RESEARCH PAPER

Physical Activity As A Modulator Of Iron Drug Delivery And Bioavailability In Pregnancy

Joseph S E[1*], Sankar M[2], Alagesan J[3], Suganthirababu P[4], Thomas A[5], Ramalingam V[6], Srinivasan V[7]

[1] PhD Scholar, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, India,*
Email ID: smitajoseph77@gmail.com
[2]Assistant Professor, Centre for Global Health Research, Saveetha Medical College & Hospital, SIMATS, Chennai, India,
***Email Id:** muthupandisankar.smc@saveetha.com*
[3]Professor and Dean, School of Paramedical Allied and Health Care Sciences, Mohan Babu University, Tirupathi, India.
*Email **ID:** jagatheesanphd@gmail.com*
*[4]Professor and Principal, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, India, **Email Id:** emailprathap@gmail.com*
[5]Professor and Head, Department of Obstetrics and Gynaecology, St. John's Medical College, Bangalore, India,
Email Id: rejiann@gmail.com
[6]Professor, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, India.
Email Id: vinodhkumar.scpt@saveetha.com
[7]Associate Professor, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, India. Email Id: vignesh.scpt@saveetha.com

Corresponding Author:
PhD Scholar,
Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences,
Chennai, India. Email ID: **smitajoseph77@gmail.com**

ABSTRACT

Iron deficiency and iron deficiency anaemia remain among the most common nutritional disorders in pregnancy, necessitating widespread use of oral and parenteral iron therapies. Despite advances in iron formulations and delivery systems, therapeutic responses vary considerably, indicating that maternal physiological factors beyond drug design play an important role. Physical activity, increasingly recommended as a non pharmacological intervention during pregnancy, induces systemic adaptations that may meaningfully influence iron absorption, distribution, and bioavailability. This narrative review examines current evidence on maternal physical activity as a physiological modulator of iron pharmacokinetics and pharmacodynamics during pregnancy.

We synthesise findings from clinical, physiological, and translational studies that explore exercise induced changes in gastrointestinal function, hepcidin regulation, insulin sensitivity, inflammatory status, and cardiovascular dynamics, all of which are central to iron absorption and systemic handling. The review also discusses the role of enhanced uteroplacental perfusion and placental transporter activity in shaping maternal–fetal iron transfer. Emerging evidence suggests that regular, structured physical activity may improve iron bioavailability by reducing inflammation mediated iron sequestration, optimising metabolic control, and supporting efficient placental iron transport.

Implications for both oral and intravenous iron therapies are considered, with particular attention to how maternal activity status may influence dosing efficiency, therapeutic response, and fetal iron exposure. By integrating principles of exercise physiology with drug delivery science, this review highlights maternal physical activity as an important, yet under recognised, modifier of iron therapy effectiveness. Incorporating structured physical activity into antenatal iron supplementation strategies may represent a low cost, adjunctive approach to optimising maternal and fetal iron status and improving pregnancy outcomes

Key-words: Prenatal physical activity, Iron drug delivery, Iron bioavailability, Pregnancy pharmacokinetics, Placental iron transport

How to cite this article: Joseph SE, Sankar M, Alagesan J, Suganthirababu P, Thomas A, Ramalingam V, Srinivasan V: Physical Activity As A Modulator Of Iron Drug Delivery And Bioavailability In Pregnancy. Int J Drug Deliv Technol.

