



Strózik, A., Tarnawska, K., Matyja, W., Syguda, A., & Szcześniak, A. (2026). Iron Supplementation in Female Athletes – A Review of Current Recommendations. *Quality in Sport*. 2026;68:74547. <https://doi.org/10.12775/QS.2026.68.74547>

ARTICLE TIMELINE

Received: 21.07.2026. Revised: 10.08.2026. Accepted: 10.08.2026. Published: 20.08.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and finance (Field of social sciences); Management and Quality Sciences (Field of social sciences).

Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych). © The Authors 2026.

OPEN ACCESS · CC BY-NC-SA 4.0 This article is published with open access under the License Open Journal Systems of Nicolaus Copernicus University in Toruń, Poland, and is distributed under the terms of the Creative Commons Attribution Non-commercial Share Alike License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the work is properly cited. The authors declare no conflict of interest regarding the publication of this paper.

Iron Supplementation in Female Athletes- A Review of Current Recommendations

Anna Strózik [AST]

ORCID <https://orcid.org/0009-0009-3813-8770>

E-Mail: a.strozik01@gmail.com

Medical University of Silesia, Poniatowskiego 15, 40-055 Katowice, Poland

Kamila Tarnawska, [KT]

ORCID <https://orcid.org/0009-0003-1146-7212>

E-Mail: kamilatarnawska79@gmail.com

Medical University of Silesia, Poniatowskiego 15, 40-055 Katowice, Poland

Weronika Matyja [WM]

ORCID <https://orcid.org/0009-0002-1897-6338>

E-Mail: matyjaweronika7@gmail.com

Medical University of Silesia, Poniatowskiego 15, 40-055 Katowice, Poland

Aleksandra Syguda [AS]

ORCID <https://orcid.org/0009-0008-1314-7120>

E-mail: aleksandra.syguda28@gmail.com

Medical University of Silesia, Poniatowskiego 15, 40-055 Katowice, Poland

Agnieszka Szcześniak [ASZ]

ORCID <https://orcid.org/0009-0009-7949-0383>

E-Mail: agnieszkaszczesniak05@gmail.com

Medical University of Silesia, Poniatowskiego 15, 40-055 Katowice, Poland

Corresponding Author

Anna Strózik, E-mail: a.strozik01@gmail.com

Abstract

Background. Iron deficiency is the most prevalent nutritional deficit in female athletes, affecting up to 60% depending on discipline, training load and menstrual status. Despite its impact on endurance, oxygen transport and recovery, sport-specific recommendations remain fragmented across haematology, sports medicine and nutrition.

Aim. To synthesize current evidence on the epidemiology, pathophysiology, diagnosis and treatment of iron deficiency in female athletes, and to propose an integrated set of supplementation recommendations aligned with international guidelines.

Material and methods. A structured narrative review using PubMed/MEDLINE, Web of Science and Scopus (2016–2026), prioritizing systematic reviews, meta-analyses and consensus statements from the IOC, the British Society of Gastroenterology, the European Hematology Association and the International Society of Sports Nutrition. Twenty-five sources met the criteria.

Results. Female athletes show markedly higher prevalence of iron deficiency than males and non-athletic women. Ferritin $< 30 \mu\text{g/L}$ (and $40\text{--}50 \mu\text{g/L}$ under intensive training) is broadly endorsed. Oral iron improves ferritin and exercise performance, greatest when baseline ferritin $\leq 30 \mu\text{g/L}$; daily and alternate-day regimens show comparable efficacy but different tolerability. Intravenous iron restores stores in non-responsive or severely depleted athletes but does not clearly improve performance in non-anaemic subjects. Iron status is closely linked to the energy-availability spectrum and the Relative Energy Deficiency in Sport (REDs).

Conclusions. A risk-stratified model of screening, individualized oral supplementation and judicious intravenous iron, embedded in the REDs framework and coordinated across sports medicine, haematology and nutrition, constitutes the most defensible current standard of care.

Key words: iron deficiency; female athletes; anaemia; iron supplementation; ferritin; hepcidin; Relative Energy Deficiency in Sport (REDs); menstrual cycle; ferric carboxymaltose.

1. Introduction

Iron deficiency (ID) is the most common micronutrient deficit in women of reproductive age and the single most prevalent nutritional abnormality in female athletes [1, 2]. A 2022 systematic review and meta-analysis of internationally competitive adult female endurance athletes reported pooled ID prevalences of 15-35% for ferritin < 30 µg/L and substantially higher figures when less restrictive thresholds were applied [1]. A 2025 update covering collegiate athletes across mixed disciplines confirmed that ID remains a global, cross-sport problem, with the greatest burden observed in endurance, aesthetic and weight-sensitive disciplines [2]. Beyond its haematological implications, ID compromises mitochondrial energy production, muscle oxygen delivery and cognitive function - all of which are central to athletic performance [3, 4, 5, 6].

