:

- Diet rich in heme iron
- Timing iron intake with enhancers (e.g., vitamin C)
- Avoiding inhibitors (coffee, tea, calcium) around meals
- Supplementation when indicated, ideally under the supervision of a sports physician or dietitian

DISCUSSION

Iron deficiency in athletes remains a multifactorial condition, influenced by increased physiological demands, training-induced inflammation, dietary factors, and, in some cases, insufficient intake of bioavailable iron. The data reviewed in this article clearly demonstrate that both iron deficiency with anemia and iron deficiency without anemia can significantly impair athletic performance, primarily through reduced oxygen delivery and impaired mitochondrial function. [29,30] This suggests that the problem extends beyond simple hemoglobin reduction and involves broader disruptions in energy metabolism.

Endurance athletes are particularly vulnerable due to cumulative iron losses through sweat, gastrointestinal microbleeding, and foot-strike hemolysis.[7-11] Female athletes additionally face menstrual losses, which further increases their risk. [10,14] Studies consistently show that up to 50% of female endurance athletes present with depleted iron stores, highlighting the importance of regular monitoring and preventive strategies. [24,25] Interestingly, recent findings point to the role of hepcidin as a key regulator of iron absorption. Exercise-induced increases in hepcidin may limit intestinal absorption and release of stored iron, even in the presence of adequate intake, suggesting that timing of iron supplementation in relation to training could be crucial. [12,27,28]

Diagnostic approaches should go beyond hemoglobin measurement alone. Ferritin, despite being affected by inflammation, remains the most reliable marker for evaluating iron status in athletes. [14,16] However, it is essential to interpret ferritin levels alongside inflammatory markers such as CRP to avoid misdiagnosis.[18] Non-anemic iron deficiency is particularly challenging to detect and may be underdiagnosed in the athletic population, despite its substantial impact on endurance and recovery. [15,16,24]

With respect to treatment, oral supplementation remains the first-line strategy, although gastrointestinal side effects and reduced compliance may limit its effectiveness. Alternate-day dosing has emerged as a promising approach, mitigating hepcidin-related absorption blocks while improving tolerance. Intravenous supplementation, although effective, should be reserved for severe cases and administered under medical supervision due to its potential risks.[25] Importantly, dietary strategies play a dual role—both in prevention and as supportive therapy during recovery from deficiency.[20,21,23]

Overall, iron deficiency represents a critical yet often underestimated factor in sports performance. Regular monitoring, early diagnosis, and individualized management strategies should form an integral part of training and medical support for endurance athletes.

LIMITATIONS

While writing the review article on iron deficiency in professional athletes, several limitations were encountered. One of the main challenges was the limited availability of recent, high-quality studies focusing exclusively on elite athletes—many publications addressed the general population or amateur athletes, making it difficult to draw conclusions specific to the professional level. Additionally, the heterogeneity of the sports disciplines examined also posed a challenge, as iron requirements can vary depending on the type and intensity of physical activity. Finally, some relevant data were published in non-English sources or were difficult to access,

which may have affected the comprehensiveness of the literature review.

CONCLUSION

Iron deficiency is a common and significant problem among endurance athletes. Due to increased physiological demand, training-induced losses, and dietary factors, athletes—especially women—are at high risk of developing both latent and manifest iron deficiency. This condition may significantly impair performance and recovery.

Proper diagnosis, regular monitoring, and targeted treatment—including both dietary and supplemental approaches—are crucial for maintaining optimal iron status and maximizing athletic potential. Education on iron metabolism and individualized nutrition plans should be integral parts of training strategies in endurance disciplines

ACKNOWLEDGEMENT

The authors self-acknowledge their effort in writing a review on iron deficiency in professional athletes. The authors acknowledge the immense help received from the scholars whose articles are cited and included in references of this manuscript.

Conflict of Interest: The authors declare no conflict of interest.

Source of Funding: This research received no specific grant from any funding agency in the public, commercial, or not for-profit sectors.

Authors' Contribution: The authors confirms sole responsibility for all aspects of this work and final approval of the version to be published

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