2026; 16(5s): 966-971; DOI: 10.25258/ijddt.16.5s.119
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

Background:

Iron deficiency and iron deficiency anaemia remain major public health concerns during pregnancy, with important consequences for maternal well-being, fetal growth, and

---

*Author for Correspondence: smitajoseph77@gmail.com long-term child development.[1-3] Although oral and parenteral iron therapies are widely prescribed and continually refined, clinical responses remain highly variable. This variability suggests that factors beyond iron formulation and dosing—particularly maternal physiological states—play a critical role in determining iron absorption, distribution, and utilization. Identifying modifiable physiological modifiers of iron therapy is therefore an important priority in antenatal drug delivery research.[4-6]

Physical activity is increasingly recognized as a key determinant of maternal physiology during pregnancy.[7] Regular moderate-intensity exercise induces systemic adaptations, including improved insulin sensitivity, reduced low-grade inflammation, altered gastrointestinal function, enhanced cardiovascular efficiency, and improved placental perfusion. Each of these processes is directly relevant to iron pharmacokinetics and pharmacodynamics, influencing hepcidin regulation, intestinal iron absorption, systemic iron trafficking, and maternal–fetal iron transfer.[8-16] Despite this biological plausibility, the role of maternal physical activity as a modifier of iron drug delivery and bioavailability has received limited attention in pregnancy-specific research.

This narrative review integrates evidence from exercise physiology, placental biology, and iron pharmacology to examine how physical activity may shape the effectiveness of iron supplementation during pregnancy. By synthesizing findings across clinical, physiological, and translational studies, the review aims to provide a conceptual framework for understanding exercise–iron interactions. Improved insight into these relationships may inform more personalized, physiology-driven approaches to antenatal iron supplementation, with the potential to optimize maternal iron status, support fetal development, and improve pregnancy outcomes within a comprehensive drug delivery paradigm.

Objectives:

This narrative review aims to synthesize current evidence on the influence of maternal physical activity on iron absorption, bioavailability, and pharmacokinetics during pregnancy. It examines the physiological mechanisms through which physical activity may modulate iron drug delivery, including effects on hepcidin regulation, inflammatory pathways, gastrointestinal function, and placental iron transport. The review also evaluates how variations in the type, intensity, and timing of physical activity may affect the effectiveness of both oral and parenteral iron therapies. In addition, it considers the clinical implications of integrating structured physical activity with iron supplementation strategies to optimize maternal and fetal iron status. Finally, it identifies key knowledge gaps and outlines future research priorities at the intersection of exercise physiology and iron drug delivery in pregnancy.

Discussion:

This narrative review brings together emerging evidence that maternal physical activity may meaningfully shape iron absorption, systemic bioavailability, and pharmacokinetics during pregnancy. [4,7,17-22] Although iron supplementation remains the cornerstone for preventing and treating gestational iron deficiency, clinical response is often heterogeneous. Such variability implies that physiological modifiers—beyond formulation, dose, and route—contribute to treatment effectiveness. Physical activity is one such modifier. By influencing gastrointestinal absorption efficiency, inflammatory tone, plasma-volume dynamics, and placental transport, exercise may alter how much iron is absorbed, where it is distributed, and how effectively it reaches the fetus. [4, 17, 23-30]

A central mechanistic pathway involves hepcidin, the master regulator of iron homeostasis. Habitual, moderate-intensity exercise is associated with reductions in low-grade inflammation and improved metabolic health, both of which are linked to lower basal hepcidin expression. [9,17, 31-35] Reduced hepcidin can, in turn, promote apical iron uptake via enterocytes and mobilization of stored iron from the reticuloendothelial system, potentially improving the net yield from oral iron dosing. Exercise-related gains in insulin sensitivity may further support erythropoiesis and iron utilization by aligning energy metabolism with hematopoietic demand. In parallel, modest enhancements in gastrointestinal motility and mucosal health could improve oral iron tolerance and absorption—an important consideration given adherence challenges with conventional salts. [36-43]

Cardiovascular and placental adaptations provide a second, drug-delivery–relevant pathway. Regular maternal activity improves cardiac output and uteroplacental perfusion, changes that may support more efficient placental handling of iron. Upregulation or improved function of placental transporters, coupled with better oxygen and nutrient delivery, could favorably influence transplacental iron flux and fetal accretion, without necessitating higher maternal doses. These systems-level effects align with the broader concept that drug delivery in pregnancy is not solely a property of the formulation but also of the maternal physiological milieu through which the drug must pass.