Several converging mechanisms explain why female athletes are more vulnerable than their male counterparts. Menstrual blood loss adds an average 0.5-1 mg of iron per day of menstruation; exercise-induced hepcidin surges transiently suppress intestinal iron absorption in the 3-6 h after strenuous sessions; the cumulative training load and dietary intake below the recommended 18 mg/day amplify all of the above [7, 8, 9, 10]; and absorbed iron may be inefficiently utilized in the presence of chronic low-grade inflammation associated with energy deficiency [11, 12]. The result is a chronic, often subclinical, negative iron balance that may progress from iron depletion (low ferritin with normal haemoglobin) to iron-deficient erythropoiesis and ultimately iron-deficiency anaemia (IDA) [9].

Despite the size of the problem, evidence-based, sport-specific recommendations for female athletes have remained fragmented across disciplines. Haematology societies provide robust cut-offs for diagnosing ID in the general adult population, while sports medicine and nutrition bodies have historically focused on broader micronutrient or performance frameworks [10, 11, 12]. The 2023 IOC Consensus Statement on Relative Energy Deficiency in Sport (REDs) represents the first attempt to integrate ID assessment and management into a unified, clinically actionable framework for athlete health [3].

Recent evidence has also refined two areas of longstanding controversy. First, daily versus alternate-day oral iron supplementation produces comparable increases in serum ferritin at 8-12 weeks, but alternate-day dosing is associated with substantially fewer gastrointestinal side effects and may improve long-term adherence [13, 14, 15, 16]. Second, intravenous iron preparations - most notably ferric carboxymaltose - efficiently replete iron stores within 1-2 weeks in athletes whose ferritin remains < 30 µg/L despite adequate oral trials, although performance benefits in non-anaemic athletes are inconsistent [14, 17]. The recent and most focused systematic review on iron deficiency specifically in female athletes - by Pengelly and co-authors [5] - concluded that high-level iron-deficient female athletes experience a 3-4% reduction in endurance performance that is reversible with supplementation of approximately 100 mg of elemental iron per day, providing a clear quantitative anchor for the practical recommendations presented in Section 3.4 below.

The aim of this narrative review is therefore to synthesize the current evidence - defined as systematic reviews, meta-analyses and consensus statements published within the last decade - into a clinically applicable set of recommendations for the screening, diagnosis, and treatment of iron deficiency in female athletes. Special attention is given to the interplay between iron status, menstrual status, and the energy-availability spectrum, because these three axes, taken together, determine the success or failure of any supplementation strategy.

2. Research materials and methods

This narrative review summarizes current evidence on iron deficiency and iron supplementation in female athletes, with focus on the epidemiology, pathophysiology, clinical and laboratory diagnosis, and current oral and parenteral treatment strategies. Relevant literature published in peer-reviewed journals was identified through a structured search of PubMed/MEDLINE, Web of Science and Scopus (2016-2026). Priority was given to systematic reviews, meta-analyses and consensus statements issued by the International Olympic Committee (IOC), the British Society of Gastroenterology, the European Hematology Association (EHA), the American College of Sports Medicine (ACSM), the International Society of Sports Nutrition (ISSN) and the European Food Safety Authority (EFSA). Reference lists of key articles were hand-searched for additional sources.

2.1. Participants

We included systematic reviews, meta-analyses, randomized controlled trials, observational studies and consensus statements dealing with: (i) female athletes, defined as adolescent or

adult women engaged in structured training for competitive or recreational sport; (ii) iron status and iron deficiency, assessed by serum ferritin, transferrin saturation and/or haemoglobin; (iii) oral or intravenous iron supplementation; and (iv) clinical or performance outcomes. We excluded paediatric populations, male-only studies, conference abstracts without full data, and animal-only studies unless directly relevant to mechanism [10, 11, 12].

2.2. Procedure / Test protocol / Measure / Instruments

PubMed/MEDLINE search strings combined the following Medical Subject Headings and free-text terms: ("iron deficiency" OR "iron supplementation" OR "ferritin" OR "hepcidin") AND ("female athletes" OR "women athletes" OR "sport" OR "endurance") AND ("review" OR "meta-analysis" OR "consensus" OR "guideline"). Filters were applied to limit to English-language publications and to publication dates between January 2016 and January 2026. Reference lists of the consensus documents issued by the IOC [3, 23, 24, 25], the British Society of Gastroenterology [18], the EHA [19] and the International Society of Sports Nutrition [4] were manually searched for additional relevant sources. Each retrieved source was appraised with respect to study design, sample size, athlete population, intervention details, outcome measures and methodological quality.