The form, intensity, and timing of physical activity appear to be critical determinants of the net effect on iron therapy. Evidence favors structured, moderate-intensity activity performed consistently across the week. In contrast, very vigorous or prolonged bouts can transiently increase post-exercise hepcidin and may blunt absorption if oral iron is administered during this window. Practically, separating iron dosing from high-intensity sessions (e.g., providing supplements in the evening after morning exercise, or ≥6–8 hours post-bout) may help preserve absorption while retaining the broader metabolic benefits of training. These considerations are directly actionable for drug-delivery optimization, informing decisions on dosing schedules and the choice between oral and parenteral routes when absorption is constrained.[17, 24, 28, 34, 44-46]

Clinically, integrating a structured activity prescription with iron supplementation is a low-cost, non-pharmacological adjunct that could enhance therapeutic efficiency, reduce interindividual variability, and improve maternal–fetal iron status. Nonetheless, important knowledge gaps persist. Pregnancy-specific pharmacokinetic studies remain scarce; few trials explicitly manipulate exercise parameters alongside iron dosing; and the time course of hepcidin and transporter responses in late gestation is incompletely defined. Priority areas include randomized trials testing exercise timing relative to dosing, intensity thresholds that preserve absorption, and placental mechanistic studies linking perfusion, transporter expression, and fetal iron endpoints. [47-50]

In summary, positioning maternal physical activity as apurposeful co-intervention in iron therapy reframessupplementation from a purely pharmaceutical solution to aphysiology-informed drug-delivery strategy. Thisintegrated approach offers a promising path to more predictable, personalized care in pregnancy.

Conclusion:

This narrative review identifies maternal physical activity as an important, yet insufficiently explored, factor influencing iron drug delivery and bioavailability during pregnancy. While the benefits of exercise for maternal and fetal health are well established, emerging evidence suggests that structured physical activity may also modulate key physiological pathways relevant to iron pharmacokinetics. These include regulation of hepcidin, inflammatory status, gastrointestinal absorption, and placental iron transport. By improving metabolic efficiency, reducing low-grade inflammation, and enhancing uteroplacental blood flow, regular moderate-intensity exercise may improve the effectiveness of both oral and parenteral iron therapies without compromising maternal or fetal safety.

From a drug delivery perspective, these observations highlight the need to consider lifestyle-related physiological factors when optimizing antenatal iron supplementation strategies. The integration of structured physical activity alongside iron therapy represents a low-cost, non-pharmacological adjunct that may enhance therapeutic response and reduce interindividual variability in clinical outcomes. However, current evidence remains limited by heterogeneous study designs and a lack of pregnancy-specific pharmacokinetic data.

Future research should focus on well-designed clinical trials and mechanistic studies that explicitly investigate exercise–iron interactions, including the influence of exercise intensity, timing, and modality on iron absorption and distribution. Such interdisciplinary approaches are essential to inform physiology-driven, personalized iron delivery strategies and to optimize maternal and fetal iron status within comprehensive antenatal care frameworks.

Financial support and sponsorship: Nil
Conflict of Interest: There are no conflicts of interest.