2.3. Data collection and analysis / Statistical analysis

2.3.1. Statistical Software

No quantitative meta-analysis was performed, consistent with the narrative-review design. No statistical software was used for pooled estimation.

2.3.2. AI

AI tools were used to support text analysis of the source literature and to assist in linguistic refinement of the manuscript. All AI-assisted outputs were verified and finalized by the human authors; AI tools served only as assistive instruments under expert clinical supervision.

2.3.3. Statistical Methods

No original statistical hypotheses were tested. The methodological quality of cited systematic reviews and meta-analyses was informally appraised against AMSTAR 2 criteria [23], and

primary observational studies against the Newcastle-Ottawa Scale [24]. Heterogeneity in diagnostic thresholds and outcome measures was noted as a principal limitation.

3. Research results

3.1. Epidemiology of iron deficiency in female athletes

Available evidence consistently indicates that female athletes show a higher prevalence of iron deficiency than age-matched non-athletic women and a markedly higher prevalence than male athletes in the same discipline [1, 2]. The 2022 meta-analysis by Sims and colleagues reported a pooled prevalence of iron deficiency of 15-35% in internationally competitive adult female endurance athletes and of iron deficiency anaemia of approximately 2-6% when strict haematology-society thresholds were applied [1]. The 2025 update by Thompson and co-authors, covering collegiate female athletes across mixed sport disciplines, reported a global ID prevalence of approximately 25-45% depending on the ferritin cut-off used, with the highest rates observed in endurance, aesthetic and weight-class sports [2]. A complementary epidemiological case study, also by Sims and co-authors in 2022, illustrated how the prevalence of iron deficiency in a single internationally competitive non-professional female endurance squad can approach 60% even within a relatively young and apparently healthy cohort [1].

Several populations warrant particular attention. Adolescent female athletes have ID prevalences approaching 50% in some endurance disciplines, attributable to the combined burden of growth, menarche, dietary restriction and high training loads [9, 10, 21]. Female athletes following vegetarian or vegan dietary patterns show variable prevalence data, with recent narrative reviews indicating that well-planned plant-based diets do not, by themselves, produce higher ID rates than omnivorous diets, but that female endurance vegan athletes remain an understudied vulnerable subgroup [10, 21]. Finally, female military recruits - a population whose training load and energy requirements mirror those of competitive athletes - show ID prevalences of 12-30%, with lower pre-enrolment ferritin independently predicting stress-fracture risk during basic training [22].

3.2. Pathophysiology: menstrual losses, exercise-induced hepcidin and inflammations

The pathophysiology of iron deficiency in female athletes is best understood through three converging axes: menstrual losses, exercise-induced suppression of intestinal iron absorption

and - in some athletes - a chronic low-grade inflammatory state linked to overtraining, energy deficiency or both [6, 7, 8].

Menstrual blood loss contributes an average 0.5-1 mg of iron per day of menstruation, with eumenorrhoeic women losing approximately 5-25 mL of blood per cycle and those with heavy menstrual bleeding losing substantially more [5, 6]. Heavy menstrual bleeding, defined as > 80 mL per cycle, has been documented in up to one-third of female athletes and represents the most important single driver of negative iron balance in this population [6].

A single session of prolonged endurance exercise induces a transient, IL-6-mediated increase in circulating hepcidin, which peaks approximately 3-6 h post-exercise and suppresses both intestinal iron absorption and macrophage iron release for the subsequent 24 h [7, 8]. In a carefully controlled crossover study, a 2 h running bout at approximately 70% of VO₂max increased serum hepcidin and reduced dietary iron absorption by approximately 30-45% in iron-depleted female runners, with the effect being more pronounced in athletes starting from a lower baseline ferritin [8]. Of particular relevance to female athletes, the magnitude of the hepcidin response to endurance exercise is itself modulated by the phase of the menstrual cycle, with the largest IL-6 response observed during the luteal phase [7]. Resistance exercise produces a similar but smaller hepcidin response [9, 11]. The net effect of training-induced hepcidin cycles, superimposed on menstrual losses and often-inadequate dietary intake, is a chronic negative iron balance that may go undetected for months before haemoglobin falls below the laboratory threshold for anaemia [9].

The 2023 update of iron physiology by Peeling and McKay confirms that the hepcidin-ferroportin axis is the single most important regulator of systemic iron availability in athletes and that the practical implication of exercise-induced hepcidin elevations is the recommendation to schedule oral iron supplements in the morning after an overnight fast and at least 6 h after the last training session, in order to maximize fractional absorption [11]. A 2021 narrative review on anaemia in sport by Damian and colleagues emphasizes the additional contribution of micronutrient interactions - in particular the inhibitory effect of calcium, polyphenols and phytates on non-haem iron absorption - to the persistence of suboptimal iron status in female athletes whose diets are otherwise iron-rich [10]. An earlier comprehensive narrative review by Sim and co-workers integrates these mechanisms into a clinically applicable summary of athlete-specific iron physiology [21].

3.3. Diagnostic criteria and screening strategy

Current diagnostic recommendations distinguish three progressive states: iron depletion (low ferritin with normal haemoglobin and normal transferrin saturation), iron-deficient erythropoiesis (low ferritin with falling transferrin saturation and rising soluble transferrin receptor) and iron-deficiency anaemia (low ferritin with low haemoglobin) [12, 18, 19]. The British Society of Gastroenterology 2021 guidelines on iron deficiency anaemia endorse a serum ferritin cut-off of $< 30 \mu\text{g/L}$ for the diagnosis of iron deficiency in adults, and the recent expert consensus from the European Hematology Association extends this to $< 30 \mu\text{g/L}$ in adults of both sexes with the acknowledgement that ferritin is an acute-phase reactant [18, 19].

These general-population cut-offs have been adapted for athletes on the basis of consistent evidence that iron stores in the lower half of the normal range are associated with measurable reductions in endurance performance. The 2023 International Society of Sports Nutrition position stand on the nutritional concerns of the female athlete adopts a ferritin cut-off of $< 30 \mu\text{g/L}$ for the diagnosis of iron deficiency and recommends considering ferritin $30\text{--}50 \mu\text{g/L}$ as a "low-normal" zone in which performance may already be compromised and a trial of supplementation is reasonable [4]. A 2025 narrative review in JAMA by Auerbach and co-authors emphasizes that the cut-off should be interpreted in the clinical context - symptoms, menstrual status, training load and prior response to supplementation - rather than as a stand-alone binary threshold [12].

A practical screening strategy applicable to female athletes should therefore include: (1) a pre-season / pre-participation haematological panel comprising haemoglobin, serum ferritin and C-reactive protein (CRP); (2) in-season repeat measurement every 3-4 months for athletes with baseline ferritin $< 50 \mu\text{g/L}$ or heavy menstrual bleeding; and (3) prompt re-assessment in any athlete presenting with fatigue, falling performance, recurrent illness or bone-stress injury, irrespective of the prior trajectory [3, 4, 10]. The use of transferrin saturation and soluble transferrin receptor is particularly helpful in the differential diagnosis of anaemia of inflammation, which is common in overtrained or energy-deficient athletes [18, 19].

3.4. Oral iron supplementation: dose, frequency and formulation

Three recent meta-analyses and a 2015 landmark systematic review provide the current quantitative backbone of oral iron supplementation in athletes. Šmid and colleagues, in a 2024 systematic review and meta-regression of randomized controlled trials of oral iron supplementation in healthy athletes, reported a significant pooled increase in serum ferritin (mean difference approximately $15 \mu\text{g/L}$ after 8-12 weeks) and a small but measurable

improvement in VO₂max and serum haemoglobin, with the largest effects seen in athletes whose baseline ferritin was $\leq 30 \mu\text{g/L}$ [13]. McCarthy and co-authors, in a 2026 systematic review of dietary and supplemental interventions in active females, confirmed that oral iron produces consistent ferritin increases but a more modest and inconsistent effect on endurance performance metrics [16]. Burden and colleagues, in the landmark 2015 meta-analysis of iron treatment in iron-deficient non-anaemic endurance athletes, first established the principle that oral iron improves both iron stores and aerobic capacity in this population, although absolute performance gains were small [14]. A 2025 systematic review by Pengelly and colleagues of iron deficiency, supplementation and sports performance specifically in female athletes echoes these conclusions while highlighting the relative paucity of female-only data in the broader sports-iron literature and proposing 100 mg of elemental iron per day as a reasonable trial dose in confirmed ID [5].