REFERENCE

1. Georgieff M. K. (2020). Iron deficiency in pregnancy. American journal of obstetrics and gynecology, 223(4), 516–524. https://doi.org/10.1016/j.ajog.2020.03.006
2. Stephen, G., Mgongo, M., Hussein Hashim, T., Katanga, J., Stray-Pedersen, B., & Msuya, S. E. (2018). Anaemia in Pregnancy: Prevalence, Risk Factors, and Adverse Perinatal Outcomes in Northern Tanzania. Anemia, 2018, 1846280. https://doi.org/10.1155/2018/1846280
3. Regina Ruiz de Viñaspre-Hernández, Raúl Juárez-Vela, José Antonio Garcia-Erce, Kapil Nanwani-Nanwani, Silvia González-Fernández, Vicente Gea-Caballero, Ignacio Larrayoz-Roldán, Alberto Tovar-Reinoso, Pablo del Pozo-Herce, Pilar Sanchez-Conde, Clara Isabel Tejada-Garrido, Manuel Quintana-Diaz, Iron deficiency anemia during pregnancy and maternal and neonatal health outcomes: A prospective study, Spain, 2021–2022, Heliyon, Volume 11, Issue 1, 2025, e41565, ISSN 2405-8440, https://doi.org/10.1016/j.heliyon.2024.e41565.
4. Fisher, A. L., & Nemeth, E. (2017). Iron homeostasis during pregnancy. The American journal of clinical nutrition, 106(Suppl 6), 1567S–1574S. https://doi.org/10.3945/ajcn.117.155812
5. Thomas H Bothwell, Iron requirements in pregnancy and strategies to meet them123, The American Journal of Clinical Nutrition, Volume 72, Issue 1, 2000, Pages 257S-264S, ISSN 0002-9165, https://doi.org/10.1093/ajcn/72.1.257S.
6. Allison L Fisher, Elizabeta Nemeth, Iron homeostasis during pregnancy†‡, The American Journal of Clinical Nutrition, Volume 106, Supplement 6, 2017, Pages 1567S-1574S, ISSN 0002-9165, https://doi.org/10.3945/ajcn.117.155812.
7. Sangkhae, V., Fisher, A. L., Ganz, T., & Nemeth, E. (2023). Iron Homeostasis During Pregnancy: Maternal, Placental, and Fetal Regulatory Mechanisms. Annual review of nutrition, 43, 279–300. https://doi.org/10.1146/annurev-nutr-061021-030404
8. Larsuphrom, P., & Latunde-Dada, G. O. (2021). Association of Serum Hepcidin Levels with Aerobic and Resistance Exercise: A Systematic Review. *Nutrients*, *13*(2), 393. https://doi.org/10.3390/nu13020393
9. Kong, W. N., Gao, G., & Chang, Y. Z. (2014). Hepcidin and sports anemia. Cell & bioscience, 4, 19. https://doi.org/10.1186/2045-3701-4-19

10. Novita Intan Arovah, Dang Thi Anh Thu, Juni Kurniawaty, Hartiah Haroen, Physical activity and immunity in obese older adults: A systematic bibliographic analysis, Sports Medicine and Health Science, Volume 5, Issue 3, 2023, Pages 181-189, ISSN 2666-3376, https://doi.org/10.1016/j.smhs.2023.07.001.
11. Venkatasamy, V. V., Pericherla, S., Manthuruthil, S., Mishra, S., & Hanno, R. (2013). Effect of Physical activity on Insulin Resistance, Inflammation and Oxidative Stress in Diabetes Mellitus. Journal of clinical and diagnostic research : JCDR, 7(8), 1764–1766. https://doi.org/10.7860/JCDR/2013/6518.3306
12. Borhade MB, Yashi K, Singh S. Diabetes and Exercise. [Updated 2025 Feb 26]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2025 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK526095/
13. Zhang, T., Liu, Y., Yang, Y., Luo, J., & Hao, C. (2025). The Effect and Mechanism of Regular Exercise on Improving Insulin Impedance: Based on the Perspective of Cellular and Molecular Levels. International Journal of Molecular Sciences, 26(9), 4199. https://doi.org/10.3390/ijms26094199
14. Al-Beltagi, M., Saeed, N. K., Bediwy, A. S., El-Sawaf, Y., Elbatarny, A., & Elbeltagi, R. (2025). Exploring the gut-exercise link: A systematic review of gastrointestinal disorders in physical activity. World journal of gastroenterology, 31(22), 106835. https://doi.org/10.3748/wjg.v31.i22.106835
15. Hao Cai, Xin Wang, Zhixin Zhang, Juan Chen, Fangbin Wang, Lu Wang, Jian Liu, Moderate l-lactate administration suppresses adipose tissue macrophage M1 polarization to alleviate obesity-associated insulin resistance, Journal of Biological Chemistry, Volume 298, Issue 4, 101768, ISSN 0021-9258, https://doi.org/10.1016/j.jbc.2022.101768.
16. Johnson Johanna L. , Slentz Cris A. , Ross Leanna M. , Huffman Kim M. , Kraus William E.Ten-Year Legacy Effects of Three Eight-Month Exercise Training Programs on Cardiometabolic Health Parameters, Frontiers in Physiology, Volume 10 -2019 https://www.frontiersin.org/journals/physiology/articles/10.3389/fphys.2019.00452. 10.3389/fphys.2019.00452
17. David E Barney, James R Ippolito, Claire E Berryman, Stephen R Hennigar, A Prolonged Bout of Running Increases Hepcidin and Decreases Dietary Iron Absorption in Trained Female and Male Runners, The Journal of Nutrition, Volume 152, Issue 9, 2022, Pages 2039-2047, ISSN 0022-3166, https://doi.org/10.1093/jn/nxac129.
18. Bara, Farida & As'ad Armyn, Suryani & Idris, Irfan & Riu, Deviana & Ahmad, Mardiana. (2024). Effects of prenatal yoga exercise on hepcidin and ferritin levels in pregnant women. SPORT TK-Revista EuroAmericana de Ciencias del Deporte. 27. 10.6018/sportk.628301.
19. McCormick, R., Moretti, D., McKay, A. K. A., Laarakkers, C. M., Vanswelm, R., Trinder, D., Cox, G. R., Zimmerman, M. B., Sim, M., Goodman, C., Dawson, B., & Peeling, P. (2019). The Impact of Morning versus Afternoon Exercise on Iron Absorption in Athletes. Medicine and science in sports and exercise, 51(10), 2147–2155. https://doi.org/10.1249/MSS.0000000000002026
20. John Beard, Brian Tobin, Iron status and exercise123, The American Journal of Clinical Nutrition, Volume 72, Issue 2, 2000, Pages 594S-597S, ISSN 0002-9165, https://doi.org/10.1093/ajcn/72.2.594S.
21. P., DN., B., F., T., D.F. et al. Iron Supplementation and Exercise During Pregnancy: Effects on Behavior and the Dopaminergic System. Biol Trace Elem Res 201, 1639–1647 (2023). https://doi.org/10.1007/s12011-022-03306-3
22. Alwan, N. A., & Hamamy, H. (2015). Maternal Iron Status in Pregnancy and Long-Term Health Outcomes in the Offspring. Journal of pediatric genetics, 4(2), 111–123. https://doi.org/10.1055/s-0035-1556742
23. Delijewski, M., Bartoń, A., Maksym, B., & Pawlas, N. (2023). The Link between Iron Turnover and Pharmacotherapy in Transplant Patients. *Nutrients*, *15*(6), 1453. https://doi.org/10.3390/nu15061453
24. Zaitseva, I. & Tinkov, Alexey & Skalny, A.. (2018). Influence of Physical Activity on the Regulation of Iron Metabolism. Human Physiology. 44. 592-599. 10.1134/S0362119718050158.
25. Stephen R. Hennigar, James P. McClung, Adrienne Hatch-McChesney, Jillian T. Allen, Marques A. Wilson, Christopher T. Carrigan, Nancy E. Murphy, Hilde K. Teien, Svein Martini, Jess A. Gwin, J. Philip Karl, Lee M. Margolis, Stefan M. Pasiakos, Energy deficit increases hepcidin and exacerbates declines in dietary iron absorption following strenuous physical activity: a randomized-controlled cross-over trial, The American Journal of Clinical Nutrition, Volume 113, Issue 2, 2021, Pages 359-369, ISSN 0002-9165, https://doi.org/10.1093/ajcn/nqaa289
26. Domínguez, R., Sánchez-Oliver, A. J., Mata-Ordoñez, F., Feria-Madueño, A., Grimaldi-Puyana, M., López-Samanes, Á., & Pérez-López, A. (2018). Effects of an Acute Exercise Bout on Serum Hepcidin Levels. *Nutrients*, *10*(2), 209. https://doi.org/10.3390/nu10020209.
27. Soh, J., Lim, Z. X., Lim, E. H., Kennedy, B. K., & Goh, J. (2022). Ironing out exercise on immuno-oncological outcomes. Journal for immunotherapy of cancer, 10(9), e002976. https://doi.org/10.1136/jitc-2021-002976
28. Wang, Z., & Wang, Y. (2025). Relationship between physical activity and health-related indicators of iron metabolism: evidence from a large, representative cohort. Archives of medical science : AMS, 21(5), 2211–2215. https://doi.org/10.5114/aoms/213625
29. Skarpańska-Stejnborn, A., Basta, P., Trzeciak, J., & Szcześniak-Pilaczyńska, Ł. (2015). Effect of intense