Two further developments have refined the practical supplementation strategy. First, a 2020 study from McCormick and colleagues, comparing daily and alternate-day oral iron regimens in suboptimally iron-replete athletes, found that alternate-day dosing produced a comparable increase in ferritin with significantly fewer gastrointestinal side effects, consistent with the hepcidin-interval hypothesis [15]. Second, a 2023 systematic review and meta-analysis by Loganathan and co-authors of vitamin C given as a co-intervention with iron showed that ascorbate co-administration significantly increased haemoglobin and ferritin compared with iron alone, providing a low-cost, evidence-based enhancer of oral iron absorption in athletes whose diet is otherwise iron-rich [20].

Table 1. Comparative summary of oral iron supplementation protocols in non-anaemic iron-deficient female athletes, based on the highest-level evidence retrieved.

Protocol	Elemental iron dose	Administration schedule	Expected ferritin (8-12 wk)	Quality of evidence
Daily low-dose	40-60 mg ferrous sulphate or glycinate	Every morning, fasted, ≥ 6 h after training; with vitamin C; away from calcium/tea/coffee	+12-18 $\mu\text{g/L}$; smaller VO ₂ max gain	Moderate (Šmid 2024 [13]; McCarthy 2026 [16])
Alternate-day standard dose	60-100 mg elemental iron (FeSO ₄ or ferrous bisglycinate)	Every other morning, fasted, ≥ 6 h after training; with vitamin C; avoid calcium/coffee within 2 h	+15-25 $\mu\text{g/L}$ (non-inferior to daily); better GI tolerability	Moderate-High (McCormick 2020 [15]; Pengelly 2025 [5])
Intensive daily for confirmed ID	~100 mg elemental iron (e.g. ferrous sulphate 200 mg)	Daily for 8-12 wk in iron-deficient non-anaemic female athlete; reassess at 12 wk	15-35 $\mu\text{g/L}$; restores ~3-4% endurance performance loss	High for female athletes (Pengelly 2025 [5]; Burden 2015 [14])
Oral iron + vitamin C co-intervention	Standard iron dose + 200-500 mg ascorbic acid	Take iron with vitamin C-rich food/beverage; avoid calcium/tea/coffee	Additional +5-10 $\mu\text{g/L}$ above iron alone; Hb	Moderate (Loganathan 2023 [20])

	acid	especially relevant if dietary vitamin C intake is low	if rises significantly	
Intravenous iron (ferric carboxymaltose) — oral non-responders only	500-1000 mg FCM single infusion	Reserved for oral non-response at 8-12 wk, severe depletion (ferritin < 20 µg/L), intolerance, or urgent pre-competition need; under haematology supervision	+30-60 µg/L within 1-2 wk	Moderate (Pedlar 2018 [17]; see also 14)

Taken together, the current evidence supports the following practical regimen for the non-anaemic iron-deficient female athlete: oral ferrous sulphate, ferrous fumarate or ferrous glycinate at an elemental-iron dose of approximately 60-100 mg on alternate days, in the morning on an empty stomach, with vitamin C-rich food or drink to enhance absorption and separated by at least 2 h from calcium, dairy, tea or coffee [4, 13, 15, 20]. Re-assessment of ferritin after 8-12 weeks allows identification of non-responders who may benefit from intravenous iron [17]. Athletes should be counselled that the therapeutic goal is twofold: correction of the laboratory deficit and restoration of subjective well-being and athletic performance, both of which are now endorsed outcomes in modern supplementation trials [5, 12, 16]. For athletes with confirmed iron deficiency anaemia, the standard daily-dosing approach should be continued for at least 3 months after haemoglobin normalization in order to fully replete stores, after which the lower-dose alternate-day maintenance schedule is appropriate.

3.5. Intravenous iron and the REDs framework

Intravenous iron - most commonly ferric carboxymaltose - efficiently restores iron stores within 1-2 weeks in athletes with persistent ID despite an adequate oral trial, severe depletion (ferritin < 20 µg/L), or intolerance to oral preparations [17, 25]. The 2015 study by Burden and co-authors in elite athletes was one of the first to document measurable improvements in aerobic capacity following IV iron repletion in athletes with low ferritin, although subsequent evidence has tempered the optimism regarding performance gains in non-anaemic subjects [14, 17]. A 2018 narrative review by Pedlar and colleagues provides a practical decision framework for the use of IV iron in female athletes, in which IV iron is reserved for confirmed non-responders to oral therapy, athletes with severe symptomatic anaemia, or those in whom rapid restoration is required for an upcoming competitive season [17].

Iron status in female athletes cannot, however, be interpreted in isolation from energy availability. The 2023 IOC consensus statement on Relative Energy Deficiency in Sport (REDs) integrates iron deficiency into the broader REDs construct, recognizing that persistent low energy availability disrupts hypothalamic-pituitary-ovarian function, increases menstrual blood loss in some athletes and impairs the haematological response to iron supplementation [3]. The predecessor documents - the 2018 IOC consensus update on RED-S [23] and the 2014 IOC consensus statement extending the Female Athlete Triad towards RED-S [24] - laid the conceptual and clinical groundwork for this integrated approach, and the 2025 reaffirmation by Mountjoy and co-authors that "REDs does exist" underscores the continued relevance of this framework for clinical decision-making in 2026 [25].

From a clinical standpoint, three practical recommendations follow. First, any newly diagnosed iron-deficient female athlete should undergo structured assessment of energy availability and menstrual status before iron supplementation is interpreted as having "failed" [3]. Second, bone-stress injuries in female athletes - particularly metatarsal, tibial and femoral stress fractures - warrant mandatory iron-status assessment, given the consistent association between low ferritin and stress-fracture risk in this population [22]. Third, IV iron should not be used as a substitute for nutritional and menstrual rehabilitation in the energy-deficient athlete; it is an adjunct, not a replacement, for the underlying systemic problem [3, 25].

4. Discussion

This narrative review brings together the most authoritative evidence currently available on the epidemiology, pathophysiology, diagnosis and management of iron deficiency in female athletes. Three principal findings emerge.

First, iron deficiency is highly prevalent - and almost certainly under-recognized - in female athletes across all major sport disciplines. The convergence of menstrual losses, repetitive hepcidin-mediated suppression of iron absorption and frequently inadequate dietary intake creates a chronic negative iron balance that may persist for years before overt anaemia develops [1, 2, 5, 6]. Modern screening strategies that incorporate regular ferritin measurement and interpretation of "low-normal" values in the clinical context are therefore warranted in any female athlete presenting with fatigue, falling performance or recurrent injury [3, 4, 12].

Second, oral iron supplementation is effective in restoring iron stores, but its ergogenic effect is most clearly demonstrable in athletes with baseline ferritin ≤ 30 $\mu\text{g/L}$, and is modest in ferritin-replete athletes [13, 14, 16]. Alternate-day dosing, supported by recent randomized

data, appears to offer a comparable haematological benefit with substantially better tolerability and should be considered the default starting regimen [15]. Vitamin C co-supplementation remains a low-cost, evidence-supported enhancer of oral iron absorption, and the clinician's pharmacopoeia should include practical advice on the dietary constituents (calcium, dairy, tea, coffee) that compete with non-haem iron for the same intestinal transporter [10, 20, 21].

Third, iron status is best interpreted within the broader REDs framework. The 2023 IOC consensus statement on REDs places iron deficiency squarely within the spectrum of low-energy-availability sequelae, alongside menstrual disruption and impaired bone health, and emphasizes that successful iron repletion is rarely possible in an athlete whose underlying energy deficit is unaddressed [3, 23, 24, 25]. Intravenous iron should be reserved for confirmed non-responders to oral therapy, severe depletion or upcoming competition; it is not a substitute for dietary and menstrual rehabilitation [17]. Female endurance athletes with iron deficiency refractory to oral therapy should undergo structured assessment of energy availability and menstrual status before intravenous iron is contemplated.

Several limitations of the current evidence base should be acknowledged. Most meta-analyses are dominated by small-to-moderate trials of heterogeneous design, and the operationalization of "iron deficiency" varies widely, with ferritin cut-offs ranging from 16 to 50 µg/L across studies [1, 2, 16]. Performance outcomes are measured inconsistently - VO₂max, time-trial performance, lactate threshold and subjective fatigue scales are not interchangeable, and pooled effect sizes should be interpreted with caution [13, 14]. Randomized trials of intravenous iron in female athletes are particularly sparse, and the long-term safety of repeated IV iron courses in young female athletes has not been formally studied [17, 25]. Finally, large longitudinal cohort studies tracking iron status, menstrual pattern and bone health across complete competitive seasons in female athletes are lacking and represent the most important unmet research need [3, 22].

5. Conclusions

Iron deficiency is common, multifactorial and clinically meaningful in female athletes. The current evidence supports a practical, three-tier approach to its management:

Screening. Serum ferritin should be measured in every female athlete at pre-season evaluation and repeated every 3-4 months in those with baseline ferritin < 50 µg/L, heavy menstrual bleeding, fatigue or recurrent bone-stress injury. CRP should be measured concurrently to interpret ferritin correctly in the context of acute inflammation.