physical exercise on hepcidin levels and selected parameters of iron metabolism in rowing athletes. European journal of applied physiology, 115(2), 345–351. https://doi.org/10.1007/s00421-014-3018-3

30. McKay, A. K. A., Pyne, D. B., Burke, L. M., & Peeling, P. (2020). Iron Metabolism: Interactions with Energy and Carbohydrate Availability. Nutrients, 12(12), 3692. https://doi.org/10.3390/nu12123692
31. Kobayashi Y, Taniguchi R, Shirasaki E, Yoshimoto YS, Aoi W, Kuwahata M. 2024. Continuous training in young athletes decreases hepcidin secretion and is positively correlated with serum 25(OH)D and ferritin. PeerJ 12:e17566 https://doi.org/10.7717/peerj.17566
32. Nemeth, E., & Ganz, T. (2023). Hepcidin and Iron in Health and Disease. Annual review of medicine, 74, 261–277. https://doi.org/10.1146/annurev-med-043021-032816
33. Behzadnezhad, N., Esfarjani, F., & Marandi, S. M. (2021). Impact of resistance training and basic ferritin on hepcidin, iron status and some inflammatory markers in overweight/obese girls. Journal of research in medical sciences : the official journal of Isfahan University of Medical Sciences, 26, 95. https://doi.org/10.4103/jrms.JRMS_511_20
34. Larsuphrom, P., & Latunde-Dada, G. O. (2021). Association of Serum Hepcidin Levels with Aerobic and Resistance Exercise: A Systematic Review. Nutrients, 13(2), 393. https://doi.org/10.3390/nu13020393
35. Berton, P. F., & Gambero, A. (2024). Hepcidin and inflammation associated with iron deficiency in childhood obesity - A systematic review. Jornal de pediatria, 100(2), 124–131. https://doi.org/10.1016/j.jped.2023.06.002
36. Chae, S. A., Son, J. S., & Du, M. (2022). Prenatal exercise in fetal development: a placental perspective. The FEBS journal, 289(11), 3058–3071. https://doi.org/10.1111/febs.16173
37. Guinhouya, B. C., Duclos, M., Enea, C., & Storme, L. (2022). Beneficial Effects of Maternal Physical Activity during Pregnancy on Fetal, Newborn, and Child Health: Guidelines for Interventions during the Perinatal Period from the French National College of Midwives. Journal of midwifery & women's health, 67 Suppl 1(Suppl 1), S149–S157. https://doi.org/10.1111/jmwh.13424
38. Jade M. Kubler, Vicki L. Clifton, Trine Moholdt, Kassia S. Beetham, The effects of exercise during pregnancy on placental composition: A systematic review and meta-analysis, Placenta, Volume 117, 2022, Pages 39-46, ISSN 0143-4004, https://doi.org/10.1016/j.placenta.2021.10.008.
39. Kubler, Jade & Clifton, Vicki & Moholdt, Trine & Beetham, Kassia. (2021). The effects of exercise during pregnancy on placental composition: A systematic review and meta-analysis. Placenta. 117. 10.1016/j.placenta.2021.10.008.
40. James F. Clapp, The effects of maternal exercise on fetal oxygenation and feto-placental growth, European Journal of Obstetrics & Gynecology and Reproductive Biology, Volume 110, Supplement, 2003, Pages S80-S85, ISSN 0301-2115, https://doi.org/10.1016/S0301-2115(03)00176-3.