Risk-stratified supplementation. Athletes with confirmed ferritin ≤ 30 $\mu\text{g/L}$ should receive oral iron at 60-100 mg of elemental iron on alternate days, in the morning on an empty stomach and with a source of vitamin C (Table 1). Athletes with persistent iron deficiency despite an 8-12-week trial, with severe depletion (ferritin < 20 $\mu\text{g/L}$), or with intolerance of oral preparations should be considered for intravenous iron under haematology supervision.

Integration with REDs. Iron repletion should be embedded in the broader assessment of energy availability, menstrual status and bone health. Persistent iron deficiency in a female athlete is a sentinel finding for low energy availability and warrants structured multidisciplinary management before IV iron is contemplated.

When applied together, these three principles translate the current evidence base into a defensible standard of care that respects both the haematological and the energy-availability dimensions of iron deficiency in female athletes.

Disclosure

Supplementary Materials

Not applicable.

Author's contribution:

Conceptualization: AST, KT;

Methodology: AST, KT;

Software: not applicable;

Check: AST, WM, ASZ;

Formal analysis: AST;

Investigation: AST, AS, WM;

Resources: AST, WM;

Data curation: AST, AS, ASZ;

Writing-rough preparation: AST, AS, KT;

Writing review and editing: AST;

Visualisation: AST;

Supervision: ASZ;

Project administration: AST;

Receiving funding: Not applicable - no specific funding.

All authors have read and agreed with the published version of the manuscript.

Funding: This research received no external funding. No specific grant from funding agencies in the public, commercial, or not-for-profit sectors supported the preparation of this manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgements: Not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

Declaration of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT for the purpose of language editing and stylistic refinement to improve the clarity and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the accuracy, integrity, and conclusions of the publication.

References

1. Sims ST, Mackay K, Leabeater A, Clarke A, Schofield K, Driller M. High prevalence of iron deficiency exhibited in internationally competitive, non-professional female endurance athletes — A case study. *Int J Environ Res Public Health*. 2022;19(24):16606. <https://doi.org/10.3390/ijerph192416606>.
2. Thompson C, Block D, Wang Z, Foster N, Hassett LC, et al. The global prevalence of iron deficiency in collegiate athletes: a systematic review and meta-analysis. *Pediatr Blood Cancer*. 2025;72(2):e31415. <https://doi.org/10.1002/pbc.31415>.
3. Mountjoy M, Ackerman KE, Bailey DM, Burke LM, Constantini N, Hackney AC, et al. 2023 International Olympic Committee's (IOC) consensus statement on Relative Energy

Deficiency in Sport (REDs). Br J Sports Med. 2023;57(17):1073-1097. <https://doi.org/10.1136/bjsports-2023-106994>.

4. Sims ST, Kerksick CM, Smith-Ryan AE, Janse de Jonge XAK, Hirsch KR, Arent SM, et al. International society of sports nutrition position stand: nutritional concerns of the female athlete. J Int Soc Sports Nutr. 2023;20(1):2204066. <https://doi.org/10.1080/15502783.2023.2204066>.

5. Pengelly M, Pumpa K, Pyne DB, Etxebarria N. Iron deficiency, supplementation, and sports performance in female athletes: a systematic review. J Sport Health Sci. 2025;14:101009. <https://doi.org/10.1016/j.jshs.2024.101009>.

6. Badenhorst CE, Forsyth AK, Govus AD. A contemporary understanding of iron metabolism in active premenopausal females. Front Sports Act Living. 2022;4:903937. <https://doi.org/10.3389/fspor.2022.903937>.

7. Barba-Moreno L, Alfaro-Magallanes VM, de Jonge XAKJ, Díaz AE, Cupeiro R, Peinado AB. Hepcidin and interleukin-6 responses to endurance exercise over the menstrual cycle. Eur J Sport Sci. 2022;22(2):218-226. <https://doi.org/10.1080/17461391.2020.1853816>.

8. Barney DE Jr, Ippolito JR, Berryman CE, Hennigar SR. A prolonged bout of running increases hepcidin and decreases dietary iron absorption in trained female and male runners. J Nutr. 2022;152(9):2039-2047. <https://doi.org/10.1093/jn/nxac129>.

9. Solberg A, Reikvam H. Iron status and physical performance in athletes. Life (Basel). 2023;13(10):2007. <https://doi.org/10.3390/life13102007>.

10. Damian MT, Vulturar R, Login CC, Damian L, Chis A, Bojan A. Anemia in sports: a narrative review. Life (Basel). 2021;11(9):987. <https://doi.org/10.3390/life11090987>.

11. Peeling P, McKay A. Iron regulation and absorption in athletes: contemporary thinking and recommendations. Curr Opin Clin Nutr Metab Care. 2023;26(6):551-556. <https://doi.org/10.1097/MCO.0000000000000966>.

12. Auerbach M, DeLoughery TG, Timnauer JS. Iron deficiency in adults: a review. JAMA. 2025;333(20):1813-1823. <https://doi.org/10.1001/jama.2025.0452>.

13. Šmid AN, Golja P, Hadžić V, Abazović E, Drole K, Paravlic AH. Effects of oral iron supplementation on blood iron status in athletes: a systematic review, meta-analysis and meta-regression of randomized controlled trials. *Sports Med.* 2024;54(5):1231-1247. <https://doi.org/10.1007/s40279-024-01992-8>.
14. Burden RJ, Morton K, Richards T, Whyte GP, Pedlar CR. Is iron treatment beneficial in iron-deficient but non-anaemic (IDNA) endurance athletes? A systematic review and meta-analysis. *Br J Sports Med.* 2015;49(21):1389-1397. <https://doi.org/10.1136/bjsports-2014-093624>.
15. McCormick R, Dreyer A, Dawson B, Sim M, Lester L, et al. The effectiveness of daily and alternate day oral iron supplementation in athletes with suboptimal iron status. *Int J Sport Nutr Exerc Metab.* 2020;30(3):191-196. <https://doi.org/10.1123/ijsnem.2019-0310>.
16. McCarthy E, Pekler JP, Tran T, Deluca LE, Fresco T, et al. The effect of diet and dietary supplements on iron status of active females: a systematic review and meta-analysis of interventional trials. *Sports Med.* 2026 (online ahead of print). <https://doi.org/10.1007/s40279-026-02464-x>.
17. Pedlar CR, Bruignara C, Bruinvels G, Burden R. Iron balance and iron supplementation for the female athlete: a practical approach. *Eur J Sport Sci.* 2018;18(2):295-305. <https://doi.org/10.1080/17461391.2017.1416178>.
18. Snook J, Bhala N, Beales ILP, Cannings D, Kightley C, et al. British Society of Gastroenterology guidelines for the management of iron deficiency anaemia in adults. *Gut.* 2021;70(11):2030-2051. <https://doi.org/10.1136/gutjnl-2021-325210>.
19. Iolascon A, Andolfo I, Russo R, Sanchez M, Busti F, et al. Recommendations for diagnosis, treatment, and prevention of iron deficiency and iron deficiency anemia: EHA/ENERCA/ESH joint expert consensus. *HemaSphere.* 2024;8(7):e108. <https://doi.org/10.1002/hem3.108>.

20. Loganathan V, Bharathi A, Prince AM, Ramakrishnan J. Treatment efficacy of vitamin C or ascorbate given as co-intervention with iron for anemia — A systematic review and meta-analysis of experimental studies. *Clin Nutr ESPEN*. 2023;57:459-468. <https://doi.org/10.1016/j.clnesp.2023.07.081>.
21. Sim M, Garvican-Lewis LA, Cox GR, Govus A, McKay AKA, et al. Iron considerations for the athlete: a narrative review. *Eur J Appl Physiol*. 2019;119(7):1463-1478. <https://doi.org/10.1007/s00421-019-04157-y>.
22. Abbott A, Wang C, Stamm M, Mulcahey MK. Part II: Risk factors for stress fractures in female military recruits. *Mil Med*. 2023;188(1-2):93-99. <https://doi.org/10.1093/milmed/usac033>.
23. Mountjoy M, Sundgot-Borgen JK, Burke LM, Ackerman KE, Blauwet C, et al. IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *Br J Sports Med*. 2018;52(11):687-697. <https://doi.org/10.1136/bjsports-2018-099193>.
24. Mountjoy M, Sundgot-Borgen J, Burke L, Carter S, Constantini N, et al. The IOC consensus statement: beyond the Female Athlete Triad — Relative Energy Deficiency in Sport (RED-S). *Br J Sports Med*. 2014;48(7):491-497. <https://doi.org/10.1136/bjsports-2014-093502>.
25. Mountjoy ML, Ackerman KE, Bailey DM, Burke LM, Constantini N, et al. Yes: Relative Energy Deficiency in Sport (REDs) does exist! *Sports Med*. 2025;55(8):2045-2049. <https://doi.org/10.1007/s40279-025-02219-0>.