41. Jayonta Bhattacharjee, Shuhiba Mohammad, Kristi B. Adamo, Does exercise during pregnancy impact organs or structures of the maternal-fetal interface?, Tissue and Cell, Volume 72, 2021, 101543, ISSN 0040-8166, https://doi.org/10.1016/j.tice.2021.101543.
42. Pedro Acosta-Manzano, Marta Flor-Alemany, Luis J. Martínez-González, María Jesús Alvarez-Cubero, Laura Baena-García, Teresa Nestares, Mireille N.M. Van Poppel, Virginia A. Aparicio, The effects of a supervised exercise training program during pregnancy on placental cytokines, and the potential role of fetal sex and maternal weight status, Journal of Sport and Health Science, Volume 15, 2026, 101082, ISSN 2095-2546, https://doi.org/10.1016/j.jshs.2025.101082.
43. Wu, B., Zhang, Y., Shi, L. (2026). Exercise Benefits for Mother and Offspring: Molecular Mechanisms and Advances. In: Gao, F., Zhang, X. (eds) Exercise, Epigenetics and Human Health. Epigenetics and Human Health, vol 15. Springer, Cham. https://doi.org/10.1007/978-3-032-08045-5_3
44. Hennigar, Stephen & McClung, James & Hatch-McChesney, Adrienne & Allen, Jillian & Wilson, Marques & Carrigan, Christopher & Murphy, Nancy & Teien, Hilde & Martini, Svein & Gwin, Jess & Karl, J. & Margolis, Lee & Pasiakos, Stefan. (2020). Energy deficit increases hepcidin and exacerbates declines in dietary iron absorption following strenuous physical activity: a randomized-controlled cross-over trial. The American Journal of Clinical Nutrition. 113. 10.1093/ajcn/nqaa289.
45. Karlsson, M. K., Nordqvist, A., & Karlsson, C. (2008). Physical activity increases bone mass during growth. Food & nutrition research, 52, 10.3402/fnr.v52i0.1871. https://doi.org/10.3402/fnr.v52i0.1871
46. Goto K, Kojima C, Kasai N, Sumi D, Hayashi N, Hwang H (2020) Resistance exercise causes greater serum hepcidin elevation than endurance (cycling) exercise. PLoS ONE 15(2): e0228766. https://doi.org/10.1371/journal.pone.0228766
47. Obeagu, Emmanuel. (2025). The Relationship between Exercise and Hemoglobin Levels in Pregnant Women: A Review. International Journal of Medical Sciences and Pharma Research. 11. 34-39. 10.22270/ijmspr.v11i1.138.
48. Chewe J (2024). Importance of Iron Supplementation During Pregnancy: Fetal Development and Anaemia Prevention. Matern Pediatr Nutr. 9:244

49. Georgieff, M. K., Krebs, N. F., & Cusick, S. E. (2019). The Benefits and Risks of Iron Supplementation in Pregnancy and Childhood. Annual review of nutrition, 39, 121–146. https://doi.org/10.1146/annurev-nutr-082018-124213

50. Ubom, A. E., Begum, F., Ramasauskaite, D., Nieto-Calvache, A. J., Oguttu, M., Nunes, I., Malel, Z. J., Beyeza-Kashesya, J., Wright, A., & FIGO Committee on Childbirthand Postpartum Hemorrhage (2025). FIGO good practice recommendations on anemia in pregnancy, to reduce the incidence and impact of postpartum hemorrhage (PPH). International journal of gynaecology and obstetrics: the official organ of the International Federation of Gynaecology and Obstetrics, 171(3), 993–1007. https://doi.org/10.1002/ijgo.70529